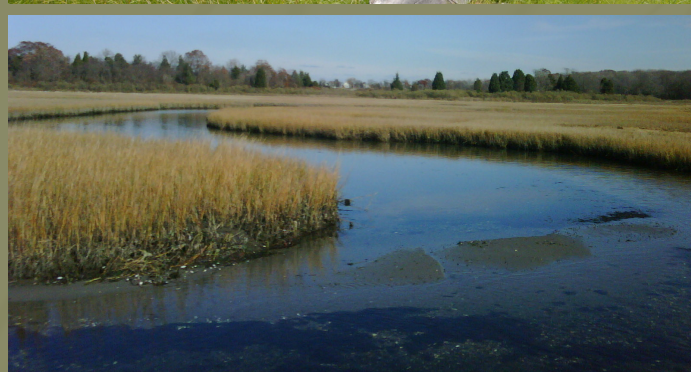
Measuring Tidal Wetland Response to Restoration Using Performance Benchmarks from Local Reference Sites



Michele Dionne and Christopher Peter
With contributions from Kenneth Raposa, Robin Weber, John Fear, Scott Lerberg, Craig Cornu, Heidi Harris, and Nina Garfield

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Acknowledgements
Project participants would like to thank Melanie Gange and the staff at the NOAA Restoration Center, Sliver Spring, MD for providing the support and guidance that made this project possible.

Cover photos: Top- New England salt marsh, ME; Second row left- Duke Marine Lab marsh, NC; Second row right- Hermatage marsh breakwater, VA; Third row- South Slough salt marsh, OR; Bottom row- Nag marsh, RI.

Overview

In this study we collected data from a series of relatively undisturbed tidal wetlands at or near five National Estuarine Research Reserves (Reserves) located in Maine, Rhode Island, Virginia, North Carolina and Oregon as reference sites against which to compare the restoration status of 17 local tidal wetland restoration projects previously funded by the Estuarine Restoration Act since 2000.

The objectives of this study, funded by the NOAA Restoration Center, are fourfold:

1. Determine the level of restoration achieved at each project restoration site;

2. Identify key biotic (vegetation) and abiotic (hydrology, soils, marsh elevation) indicators that best explain variation in restoration response;

3. Determine the utility of long-term wetland monitoring sites at Reserves as reference sites for restoration projects implemented within the region; and

4. Compare responses of hydrologic and excavation/fill types of restoration.

This report summarizes findings at all study sites for three years (2008-2010). Each Reserve has also provided a report to the Restoration Center with detailed site information, maps, analyses and conclusions specific to that region (Cornu et al. 2011, Dionne and Peter 2011, Fear 2011, Lerberg and Reay 2011, Raposa and Weber 2011).

Primary Findings

Through our data collection, analyses and interpretation, we offer the following conclusions:

- *Reserve tidal wetland sites can provide appropriate long-term reference sites for local tidal wetland restoration projects.*
- *A recently formalized ecological index, the* ***Restoration Performance Index*** *(RPI) which compares change in user-selected indicator variables over time between reference and restoration sites (Moore et al. 2009) offers promise as an effective* ***trajectory analysis strategy*** *(SER 2004) for measuring restoration status.*
- *According to our RPI values, most restoration projects surveyed in this study appeared to have achieved an intermediate level of restoration with two sites appearing to have become very similar to their paired reference sites, suggesting a high level of restoration.*
- *Two abiotic variables – 1) elevation of marsh platform, and 2) depth to groundwater were significantly correlated with plant community structure, providing important indicators of tidal wetland restoration performance.*

Parameters
Biotic:
Species, composition and percent cover of herbaceous vascular plants
Plant height
Stem Density
Abiotic:
Hydrological- water fluctuation over time
Salinity in tidal areas
Soil/sediment: organic content and bulk density
Soil/sediment: pore water salinity
Wetland surface elevation

Table 1. Biotic and abiotic parameters monitored for this study.

Data Collection

We collected data describing a suite of specific biotic and abiotic parameters at all reference and restoration sites at the five Reserves involved in the project (Table 1). Monitored parameters were based on NOAA's reference manual for restoration monitoring (Thayer et al. 2005) and selected in consultation with the NOAA Restoration Center. Data collected from reference sites served as benchmark parameter values for the restoration sites.

Project Results Summary and Recommendations

Level of restoration achieved by each restoration project and the utility of the Restoration Performance Index (RPI)

Using the RPI as a tidal wetland restoration evaluation tool along with other data analyses, we were able to conclude the following about our study sites, and about the use of the RPI:

1. *Among the hydrologic parameters analyzed (pore water salinity, tidal inundation period, depth to groundwater, maximum high tide), there were few large differences between reference and restoration values, suggesting hydrologic equivalence with reference conditions at most sites. These results also suggest that key physical processes needed to support the continued recovery of plant communities at these sites are in place.*

2. *Of the vegetation parameters analyzed (percent cover of the five most common reference species, species richness), there were large differences between reference and restoration sites, which suggests that most sites are still in transition to full restoration.*

   Over three years, species richness appeared to be quite variable, frequently leading to noticeable annual change in the RPI vegetation component (from 2009 to 2010, in particular), often trending to lower species richness (fewer species).

   This trend is likely explained more by our sampling design than by site changes: the small number of species present per square *meter, generally one to three species on the East Coast but ranging from zero to five, and from three to seven in Oregon, means that a small change in species number could lead to a large change in the vegetation RPI, given that this parameter was weighted as 25% of the total RPI score.*

It's likely that as more years of data are collected, it will become apparent that species numbers vary around a mean at most sites, rather than following an upward or downward trend. At sites where a trend is apparent, this parameter would be of real value.

It should be noted that the utility of the RPI to measure the recovery status of tidal wetland restoration projects was constrained for most of our restoration study sites by the fact that no baseline data (neither pre-restoration nor immediate post-restoration) were available for our analyses. In many cases, the period of dynamic response to restoration had already passed by, and our data reflect change during a more dampened period of recovery. Despite these limitations, the RPI proved useful for providing concise numeric and graphical comparisons of parameters, indicating the extent of restoration relative to the reference sites.

We feel it would be useful to add percent cover of invasive species as a third parameter to the RPI vegetation component. Based on this study and other observations, invasive species can be an important threat to tidal wetland restoration sites and should be incorporated into the RPI. In addition, by adding invasive species to the vegetation component of the RPI, the influence of species richness values, mentioned above, will also be tempered.

COASTAL REGIONS

and RESTORATION TYPES

In this study we focused on tidal wetland hydrologic and excavation/fill restoration sites and associated relatively undisturbed reference sites in the Acadian, Virginian, Carolinian, and Columbian biogeographic regions of the U.S. (NERRS 2009).

*We define **hydrologic restoration** as activity that results in the reintroduction of tidal flooding to a non- tidal or minimally tidally flooded site; and **excavation/fill restoration** as activity that results in the expansion or reconfiguration of a tidal marsh surface at an already tidally influenced site.*

It may be useful to add a fourth parameter to the RPI vegetation component: species richness of the five most abundant reference site species. This parameter could provide useful insights to the restoration process. Additional work will be needed to assess the utility of this addition to the RPI.

When interpreting RPI results, it should be noted that plant communities during the initial phases of emergent wetland restoration are often distinctly different from their more stable and mature reference sites.

Restoration site plant communities develop from colonization (or planting) after a sometimes large and near-complete disturbance. Reference sites, on the other hand, remain relatively undisturbed and can maintain their “late successional” plant community structure while incorporating altered community patches maintained by small scale, episodic disturbances due to drivers (such as ice cover, wrack, waterlogged soils, etc.), related to variation in soil drainage. Because of these early site recovery dynamics (that may not be well understood by all restoration practitioners), RPI restoration site values may linger in the lower ranges for some time after restoration plan implementation.

Interpretation of the RPI scores without the benefit of a solid understanding of restoration processes has the potential to lead to the implementation of unnecessary or premature adaptive management actions on the part of less experienced restoration practitioners and land owners.

Recommendations

- *Formal outside review of the implementation of the RPI described in this study should be conducted to provide important perspectives on this approach to restoration monitoring.*

RESTORATION PERFORMANCE INDEX: RPI

We calculated the Restoration Performance Index using structural and functional variables for which we had more than one year’s data. The RPI provides a quantitative measure of change in the restoration site, relative to the reference site or reference benchmarks over time. The index is the weighted sum of RPI scores measured for each selected variable over the specified time interval, and can be used to describe restoration trajectories.

The RPI score for a given variable is defined as:

$$\frac{\text{(Restoration present state (tx)) - (Initial restoration state (t0))}}{\text{(Reference present state (tx)) - (Initial restoration state (t0))}} = \text{RPI}$$

Pore water salinity example:

$$\frac{\text{(Salinity @ tx restoration) – (Salinity @ t0 restoration)}}{\text{(Salinity @ tx reference) – (Salinity @ t0 restoration)}} = \text{RPI Pore water Salinity}$$

or $(23\text{psu} - 11\text{psu}) / (35\text{psu} - 11\text{psu})$ **= 0.5**

- *The version of the RPI developed for this study should be revised by adding percent cover of invasive species as a third subcomponent of the Vegetation Component score.*
- *Restoration monitoring should occur until observations indicate that the original (or adaptively modified) restoration goal has been reached. In addition, the RPI developed for this study (and revised as above) should be applied to project sites as early as possible (prior to restoration, then every year for the first three years of restoration, and every 2 to 5 years thereafter) until the original (or adaptively modified) restoration goal has been reached.*
- *The NERR System should develop a detailed training document and training workshops in the use of the RPI for performance evaluation of tidal wetland restoration projects, from sampling design, to data collection methods, to data organization, analysis and interpretation.*
- *The Restoration Center should encourage their grantees to consult with restoration monitoring professionals at local NERR sites for assistance in choosing restoration monitoring protocols relevant to the region.*
- *Since, for a wide variety of reasons, the potential level of restoration possible at many disturbed tidal wetland sites can be less than 100% over the near-term (e.g., 20 years) and possibly longer, we encourage a realistic assessment of the level of restoration possible at sites be conducted during project design. The assessment should be wide ranging, taking into account any factors that would likely prevent or slow full site recovery (e.g., marsh surface subsidence, climate-related impacts, or financial, practical, or social constraints placed on restoration design or subsequent project implementation, monitoring and adaptive management… etc.).*

Key Vegetation, Hydrologic, Soil and Elevation Indicators that Best Explain Variation in Restoration Response

Emergent Vegetation Species Percent Cover

For the purposes of evaluating restoration of plant communities, using similarity of percent cover between restoration and reference sites as the primary plant community metric worked well in our study. We also agreed that the use of the point – intercept method for estimating plant species and other types of cover would provide the most accurate observations. Monitoring personnel including consultants, agency staff, volunteers…etc., can vary from site to site and year to year. Using the point-intercept method requires less personal judgment for data collection compared to visual percent cover estimation methods.

The use of percent cover of the five most abundant reference site species provided RPI scores that agreed with ANOSIM (analysis of similarity) and SIMPER (similarity percentages) results, in that they both indicated that plant communities were only partly restored at the majority of restoration sites. Given that there were up to 21 species contributing to the cumulative 90% cover in each reference-restoration site pair, this greatly simplified calculating the RPI total score, and focused attention on the species that provide evenness or stability (in the context of the marsh plant community, stability means the opposite of variability).

It’s important to note that because of local and regional variability associated with tidal wetland habitats (e.g., site size, plant community diversity, landscape setting), emergent vegetation sampling design needs to be responsive to local site attributes.

For example, west coast salt marsh plant communities tend to be more diverse than those on the east coast and plant zonation tends to be more limited in scale due to the generally smaller wetland area.
Sampling design power analyses conducted by the South Slough NERR science staff in Oregon determined that in order to characterize change in percent cover year to year, the number of salt marsh plots sampled needed to be greater than the 20 replicate plots per marsh area recommended in the vegetation sampling protocol used in this study (Roman et al. 2001). In addition, transects oriented perpendicular to plant zones per Roman et al. (2001) in west coast emergent wetlands do not allow enough plots to be placed in each intertidal plant zone to adequately characterize each plant community in its zone. Vegetation sampling plots in west coast salt marshes should be oriented per Roegner et al. (2008).

NORTH CAROLINA NERR: POINT-INTERCEPT VERSUS VISUAL PERCENT COVER METHOD

We conducted our vegetation surveys using both the point intercept method as described in Roman et al. (2001), and the visual percent cover method as described in Pete et al. (1998). The point intercept method was more labor intensive than the visual observation method, but was judged by our field crew to be less subjective. The point intercept method had a tendency to miss small individuals of rare species. For example, many times a lone Limonium plant was present in the sampling quadrat and was detected with the visual method, but was not touched by one of the point intercepts and so would not have been counted with this method alone. The visual assessment method consistently provided a lower estimate for the percent cover compared to that derived from the point intercept data. (see Figure 1). Despite the difference in magnitude, the overall trends for the data in Figure 1 are essentially mirror images. At our site where a core group of field investigators are always present during vegetation data collection, we would have reached the same conclusions regarding our marsh comparisons if we had used the visual percent cover method instead of the point intercept method.

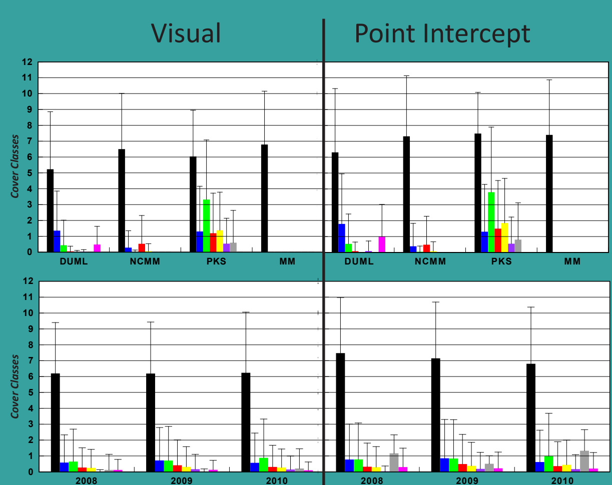

Figure 1. Point intercept versus visual percent cover method comparison. The point intercept method consistently provided higher estimates of vegetation cover. Error bars represent one standard deviation.

Recommendations

- Emergent vegetation species percent cover should be used as the primary plant community metric in evaluating the similarity between restoration and reference site plant communities.
- The point-intercept method (Godinez-Alvarez et al. 2009) should be considered for collection of plant species presence and relative abundance in all layers within one-square-meter quadrats, in particular if different field investigators are estimating percent cover year to year, or site to site (see sidebar).
- *Picturepost (http://picturepost.unh.edu/) should be used to collect standardized photo points of reference and restoration sites. Photos should be taken the first week of every third month (March, June, September, December), at least once prior to restoration, then every year for the first three years of restoration, and every two to five years thereafter). (We did not use picture-post photo points in the current study, but consider this an important technique for documenting visible change at reference and restoration sites.)*
- *The RPI vegetation component score should use the five most abundant reference site species for the percent cover subcomponent score.*
- *NOAA Restoration Center restoration grant recipients on the west coast should consult with the Reserve site in their region or other knowledgeable agency or consulting sources about appropriate tidal wetland vegetation sampling design. See also Roegner et al. (2008).*

Table 2. Recommended use of indicator variables for evaluating tidal wetland restoration performance. All monitoring should include at least one year of pre-restoration data collection.

	TIDAL WETLAND PERFORMANCE INDICATOR VARIABLES														
	ABIOTIC									BIOTIC					
	Hydrology				Soils		Elevation			Vegetation					
	Salinity	Inundation	Groundwater	Max High Tide	Bulk Density	% Organic Matter	Sample Points/Plots	Transect Profiles	Transect Transitions	% 5 Dominant Species-Ref	% Invasives	Species Richness	Native Stem Density	Invasive Stem Density& Height	Native Stem Height
Core (X)	X	X	X	X	X		X	X	X	X	X	X		X	
Option (x)						X							X		X
Sampling Scheme	1	2 or 3	2 or 3	1	4	4	1	4	4	1	1	1	1	1	1

Post-restoration sampling scheme codes:

1. Data collected annually during growing season for the first three years following restoration, then every two to five years, until the restoration goal achieved. The goal can be changed over time through adaptive management.

2. Data collected monthly, following yearly sampling as in Sampling Scheme 1.

3. Data is collected on four dates, following yearly sampling as in Sampling Scheme 1 (option is an alternative to Sampling Scheme 2).

4. Data is collected at intervals of one, two and five years following restoration, then every five years until restoration goal is achieved. Goal can be changed over time through adaptive management.

Emergent Vegetation Species Stem Height and Density

Estimating stem density and height for dominant and subdominant reference species can be a very time consuming process. However, these data can be very helpful for understanding site variation that affects plant growth, such as competition for nutrients and light, and response to stressors such as soil salinity and soil oxygen availability.

For our study these estimates proved to be quite variable across sites at most Reserves, with many significant differences among restoration sites, and between pairs of reference and restoration sites. Stem height and density patterns did not agree with RPI results or ANOSIM and SIMPER results.

Plant species density and height can be monitored to test specific hypotheses about plant ecology under varying site conditions, or to precisely follow changes in the abundance of planted species. Stem height and density for dominant species can be measured, but for the most part, we do not consider these to be core variables to consider for restoration evaluation.

The one exception is that invasive species plant density and stem heights should be recorded if possible.

CHESAPEAKE BAY VA NERR: IMPORTANCE OF ACCURATE ELEVATION DATA

Our study demonstrated the need to have very precise elevation data due to the very shallow grades in these restoration settings. Accurate elevation data was critical for interpreting the inundation data from the groundwater wells as well as some of the vegetation patterns. The elevation data was also very useful in understanding some of the "nuances" of the reference and restoration sites (for example, some localized depressional areas adjacent to the upland area of both Cheatham Annex and Taskinas Creek). With access to multiple types of equipment for measuring marsh elevations in our study, we collected elevation information each year using a combination of approaches (standard visual leveling, digital bar code leveling, and real time kinematic (RTK) GPS). While there was some variation in the data collected using the different approaches, all three methods produced reliable results.

Our approach is to determine the level of accuracy needed to answer your research questions, and then assess the costs (i.e. training, field time, processing time), versus the benefits (in terms of accuracies) of the different options. We suggest installing a network of local benchmarks for any long-term restoration monitoring, along with a maintenance schedule on which to repeat elevation surveys (for long-term restoration monitoring).

Invasive species in some regions of the U.S. (e.g., Phragmites australis in the Northeast) can be large and therefore less dense, and occur in fewer plots, hence they can be relatively easy to count and measure. Change in density and/or plant height may occur earlier than a change in percent cover for some invasive species. These data may serve as an early indicator to guide management actions designed to reduce or eliminate their threat.

Recommendations

- *Stem height and stem density measurements should be required only for invasive species. Invasive species stem height and density should be measured annually during seasonal peak above-ground biomass, beginning the year prior to restoration, for three years following restoration, and then every two to five years thereafter.*

- *Stem height and stem density measurements should remain an option for testing specific hypotheses that directly address or shed light on specific restoration goals. The same general field sampling methods would apply as described above.*

Groundwater and Surface Water Levels

These data were collected with the extensive use of continuously recording water level loggers (pressure sensors) that provide robust data sets for measuring tidal wetland inundation patterns. Some project participants chose to use In Situ Aquatroll 200™ loggers, which measure water level, salinity and temperature, in combination with manual spot measurements. At other sites a combination of In Situ Aquatroll 200™ loggers, Onset HOBO™ water level loggers, and Solinst Leveloggers which measure water level and temperature only, were used. Because of varying financial constraints, some sites were not able to purchase enough loggers to measure groundwater and surface water levels simultaneously at both the restoration and reference sites. Most were not able to collect continuous water level and salinity data at every vegetation plot.

To carry out environmental parameter-plant community correlations we used the groundwater levels measured periodically by hand, as they were mostly associated with individual vegetation plots. A financially practical way to obtain continuous water level data would be to encourage the use of relatively inexpensive ($595) Onset HOBO™ water level loggers (vs. $2500 for Aquatroll™ loggers) placed at the bottom of each shallow PVC well at each vegetation plot or some subset of these plots. Given the small volume of water contained in shallow wells, the effects of water temperature and salinity on water level are likely to be too small to be of concern. This could be verified by including an Onset HOBO™ temperature / conductivity / salinity logger ($750) at several locations within the study marsh, adjacent to a water level logger.

Barometric pressure can be measured (for water level correction) by placing one water level logger anywhere above the high water level at the site. Single Aquatrolls™ (or combination of the two HOBO™ loggers described above) could be deployed in the main channel adjacent to both the reference and restoration marshes to provide water level, temperature and salinity of the estuarine source water.

Recommendations

- *Many continuously recording mini-loggers should be used in shallow, small volume wells associated with a representative set of vegetation plots to record patterns of inundation, rather than using fewer, more expensive loggers, deployed in deep*

groundwater monitoring wells. Loggers would not necessarily be deployed at every plot, but the more the better. Loggers should be deployed simultaneously at reference and restoration sites for a minimum of one growing season lunar cycle annually, beginning one year prior to restoration, with a maximum 30-minute time interval between readings.

Placing a water quality and depth data sonde for the NERRS System-Wide Monitoring Program (SWMP) in North Carolina. SWMP data can be used to augment tidal wetland refreence site data at NERR sites.

Additional deployments should capture water levels during seasonal transition periods.

If collecting continuous water level data using loggers is not possible, we suggest collecting depth to groundwater measurements by hand from shallow groundwater wells placed adjacent to every vegetation monitoring plot (or a representative set of plots). Data should be collected a minimum of four times annually (beginning one year prior to restoration) during each growing season. Data collection should occur at mid to low tide, as close together in time as possible (same day or next day, or same week providing weather has been stable) for reference and restoration sites.

Pore Water/Groundwater Salinity

Soil salinity is a primary determinant of plant species communities in tidal emergent marshes, and is a subcomponent of the RPI hydrology component. Soil salinity was not a primary correlate of plant community assemblages within sites, possibly because there was rather low variation in this parameter within sites.

In this study, soil salinity was measured from water samples taken from shallow groundwater wells, with Aquatrolls from deep groundwater wells, and with sippers probed into the root zone (10-25 cm or deeper if needed), and from water squeezed from replicate soil samples taken from the top 15 cm of the emergent marsh root zone using a garlic press and coffee filter.

Soil salinity measurement can be simplified by measuring salinity from water samples collected from the shallow groundwater wells. These data can also be used to determine whether there is a significant effect of salinity on water levels measured by water level loggers deployed in shallow wells. That there is likely little difference between salinity measured in shallow groundwater wells or by sippers can be verified with data collected by the Wells NERR for this study (Dionne and Peter 2011).

Recommendations

- *Soil salinity measurement should be collected from shallow groundwater wells placed adjacent to every vegetation monitoring plot, or a representative set of plots. Data should be collected a minimum of four times annu-*

ally (beginning one year prior to restoration) during the growing season. Data collection should occur at mid to low tide, as close together in time as possible (same day or next day, or same week providing weather has been stable) for reference and restoration sites. At least two collection dates should coincide with the deployment period of continuously recording loggers (when used) within the wells, preferably the start and end dates.

Soil Structure (Bulk Density and Percent Organic Content)

Under stable natural conditions, soil parameters change more gradually than do hydrologic and vegetation parameters.

Bulk density and percent organic content were correlated with the plant community assemblage at only one Reserve (Wells ME), where these parameters were measured adjacent to every vegetation plot. These parameters can be quite different between restoration and reference sites prior to hydrologic restoration, due to soil oxidation, or water logging and subsidence. For excavation/fill restoration, the soils that are exposed or that are brought to the site for project construction will often be quite different from those of the natural reference system. For both excavation/fill and hydrologic restoration types, soils may change noticeably during early restoration due to sediment deposition or erosion. Once the site hydrology has been established, surface soils will change more gradually, but may undergo rapid alteration due to storm events.

Root zone soil measurements allow us to follow incremental recovery of both mineral content and below ground plant biomass. Bulk density and percent organic content of the soils tend to be related (higher bulk density soils have higher mineral content and lower organic content), so both parameters may not need to be measured if the equipment for combusting soil carbon (to assess percent organic carbon) is not available, or sending soil samples to a soils lab is not feasible.

Soil pore water oxidation-reduction (redox) potential provides a measure of the ability of a soil to provide electron acceptors for the oxidation process, characterizing hydrologic conditions, microbial activity, plant root processes, and mineral, organic and nutrient content of tidal marsh soils (Davy et al. 2011). It can be measured quickly (as mV) in a root zone pore water sample extracted with a sipper using a hand-held mv/pH field probe. We did not collect redox data for this study.

Recommendations

- *Soil bulk density and percent organic content should be measured at every vegetation plot (or as many as needed to adequately represent the plant community), beginning one year prior to restoration, and repeated at intervals of one, two, five and 10 years after restoration work is completed. If measurement of percent organic content presents a logistical or financial challenge, it can be omitted.*
- *Soil redox (not measured in this study) should be measured annually at every vegetation plot at least once per year, beginning one year prior to restoration, at mid to low tide, during the period of peak vegetation biomass (coinciding with salinity and depth to groundwater measurements). Data should be collected as close together in time as possible (same day or next day, or same week providing weather has been stable) for reference and resto-*

Collecting elevation data in North Carolina tidal flats using survey grade Real-Time Kinematic GPS instruments.

ration sites. If more sampling periods are possible, they should also coincide with salinity and depth to groundwater measurements.

Wetland Surface Elevation Profiles

Wetland surface elevation is a critical factor determining wetland plant community assemblages. In our study, vegetation plot elevations were a primary correlate of plant species assemblages. Elevation was also a critical factor determining tidal wetland plant community structure and function. Since elevation and tidal hydrology determine the pattern, frequency and duration of marsh inundation, elevation should be monitored for change over time.

Figure 2. *Carex Lyngbyei* monoculture at 14 year old tidal wetland restoration site in Oregon.

Increases in marsh elevation indicate the ability of the marsh to sustain itself in response to increased inundation, either from restoration or from sea level rise. Decreases in marsh elevation signal subsidence or erosion, and indicate the loss of ability of the marsh to sustain itself in response to increased inundation. Profiles of monitoring transects showing the elevation and location of zonal transitions, channels, pools and other surface features of note provide an excellent coarse-scale qualitative and quantitative summary of marsh ecogeomorphology that can be compared easily in time series.

Rod-surface elevation tables (RSETs) provide an excellent fine-scale quantitative summary of year-to-year or season-to-season change in marsh surface elevation. Feldspar soil horizon markers provide a critical understanding of the relative contribution of vertical accretion (mineral and organic matter accumulation on the marsh surface) to marsh surface elevation change at sites. Our ability to interpret our data would have been further enhanced by having information acquired from a modest network of rod-surface elevation tables (RSETs) and feldspar soil horizon markers established at the site pairs.

Recommendations

- *Elevations of vegetation plots and groundwater wells should be measured annually, beginning at least one year prior to restoration. Elevations should be tied to the North American Vertical Datum 1988 (NAVD88).*
- *Elevation data should be collected along vegetation monitoring transects beginning at least one year prior to restoration and repeated during the first, second and fifth years, and every five years thereafter. Elevation profiles should be created showing all marsh zones, vegetation plots and transitions, from the elevation data. Elevations should be tied to NAVD88 or a local tidal datum.*
- *Marsh surface elevations and vertical accretion using RSETs and feldspar soil horizon markers at restoration and reference sites should be measured annually (or seasonally, if possible), beginning at least one year prior to restoration.*

- *The NERR System should develop training workshops focused on the measurement of marsh surface elevation changes and vertical accretion using survey-grade GPS RTK survey instruments, RSETs and feldspar horizon marker techniques to facilitate the evaluation of tidal wetland restoration projects.*

Utility of long-term wetland monitoring sites at Reserves as reference sites for restoration sites within the region

The use of reference sites, especially those permanently protected within NERRS boundaries, provided, for the most part, appropriate benchmarks to evaluate the local restoration sites included in this study. Two reference

SOUTH SLOUGH NERR OR: MONOTYPIC DOMINANCE BY ROBUST NATIVE SEDGE

Percent cover data collected and analyzed for this three year project shows the dominance of the common native sedge, Carex Lyngbyei persisting at the Kunz Marsh restoration site and the greater species diversity at the Danger Point Marsh reference site (e.g., Figure 3). Many mid- to high marsh tidal wetland restoration projects in Oregon develop plant communities overwhelmingly dominated by C. lyngbyei (Figure 2). Some have persisted for as long as 30 years (and counting). The low diversity of these recovering emergent wetlands may be cause for concern but it helps to know that some naturally-occurring marsh habitats can also be dominated by this robust plant. And 30 years is insignificant compared with the time tidal marshes may need to develop diverse and complex biological and physical attributes. It may be that disturbance events at varying scales over the long term will push Kunz Marsh vegetation cover inevitably towards a more diverse plant community.

But since one of the most often cited justifications for habitat restoration is the re-establishment of physical and biological complexity, we wonder if the "Carex-dominance" issue in the Pacific Northwest should be investigated to determine whether tidal wetland restoration practices for projects that would normally rely on natural recruitment should include measures to accelerate the development of more diverse plant communities.

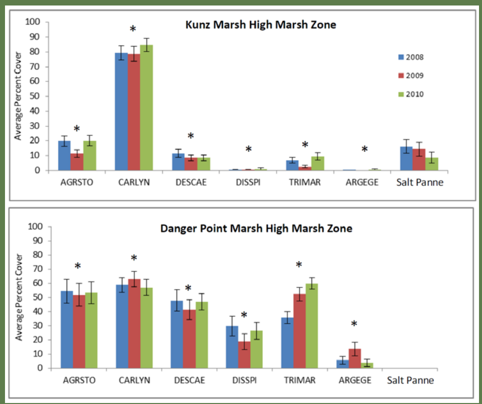

Figure 3. Percent cover means in the Kunz and Danger Point high marsh zone for each of the dominant emergent marsh species or species or element of interest at both sites. Asterisk denotes significant difference between sites for individual species. Species code for *C. Lyngbyei* is CARLYN.

sites outside of NERRS boundaries, permanently protected by national or local conservation groups, were also used in our analyses: 1) the Yaquina-28 (Y-28) site in the Yaquina estuary in Oregon was paired with the Yaquina-27 (Y-27) restoration site nearby (both sites are about 145 km from South Slough NERR), and 2) the Jacobs Point restoration site in Rhode Island used an adjacent reference site within the same estuary.

Since many of the NERRS reference sites in this study are part of system wide, long-term, monitoring programs that include emergent vegetation monitoring (e.g., NERRS Sentinel Sites), time series reference condition data for use in restoration project design and evaluation will continue to be available over the long term.

Recommendations

- *The NOAA Restoration Center and others involved with tidal wetland restoration around the nation should consider the NERRS in their regions as sources of high quality reference condition data and expertise in restoration monitoring and evaluation.*

- *The NOAA Restoration Center and the NERRS Sentinel Site Work Group should collaborate to ensure that the variables selected for evaluating emergent wetland restoration for projects funded by the Restoration Center be included in the NERRS long-term emergent vegetation monitoring program. This will provide a usable, long-term, reference site data base for the Restoration Center.*

Figure 4.. Location of National Estuarine Research Reserve sites along coastlines in the continental U.S. and Alaska. Locations of the five sites participating in this project are indicated: Wells NERR, Maine; Narragansett Bay NERR, Rhode Island; Chesapeake Bay VA NERR, Virginia; North Carolina NERR; and South Slough NERR, Oregon.

The Study

Background

The National Estuarine Research Reserve (NERR) System is comprised of 28 Reserves in all coastal states (including two Reserves on the Great Lakes)(Figure 4). Reserves maintain a core staff of scientists and educators who support active research, monitoring, outreach and training programs. One system wide element of Reserve research is long-term monitoring of wetland vegetation, soil salinity, groundwater level and surface elevation. In this study, funded by the NOAA Restoration Center, we have used study sites at five Reserves, including long-term vegetation monitoring sites, as reference sites (along with additional reference sites as appropriate) against which to compare the restoration of 17 local tidal wetland restoration projects previously funded by the NOAA Restoration Center.

Point intercept method for sampling emergent vegetation at the Danger Point marsh reference site in Oregon

Study Sites

Our tidal wetland reference and restoration study sites were located in or near five National Estuarine Research Reserve sites in Maine (Wells NERR), Rhode Island (Narragansett NERR), Virginia (Chesapeake VA NERR), North Carolina (North Carolina NERR) and Oregon (South Slough NERR)(Figure 4).

The number of reference and restoration sites monitored depended on the proximity of restoration sites to Reserves. In all, 10 hydrologic restoration sites (Wells, ME; Narragansett, RI; South Slough, OR) and 7 excavation/fill restoration sites (North Carolina; Chesapeake, VA; South Slough, OR) were monitored and compared to local reference sites (Table 2 and Figures 5-10). The reference sites, most of which were located within NERR boundaries, were paired with individual restoration sites. Reference sites were selected based on the degree to which they represented the appropriate type of least disturbed tidal wetland to match the presumed ecosystem state of the restoration sites.

It should be noted that while the Kunz Marsh restoration project at South Slough OR incorporated elements of both hydrologic and excavation/fill restoration techniques, this site was grouped with excavation/fill restoration sites for comparative analyses, since the subsided site was graded to specific elevations to in an experiment to investigate the optimal elevation for "correcting" wetland surface subsidence (Cornu 2005).

Table 2. NERR reference marshes and associated restoration sites, including restoration type, restoration date, area restored, linear distance from restoration site to paired reference site, and mean or range of site salinities. *Note that Kunz Marsh was both a hydrologic and excavation and fill restoration project, but was classified for data analyses as an excavation/fill restoration due to the extensive nature of the excavation and fill associated with that project.

Reserve	Reference Sites	Restoration Sites				
Wells, ME	**Webhannet Marsh** 25 ppt	**Site**	**Cascade Brook**	**Drakes Island**	**Spruce Creek**	**Wheeler Marsh**
		Rest type	Hydrologic	Hydrologic	Hydrologic	Hydrologic
		Rest date	2004	2005	2005	2004
		Area (ha)	36	31	8	6.9
		Prox to ref (km)	32.3	3.1	25.5	21.8
		Salinity (ppt)	11	16	20	25
Narragansett, RI	**Nag Marsh** 23.14 ppt	**Site**	**Potter Pond**	**Walker Farm**	**Silver Creek**	
		Rest type	Hydrologic	Hydrologic	Hydrologic	
		Rest date	2003	2005	2009	
		Area (ha)	2.3	6.5	5.6	
		Prox to ref (km)	2.16	14.76	7.24	
		Salinity (ppt)	23.82	19.97	17.27	
	Coggeshall Marsh 26.75 ppt	**Site**	**Gooseneck Cove**			
		Rest type	Hydrologic			
		Rest date	2005			
		Area (ha)	22.8			
		Prox to ref (km)	21.69			
		Salinity (ppt)	29.85			
	Jacobs Point 27.82 ppt	**Site**	**Jacob's Point**			
		Rest type	Hydrologic			
		Rest date	2010			
		Area (ha)	6.7			
		Prox to ref (km)	0.0			
		Salinity (ppt)	11.28			
Chesapeake VA	**Goodwin Islands** 16-23 ppt	**Site**	**Hermitage Living**			
		Rest type	Excavation/Fiill			
		Rest date	2007			
		Area (ha)	0.2			
		Prox to ref (km)	35			
		Salinity (ppt)	17-23			
	Taskinas Creek 6-16 ppt	**Site**	**Naval Weapons Stn.**	**Cheatham Annex**		
		Rest type	Excavation/Fill	Excavation/Fill		
		Rest date	2006	2007		
		Area (ha)	0.4	0.24		
		Prox to ref (km)	22	18		
		Salinity (ppt)	1.2-23	2-23		
North Carolina	**Middle Marsh** 15-38 ppt	**Site**	**Duke Marine Lab**	**NC Maritime Museum**	**Pine Knoll Shores**	
		Rest type	Excavation/Fill	Excavation/Fill	Excavation/Fill	
		Rest date	2002	2001	2002	
		Area (ha)	0.11	0.05	0.06	
		Prox to ref (km)	6	6.4	20	
		Salinity (ppt)	15-38	15-38	15-38	
South Slough OR	**Danger Point** 5-18 ppt	**Site**	**Kunz Marsh**			
		Rest type	Hydrologic-Ex/Fill*			
		Rest date	1996			
		Area (ha)	2.8			
		Prox to ref (km)	0.36			
		Salinity (ppt)	28			
	Yaquina 28 0.5-5 ppt	**Site**	**Yaquina 27**			
		Rest type	Hydrologic			
		Rest date	2002			
		Area (ha)	3.2			
		Prox to ref (km)	1.1			
		Salinity (ppt)	5			

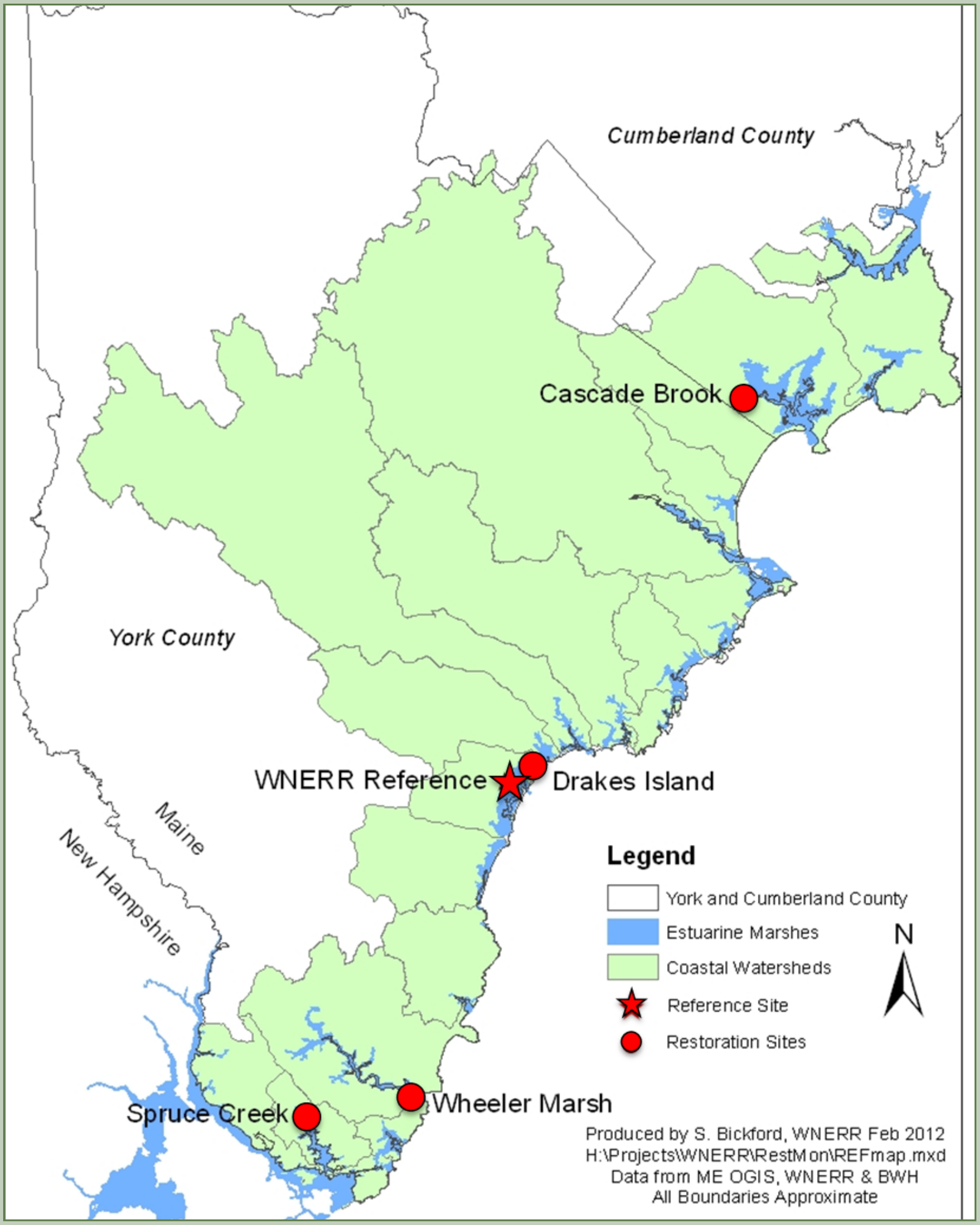

Figure 5. Location of reference site and four restoration sites monitored by the Wells NERR in southeast Maine.

Figure 5 shows the study sites associated with the Wells NERR in Maine comprised four tidal wetland restoration sites and one centrally located relatively undisturbed tidal wetland reference site. Restoration study sites were hydrologic restorations.

Site attributes are summarized in Table 2. The Wells NERR estuaries are associated with several watersheds, from northeast to southwest: Merriland, Branch, Little River; Webhannet River; and Ogunquit River.

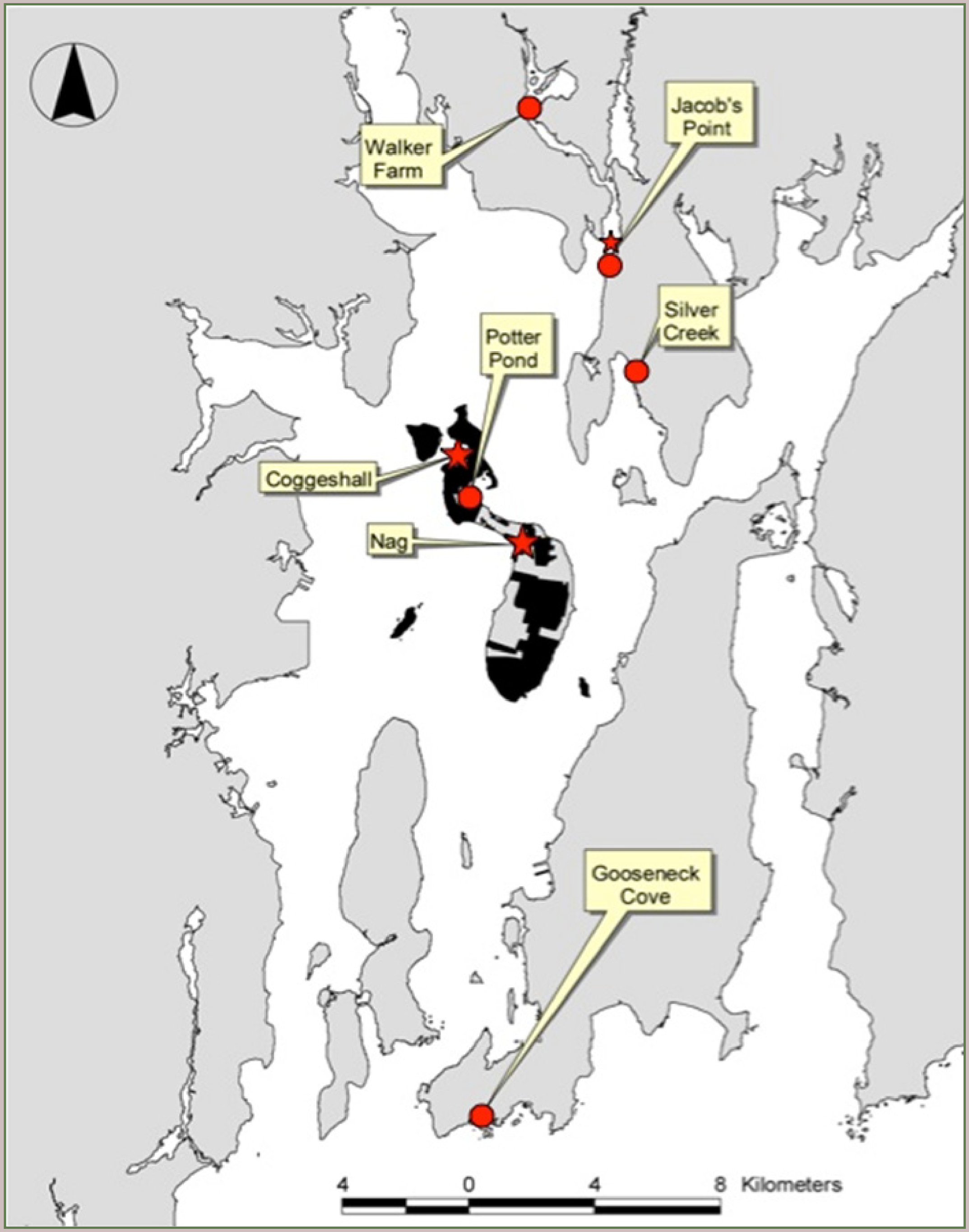

Figure 6. Location of three reference sites (red stars) and five restoration sites (red circles) monitored by the Narragansett Bay NERR in Rhode Island.

Figure 6 shows the study sites associated with the Narragansett Bay NERR comprised of five tidal wetland restoration sites and three relatively undistubed tidal wetland reference sites. Restoration study sites were hydrologic restorations. Land within the Narragansett Bay NERR is indicated in black. Site attributes are summarized in Table 2.

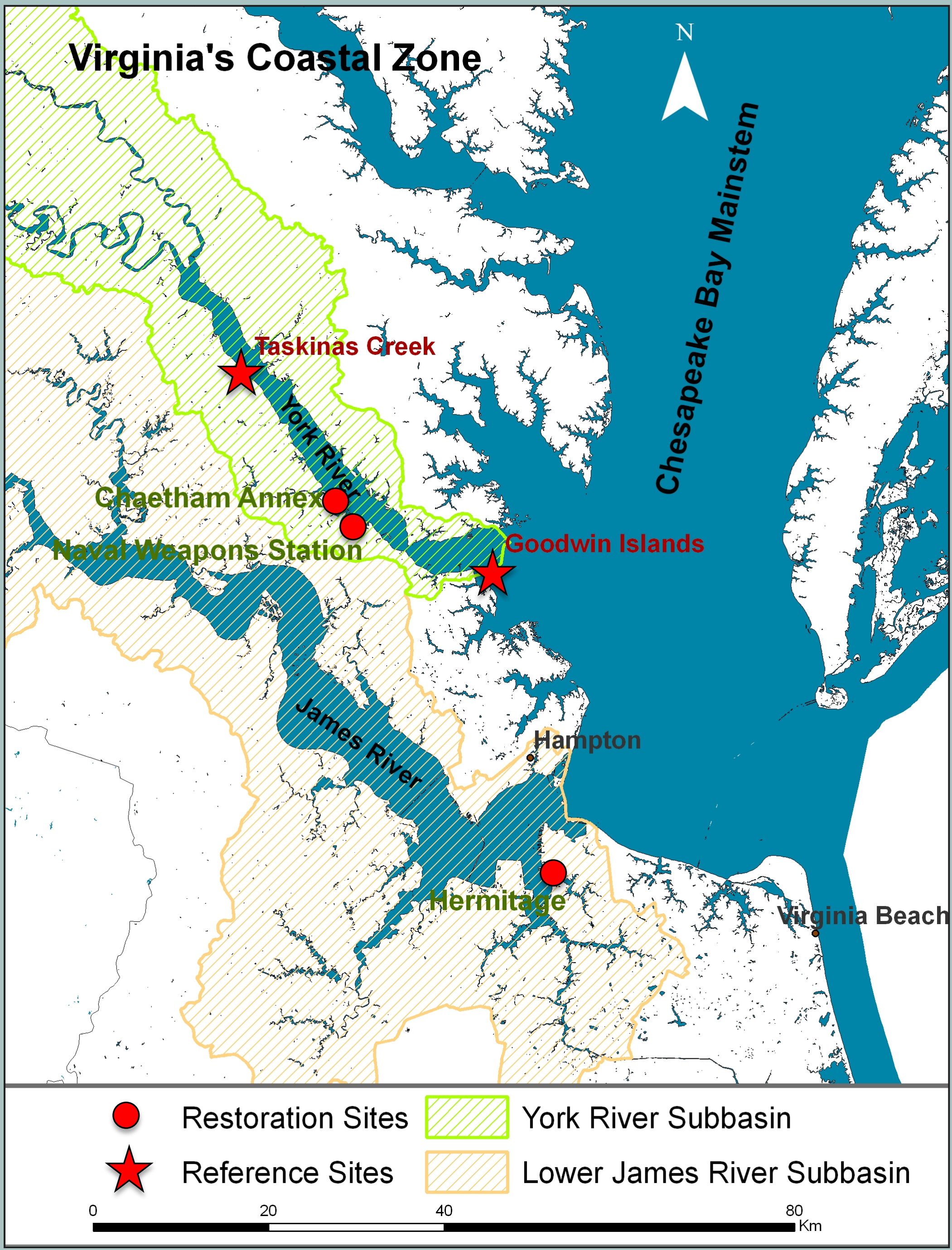

Figure 7. Location of two reference sites and three restoration sites monitored by the Chesapeake Bay VA NERR in Virginia.

Figure 7 shows the study sites associated with the Chesapeake Bay VA NERR comprised of three tidal wetland restoration sites and two relatively undistubed tidal wetland reference sites. Restoration study sites were excavation/fill restorations. Site attributes are summarized in Table 2.

Figure 8. Location of one reference site and three restoration sites monitored by the North Carolina NERR.

Figure 8 shows the study sites associated with the North Carolina NERR comprised of three tidal wetland restoration sites and one relatively undistubed tidal wetland reference site. Restoration study sites were excavation/fill restorations. Site attributes are summarized in Table 2.

Figures 9a and 9b show the study sites associated with the South Slough NERR comprising two tidal wetland restoration sites and two relatively undistubed tidal wetland reference sites. Restoration study sites were both hydrologic and excavation/fill restorations. Site attributes are summarized in Table 2.

The Danger Point - Kunz marsh reference-restoration site pair is located within the South Slough NERR administrative boundary. The Y-28 and Y-27 marsh reference-restoration site pair is located in the upper Yaquina estuary (river kilometer 24) about 185 km north of the South Slough NERR. Even though they are located far from the South Slough NERR site, the Y-27 and Y-28 sites will be referred to as South Slough OR study sites.

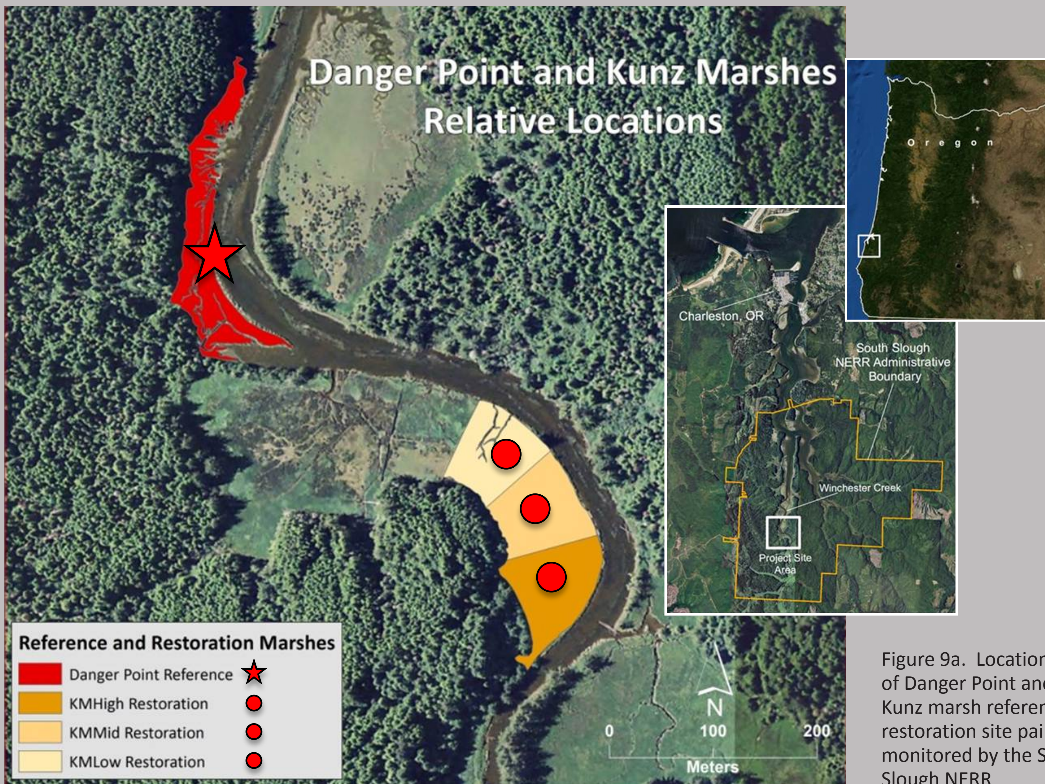

Figure 9a. Location of Danger Point and Kunz marsh reference-restoration site pair monitored by the South Slough NERR

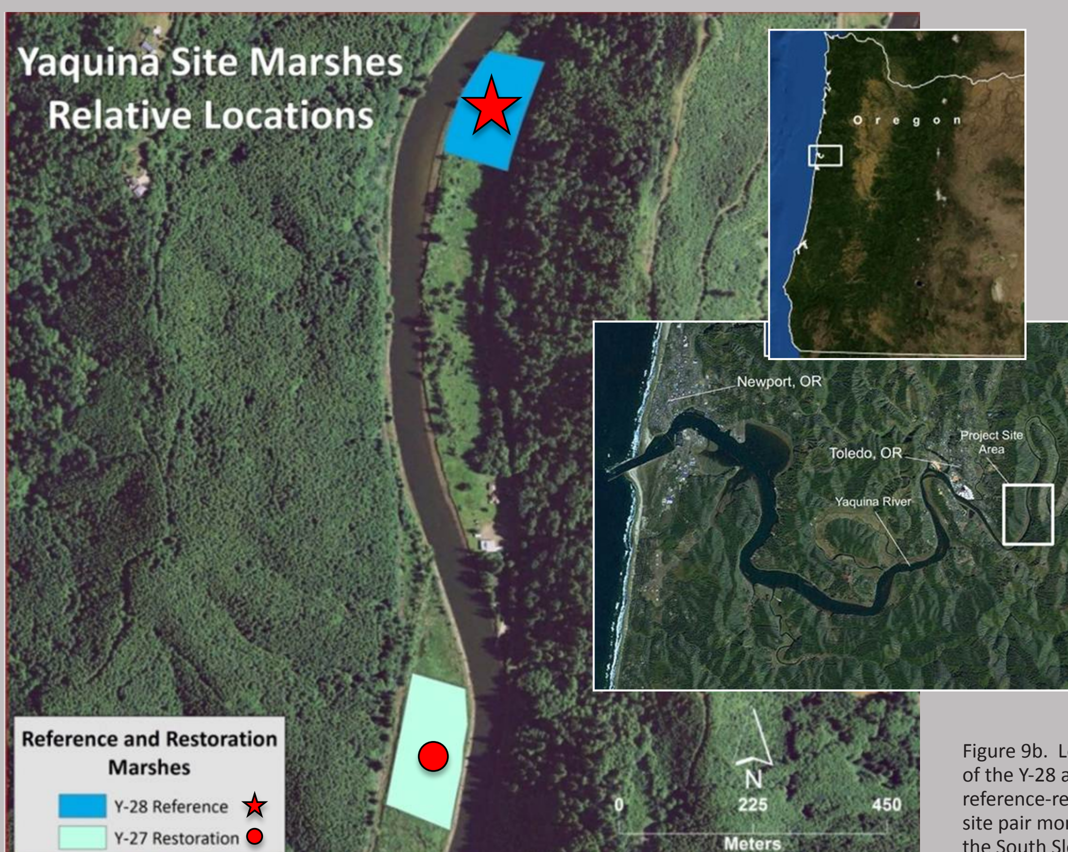

Figure 9b. Location of the Y-28 and Y-27 reference-restoration site pair monitored by the South Slough NERR

Methods Summary

Vegetation

Transects were established at sites and vegetation data collected in accordance with the NERRS Emergent Marsh Monitoring Protocol (Moore 2009). Field staff placed three transects with permanent vegetation monitoring plots in a representative area of each restoration site, sometimes using pre-existing transects and plots from the NERRS' long-term, emergent, vegetation monitoring or other studies.

Transects normally extend from the lower emergent marsh edge to the high tide line at the upper edge of the high marsh and through the marsh/upland transition zone. Three discreet zones were analyzed for this study: low marsh, high marsh and upland transition zones.

Porous PVC sipper

Porous PVC sipper in-situ

Hydrology

All Reserves installed three groundwater monitoring wells (1 m deep x 3 cm) along one transect in each marsh zone (low, high, transition). These wells were monitored with data water level loggers (Onset HOBO and/or AquaTroll 2000) for water depth, temperature, and salinity, with a fourth data logger deployed in the adjacent surface water channel to measure surface water temperature, salinity and depth in the same locale.

Porous PVC sippers were installed adjacent to groundwater logging wells to sample pore water salinity within the root zone – 5 to 30 cm depth. At Wells NERR and Narragansett NERR, a shallow PVC groundwater level/salinity well (0.45 m deep x 1.5 cm id) was associated with each transect or each permanent vegetation plot.

Soils

Soil cores were collected to represent marsh zones, in the vicinity of the permanent transects or vegetation plots. Cores were used to measure soil bulk density and soil organic matter content in the plant root zone.

Elevation

Elevation profiles were created for each transect, marking the location and elevation of the transect line, plots, wells, and marsh zonal transitions. Elevation was essential to interpretation of water level data in deep and shallow monitoring wells. All elevation values were tied to NAVD88 or a local tidal datum to facilitate comparisons between sites.

Data Analyses

Our approach to data synthesis was to combine data by Reserve, and compare variables measured across Reserves to provide a regional picture of restoration performance that allowed for the influence of frequently unique features of individual sites. For some variables we combined data from all restoration sites by restoration type to better understand differences in marsh restoration response to altered hydrology and excavation/fill.

The following analyses were conducted:

Difference Analyses: Differences between reference and restoration sites for vegetation and hydrology parameters were compared directly using Analysis of Variance (ANOVA), using annual means from 2008-2010.

Non-metric Multidimensional Scaling (MDS): MDS analyses provide two-dimensional plots showing similarities between species assemblage groups (species presence and abundance) through the distance between their locations in the plot.

The more separated in space two groups are (e.g., plant communities for restoration and reference sites for a particular Reserve), the less similar they are. The more scattered plant community sample points are within a group, the higher the plant community variability within that group. Multidimensional scaling (MDS) uses a set of statistical analysis techniques to visually compare data.

Restoration Performance Index (RPI): The Restoration Performance Index (RPI: Moore et al. 2009) is a simple method to track change at a restoration site for a specific set of parameters by comparing the difference between restoration and reference sites at a point in time to the difference at the onset of monitoring. Ideally, monitoring begins prior to restoration, but the RPI can be applied to any time series of data. For example, restoration site improvement may slow down as time progresses, and will be reflected as a smaller change from year to year in the RPI.

Linear Regression Analysis: Linear regression tests the significance and strength of association of two variables, an independent causal variable, and a dependent response variable, by fitting a straight line to the paired independent-dependent variable pairs. RPI vegetation component scores (dependent variable) were regressed individually against elevation and depth to groundwater (causal variables) to determine the strength of the relationships between vegetation results and the environmental variables.

A standardized approach to study design and data collection allows the most complete comparisons between sites, and is essential to data synthesis, analysis and interpretation. Our standardized data templates (and metadata) for these parameters are provided in Appendix C.

Point-intercept quadrat and pin

Deep groundwater monitoring well with Aquatroll 200™ data logger

Project Discussion

We discuss our project findings here organized by the analyses we conducted.

Restoration Performance Index (RPI)

For our study, excavation/fill restoration and hydrologic restoration performed equally well, as measured by the total RPI, and the component hydrology and vegetation RPIs. Hydrology trended towards lower salinities for hydrologic restoration sites, perhaps indicating the influence of socioeconomic and political constraints on project design which tend to reduce allowable tidal flooding levels in restoration designs due to concerns about risks to property and infrastructure.

Geomorphology/landscape setting was also a likely influence as several projects were situated in more riverine-dominated upper estuarine reaches (e.g. Cascade Brook at Wells ME, Silver Creek in Narragansett).

Phragmites australis

Photo: CT Sea Grant

Some sites' marsh surfaces were also historically subsided, and therefore more likely to retain freshwater inputs from floodplain tributaries and groundwater (e.g. Drakes Island at Wells ME, Gooseneck Cove at Narragansett).

Our study also reinforced the notion that hydrologic processes develop/recover more quickly at hydrologic restoration project sites than plant communities. As has been documented by Burdick et al. (1997), and Konisky et al. (2006), the full suite of hydrologic processes can recover quickly after restoration, depending on restoration design and management, which would incorporate potential and actual stakeholder requested constraints that may affect project performance and management (Dionne 2011). Plant communities can take much longer to develop and recover fully, and for the mid marsh communities progress through an initial large-scale facilitative succession (where one species alters the habitat to favor the next species in the succession). Once the larger marsh area has reached its final successional stage, similar successional changes occur on a smaller scale in response to disturbance (Pennings et al. 2001). Species richness for tidal wetland systems (especially salt marshes) is, in general, low when compared to terrestrial systems. Species richness at our tidal wetland restoration project sites were likewise low (1.14-7.01 species per m^2), providing limited scope for detecting differences between reference and restoration sites.

One difference between the two restoration types included in this study was for invasive vegetation. The aggressive invasive *Phragmites australis* was only found in abundance at hydrologic restorations sites, the result of prior establishment in response to tidal restriction and tidal wetland freshening. Evidence for Phragmites stunting after hydrologic restoration was observed at several sites in Narragansett RI (Potter Pond, Walker Farm and Silver Creek).

Difference Analyses

The lower pore water salinities seen in our project's hydrologic restoration sites (relative to paired reference sites) may indicate substantial fresh water impoundment occurring at many of the hydrologic restoration sites. Hydrologic restoration sites may still impound fresh water to some extent because of the limits often imposed on restoration designs that need to be as responsive to availability of funds and local socioeconomic and political concerns as they are to the physical and ecological process needs of the site.

In addition, marsh surface subsidence is a frequent result of hydrologic restriction and tends to increase tide water retention in the basin. At sites with significant freshwater inputs, tide water retention can result in lowered pore water salinities

At excavation/fill restoration sites there was a non-significant but noticeable trend of lower stem densities for typical native species at restoration sites compared with their paired reference sites, despite initial native species planting. Our excavation/fill restoration sites may be less protected from various types of physical disturbance than project hydrologic restoration sites, which were generally, though not always, located behind man-made barriers, potentially reducing site erosion from high flows, boat traffic, and storms; wrack deposition, and ice scour. Reduced disturbance would allow more rapid progress towards the reference condition for native plant species abundance.

Multidimensional Scaling of Abiotic Factors by Zone and Site

Similarity in Abiotic Parameters

The greater similarity of abiotic factors across marsh zones for hydrologic restoration compared to excavation/fill restoration may reflect the influence of subsidence on marsh topography. Patterns of tidal inundation are often affected by marsh surface subsidence at hydrologic restoration sites (Cahoon 1995, Portnoy and Giblin 1997, Portnoy and Valiela 1997, Anisfeld et al. 1999, Friedrichs and Perry 2001, Kennish 2001, Morlan 1991, Burdick et al. 1997, Boumans et al. 2002, Orr et al. 2003, Phillip Williams and Associates, Ltd. and P.M. Faber 2003, Cornu 2005, Bromberg Gedan et al. 2009, Mudd et al. 2009, Cahoon, D.R. and G.R. Guntenspergen 2010, Moreno-Mateos et al. 2011), which tends to reduce the normal low to mid marsh elevation gradient, so the influence of elevation on abiotic factors across zones would be reduced.

This loss of relief is the result of altered patterns of wetting and drying of the marsh soils during the period of impoundment: plants are killed by waterlogged soils during periods of poor drainage of freshwater runoff during the wetter seasons, and excessive soil drainage and desiccation during the drier seasons. Reduced plant cover reduces organic soil inputs both from aboveground and belowground biomass, and drained soils facilitate bacterial oxidation of existing organic matter, leaving behind a more compact, relatively mobile mineral soil horizon more susceptible to redistribution by water flows to flatter, lower, contours. In addition, reduced tidal exchange resulting from the hydrologic restriction reduces the deposition of suspended sediments to the impounded marsh, exacerbating marsh surface subsidence in times of rising sea levels. These results indicate that

Cheatham restoration site (Chesapeake VA) before project implementation (top) and after (bottom).

Walker Farm restoration project site in the upper Narragansett estuary.

hydrologic restoration projects should be designed to restore marsh surface topography to levels that facilitate and maintain the development of plant zonation patterns more like those of reference conditions.

Similarity in abiotic components between reference-restoration pairs revealed the greatest similarity at Narragansett RI for Jacobs Point, even though the Jacobs Point site was restored in the last year of this study. Here, as at other project sites (South Slough OR), the restoration site was compared to a reference site within the same system (Jacobs Point reference site), giving the evaluators particularly high confidence in the results. The value of selecting local, high quality reference sites whenever possible cannot be overstated (see discussion in Dionne et al. 1999).

The three restoration sites paired with the Narragansett RI Nags reference marsh showed intermediate similarity, better than might be expected for restoration sites still quite early in the recovery process (average age: 4 years).

The Narragansett RI Coggeshall-Gooseneck Cove reference-restoration pair showed the least similarity, possibly because Gooseneck Cove had been restored only one year prior to the end of this survey and the location of the reference site. The Coggeshall restoration marsh is up-estuary, while the Gooseneck Cove restoration site is adjacent to Rhode Island Sound.

South Slough OR and Chesapeake VA showed high levels of similarity between reference and restoration sites. In these two regions, there were four projects which were characterized as "excavation/fill" restoration projects and these projects tended to encompass smaller overall areas than found in hydrologic type restoration projects. These projects were also "built" to specified elevations using fill material, resulting in predictable tidal regimes and resulting abiotic conditions. The fifth site, a hydrologic restoration (South Slough OR- Y-27), involved extensive removal of dike material, filling of ditches, and excavation of pilot channels to achieve a specific tidal regime (and resulting abiotic conditions) that would over time develop conditions similar to those at the South Slough OR- Y-28 reference site.

The highest similarity rank between reference-restoration site pairs for South Slough OR and Chesapeake VA (Table 3) likely reflects close proximity of these pairs within the same estuaries (South Slough OR sites) or their very similar geomorphic settings (Chesapeake VA's Goodwin Islands vs., Hermitage). Narragansett RI and Wells ME rank next, probably because of the same factors mentioned above – all originally natural, tidally dominated systems, with restoration sites experiencing hydrologic restoration. The lowest ranking for North Carolina indicate the challenge of identifying appropriate natural reference sites for restorations that reflect a strong element of physical alteration of elevation through soil removal or fill.

Wells ME and North Carolina reference-restoration site pairs were the least similar in terms of sampled abiotic components. In the case of Wells ME, three of the four restoration sites were limited by constraints on the degree of tidal restoration acceptable to local residents, town officials, or Maine State wildlife biologists. In the case of North Carolina, the reference site was a portion of an extensive low marsh system surrounded by the open waters of Back Sound (and the only reference site not accessible to feral horses), while the restoration sites were all fringing marsh systems established adjacent to uplands to prevent shoreline erosion. The fringing marshes had distinct elevation gradients lacking at the reference site, with soils ranging from a layered mix of natural marsh soil and sand.

The greater similarity rankings across marsh zones for Wells ME and Narragansett RI (Table 3) again reflect the natural marsh soils, loss of elevation gradient due to subsidence, and tidally dominated hydrology due to proximity to open ocean waters in most cases. Chesapeake VA and South Slough OR were next in similarity across marsh zones, reflecting the influence of site variation in design with respect to elevation profiles and sources of fill. An added factor at the South Slough OR sites is the steeply sloping forested upland that cast more shade during the growing season on the high marsh zone than the mid and low marsh zones, creating different plant establishment and growth conditions and possibly affecting pore water salinities in those zones. North Carolina showed the least similarity across zones, potentially explained by the high elevations of the high marsh-upland transition at the DU and NC sites.

Variation in Abiotic Parameters

As was observed for similarity patterns described above, variation in abiotic parameters (hydrology, soils, marsh elevation) across zones tended to show different patterns for the two types of restoration. High variation for low marsh at excavation/fill sites (Chesapeake VA and North Carolina) may be influenced by the small size of the low marsh area at these sites, resulting in smaller sample sizes and therefore higher variance with which to estimate parameter values.

High variation in the high marsh transition zone (Narragansett RI, South Slough OR) at hydrologic restoration sites is likely due, in addition to small sample size, to variation in soils, slope, the more variable and episodic supralittoral tidal regime, and variation in runoff from the upland determined by local weather and land use.

Low variation for the mid-marsh platform (especially at North Carolina and South Slough OR) at excavation/fill sites suggests those sites may have achieved uniform hydrology via

	Abiotic				Biotic				
	Similarity		Variation		Similarity			Variation	
Rank	Zone	Ref-Rest	Zone	Site	Zone	Ref-Rest	Site	Zone	Site
1	Wells ME	Ches VA	Wells ME SS OR	NC	NC SS OR	Wells ME	NC	Narr RI	SS OR
2	Narr RI	SS OR	Narr RI	Wells ME	Wells ME	NC	Ches VA SS OR	Wells ME NC	Narr RI NC
3	Ches VA SS OR	Narr RI	NC	Ches VA	Ches VA	SS OR	Narr RI	Ches VA	Wells ME
4	NC	Wells ME	Ches VA	Narr RI	Narr RI	Ches VA	Wells ME	SS OR	Ches VA
5		NC		SS OR		Narr RI			

Site codes: Narr RI- Naragansett RI NC- North Carolina Ches VA- Chesapeake VA SS OR- South Slough OR

Table 3. Summary of rankings of similarity and variation of abiotic factors, and similarity and variation of biotic factors by zone, site and reference-restoration site pairings. For similarity, the ranking is 1 to 5 (with highest similarity being 1) and for variation the ranking is 1 to 5 (with highest variation being 5).

Volunteer training in vegetation data collection at the South Slough Kunz marsh study site.

restoration action, even though soils were variable due to the type of soil removal or fill source.

With low, mid and high marsh zones combined, the excavation/fill and hydrologic restoration sites showed low variation at North Carolina and Wells ME, while South Slough OR sites were uniformly intermediate in variation. This again likely reflects the greater ability to achieve the hydrologic regime targeted for those sites. The low variation at Wells ME sites was likely the result of similarity in the natural marsh soils, tidally dominated salinities, and areal dominance by broad, mid-marsh platforms. The high variation at the Chesapeake VA Cheatham Annex and intermediate variation at Naval Weapons sites may be the result of runoff from nearby uplands affecting groundwater parameters.

Variation in abiotic parameters for reference sites for Wells ME, Chesapeake VA and North Carolina were also low, providing relatively precise benchmarks for abiotic factors.

The wide range of variation in abiotic parameters for reference and restoration sites at Narragansett RI reflects the early stage of restoration for a number of sites. It also highlights the challenge of finding appropriate reference sites in this system of varied marsh configurations: Potter (marsh-tidal pond complex), Jacobs Point reference (extensive S. patens salt meadow), Silver Creek (higher freshwater inputs), and Gooseneck Cove (typical marsh but subject to excess nitrogen inputs).

Ranking of Reserves for total abiotic variation indicates that excavation/fill restoration sites have more controlled abiotic conditions than the Reserves represented by hydrologic restoration. Low variation within sites (low, mid, and high marsh zones combined) for North Carolina and Wells ME likely result from the areal dominance of low marsh in North Carolina and mid marsh in Wells ME. Chesapeake VA was intermediate in site variation, most likely due to differences in design and construction across sites.

Higher variation among sites at Narragansett RI reflects the diversity of marsh types and ages of restoration (discussed above), while the highest "within site" rank for South Slough OR may result from differences in design and time since restoration.

Multidimensional Scaling of Biotic Factors (Plant Community) by Zone and Site

Similarity in Biotic Parameters

Similarity between reference-restoration site pairs was low to intermediate, suggesting that most sites were in early to mid-term stages of plant community restoration. Two of the four restoration sites at Wells ME, one of the three restoration sites in North Carolina, and one of the two restoration sites at South Slough OR had the highest similarity, indicating these sites were the closest to achieving full plant community restoration status.

Interestingly, Wheeler Marsh at Wells ME was the only marsh to achieve the highest level of similarity when compared with its reference site, even though the elevation of this marsh (average elevation 1.47 m NAVD vs. 1.26 m NAVD for Webhannet reference) is about 20 cm higher than the natural marshes in the area, having been created by the settlement of slurried dredge material held back by retaining berms in the 1960s. This suggests that there is some upper range of mid-marsh elevation that will maintain a natural marsh plant community, so long as some minimally adequate tidal inundation is restored. Restoration designs that experiment with stepped increases in mid-marsh elevation may provide useful elevation benchmarks for the design of future restoration sites that will ultimately be subject to increasing sea level.

For an overall ranking among Reserves, Wells ME and North Carolina ranked highest, due to their proportion of site pairs with high similarity. The middle rankings for South Slough OR and Chesapeake VA respectively, likely reflect the initially larger differences between created and natural marshes. The lowest similarity ranking was for Narragansett RI, where similarity between restoration and reference sites is challenged by the early stages of some restoration sites, and the diversity of marsh types being compared.

Plant communities exhibited intermediate to low similarity across marsh zones for all study sites (reference and restoration), as would be expected of natural tidal wetland systems.

At the Reserve Level, North Carolina and South Slough OR had the highest similarity rankings across zones, reflecting the greater control over target conditions for excavated/fill restoration sites, compared to hydrologic restoration sites. The exception to the general trend was observed at Chesapeake VA with low similarity rankings across zones due to elevation differences and distinct plant communities within each zone (i.e. Primarily *Spartina alterniflora* in the low marsh zone and a mixture of *Spartina patens* and *Distichlis spicata* on the mid marsh platform).

Sites also showed intermediate to low similarity within zones, indicating that marshes were at different points along their restoration trajectories (measured as similarity to the paired reference site). At the Reserve level North Carolina exhibited high similarity within the low marsh zone across sites, the dominant zone by area, as the elevations of this zone were manipulated as part of each restoration. High and intermediate similarities within zones were due to the dominance of monocultural low marsh plant communities (North Carolina and Chesapeake VA), and the dominance of the mid-marsh zone at South Slough OR. The hydrologically restored sites at Narragansett RI and Wells ME ranked lowest in terms of within zone similarity, reflecting the more diverse mid-marsh zone among sites associated with these Reserves.

It should be noted that these analyses combined both reference and restoration sites to provide an overall picture of site similarity/dissimilarity. It would be an interesting exercise to carry out these comparisons for restoration sites alone.

Variation in Biotic Parameters

The range of variation of plant assemblages within marsh zones used to calculate Reserve rankings was very compressed, indicating a common level of variation in plant community assemblages across all regions (Tables 9-13).

Deep groundwater well installation.

The lowest variation within zones for the Narragansett RI sites may be due to the proximity of all but one of the 8 study sites (Walker Farm) to the open waters of Narragansett Bay, which provides those sites with similar tidal and salinity regimes. In addition, the large number of study sites would tend to reduce measured variation, due the large sample size. Uniform tidal influence would also explain the ranking of North Carolina and Wells ME.

Higher variation within zones for Chesapeake VA and South Slough OR sites likely reflect the smaller number of restoration sites (Chesapeake VA – 3, South Slough – 2), the distinct differences in the design of the restoration for two of the sites associated with each of these Reserves (stepped elevation vs. gradient at South Slough, soil removal and replacement vs. dredge deposition at Chesapeake VA, and potentially the difference in age between the two restoration sites associated with South Slough OR).

Plant communities in the high marsh (the upland transition zone) were the most variable in this study, reflecting greater variation in soil conditions, elevation, adjacent slopes, shading, and upland land use, as this zone is influenced more by upland conditions and less by the regular tidal flooding experienced by mid and low marsh zones.

Both reference and restoration sites showed high variation in plant communities (zones combined), indicating that plant community benchmarks will naturally exhibit a wide range around the mean values, and that there will be limits to the degree of similarity that can be achieved by most restoration projects that encompass a diverse plant community.

Narragansett Bay reference sites exhibited intermediate variation, perhaps reflecting their relative freedom from anthropogenic influence, or their proximity to the open waters of the Bay, and the strong influence of regular tidal cycles that drive processes that determine plant community assemblages. The intermediate variation for Goodwin Islands at Chesapeake VA and Middle Marsh for North Carolina can be similarly explained.

Although Danger Point reference marsh at South Slough OR is far upstream from the open waters of the Pacific, its plant community responds mainly to regular tidal flooding since the site is located along a large open estuarine channel (Winchester Creek) connected to a relatively small drainage (limited watershed influence). It is also characterized by a single marsh zone (mid marsh), with only 3 of the 27 plots representing the high marsh-upland transition zone and received a high level of sampling for its small size. The large size of the main channel and limited watershed inputs provide hydrologic and chemical (i.e. salinity) regularity. The high sampling density would reduce estimated variation, hence the distinction of lowest variation among reference systems in this study.

Restoration sites (combined zones) exhibited a similar level of variation across Reserves with average scores ranging from 2.25 to 3 (intermediate to high variation). At Wells ME, low variation at Drakes Island is likely due to the controlled tidal regime (via a self-regulating tide gate) and uniform elevation due to subsidence. The high variation at Wheeler Marsh reflects the patchy distribution of the vegetation still expanding within the formerly dry and barren areas that dominated the site (due to fill and settling of dredge slurry to a higher than normal mid-marsh elevation 40 years prior to hydrologic restoration).

High variation at the Cascade Brook restoration sites is likely the result of Phragmites encroachment encouraged by freshwater input from an upstream impoundment, while the high variation at Spruce Creek is most likely a function of the separation of the site by a roadway and runoff from upland development. Intermediate variation at the Marine Maritime Museum at North Carolina likely reflects the near monoculture of Spartina alterniflora . And at Gooseneck Cove at Narragansett, intermediate variation is likely the result of reduced variation in marsh elevation profiles due to subsidence.

Intermediate variation at the Kunz marsh restoration site is likely influenced by the size of the stable mid marsh platform, dominance of the plant community by the common native tidal wetland sedge, *Carex lyngbyei*, and the minimal contribution in the data from other marsh zones. South Slough OR sites showed the least within-site variation in plant communities, potentially resulting from the maturity of these sites (restored in 1996 and 2002), and dominance of *Carex lyngbyei*, with no low marsh and minimal representation of the high marsh upland transition. Relatively low variation of plant communities for the Wells ME sites again may be the result of dominance by the mid marsh platform, while the higher variation for Narragansett RI and North Carolina may be due to the diversity of sites and age at Narragansett, and variation in the relative proportion of zones within sites for both Narragansett RI and North Carolina (Tables 9-13).

The highest across-site variation in plant communities at Chesapeake VA most likely reflects the large natural variation associated with the percent cover estimates of the dominant plant species, due to distinct plant community differences between low and mid marsh.

Analysis of Similarity (ANOSIM) and Similarity Percentages (SIMPER) for Plant Communities

The desired end-stage result for reference-restoration plant community site comparisons is that they are not significantly different, indicating that the plant communities are comparable. In our study, only two of the 17 site comparisons made indicated no significant difference between paired reference-restoration plant communities: Wheeler Marsh at Wells ME, and for the Hermitage Marsh at Chesapeake VA (Table 4) (null hypothesis of no significant difference was rejected in 15 of 17 comparisons at the p <= 0.05 level).

Plant Community Analysis of Similarity

NERR	Reference	Restoration	*p*	SP #	Dissim %	
					Total	Mean
Wells ME	Webhannet Marsh	Cascade Brook	0.001	21	75	69
		Drakes Island	0.012	16	63	
		Spruce Creek	0.013	18	69	
		Wheeler Marsh	0.106	17	69	
Narragansett RI	Nag Marsh	Potter Pond	0.003	8	66	72
		Walkers Farm	0.001	12	80	
		Silver Creek	0.001	13	72	
	Coggeshall Marsh	Gooseneck Cove	0.005	9	60	
	Jacobs Point	Jacobs Point	0.001	11	78	
Chesapeake VA	Goodwin Islands	Hermitage	0.069	5	60	64
	Taskinas Creek	Naval Weapons	0.002	9	66	
		Cheatham Annex	0.003	5	66	
North Carolina	Middle Marsh	Duke Marine Lab	0.001	11	59	57
		NC Maritime Museum	0.001	8	52	
		Pine Knoll Shores	0.001	10	60	
South Slough OR	Danger Point	Kunz Marsh	0.001	16	65	77
	Y-28	Y-27	0.001	18	89	
			Mean SP# = 12 (1.2 SE)			

Table 4. Results of plant community Analysis of Similarity for reference-restoration site pairs. All comparisons were significantly different (p<=0.05) except for Wheeler Marsh (Wells ME) and Hermitage Marsh (Chesapeake VA) restoration sites. SP# is the combined number of plant species/cover types for each pair, and Dissim % provide the total dissimilarity between site pairs, and the mean for each Reserve.

The similarity between Wheeler Marsh and the Webhannet Marsh reference site is consistent with the highest RPI score received for this marsh among the Wells ME restoration sites.

Similarly, the Hermitage Museum restoration site showed the highest mean RPI among restoration sites at Chesapeake VA, and the highest RPI for 2010, 4% higher than Naval Weapons and 7% higher than Cheatham Annex. The Hermitage site differed from other Chesapeake VA restoration sites in that it was more of a tidal wetland enhancement site that dealt with physical improvements to an existing natural marsh: removal of hardened shoreline, creation of a soft protective beach buffer, removal of *P. australis*, and planting with *S. alterniflora* and *S. patens*. At the Naval Weapons and Cheatham restoration sites, entire areas were excavated, new fill material was placed, the marsh surface was leveled and graded, and the area was replanted.

Not surprisingly, the RPI values reflect for the Hermitage site the quick recovery of plant communities having been minimally altered by habitat enhancement actions. Similarity percentage analysis (SIMPER) provides additional information regarding analysis of similarity tests, quantifying the contribution of individual species within the combined assemblage of both groups (reference and restoration) to their total dissimilarity. Nearly all the total dissimilarities were greater than 50%, and ranged as high as 89%, providing a quantitative indicator of the degree to which each restoration site will need to change to better resemble its reference site.

Three marsh species from natural marshes (*Spartina alterniflora*, *Spartina patens*, and *Distichlis spicata*) account for 44% of the top 5 species contributing to dissimilarity between restoration-reference site pairs indicating that restoration sites should be increasing in their distribution and abundance of these species over time to become more similar to their reference communities. This result flags key species whose distribution and abundance should be evaluated at project sites to determine whether adaptive management measures designed to help move plant community recovery towards reference condition equivalence would be appropriate and relevant to project goals. To underscore the need to validate such results at the site level, consider the context of this result for west coast sites where S. alterniflora, and S. patens are invasive exotic species.

Phragmites australis is clearly a concern, as it accounts for 8% among the top 5 species contributing to dissimilarity, due almost entirely to its presence in restoration sites. This species can invade and totally alter the tidal wetland plant community and its functions (Burdick et al. 2001, Bertness et al. 2002, Burdick and Konisky 2003).

Finally, bare ground was also an important contributor to dissimilarity (e.g. Wells ME, North Carolina, and Narragansett RI), due to its greater abundance at reference sites. This likely reflects the normal disturbance regime of natural marshes that may be lacking in restoring marshes.
Age, size, geomorphology, elevation, microtopography, climate, and man-made barriers can all influence the frequency, size, and pattern of physical disturbance in tidal wetlands. It is important to note that disturbed patches can recover fully through a successional process (Pennings et al. 2001) or shift to an altered state such as pools (Wilson et al. 2009) or forb pannes (Ewanchuk and Bertness 2003, Ewanchuk and Bertness 2004a, Ewanchuk and Bertness 2004b, Griffin et al. 2011).

	Environment – Plant Community Correlations Reference and Restoration Sites					
NERR	*r*	Bulk Density	% Organic Content	PSU	Ground H_2O	Elevation
Wells ME	0.356					
Narragansett RI	0.225					
Chesapeake VA	0.335					
North Carolina	0.129					
South Slough OR	0.482					

	Environment – Plant Community Correlations Restoration Sites Only					
NERR	*r*	Bulk Density	% Organic Content	PSU	Ground H_2O	Elevation
Wells ME	0.378					
Narragansett RI	0.181					
Chesapeake VA	0.417					
North Carolina	0.252					
South Slough OR	0.415					

Table 5. Spearman rank correlations (r) between environmental factors and plant communities. Factors identified for each Reserve provided the highest r of all combinations of the 5 environmental factors (soil bulk density and percent organic content, practical salinity units, depth to ground water and surface elevation). Factors were screened in advance and did not exhibit autocorrelation. Unshaded cells indicate no data available. Top analyses include both reference and restoration sites; Bottom analyses include restoration sites only.

Plant Community-Abiotic Factor Correlations

Elevation was a primary abiotic correlate of the plant community, contributing to the highest "r" (Spearman rank correlation coefficient) at all 5 Reserves, when both reference and restoration sites were included in the analysis, and for all Reserves when reference sites were eliminated (Table 5). Because of the plant community dissimilarity between most reference-restoration site pairs (see Analysis of Similarity for Plant Communities above), we reasoned that it would be useful to assess the strength of the abiotic-biotic correlation in both ways.

Our findings agree with the general experience of tidal wetland restoration scientists and practitioners as well as the body of work published by Morris and colleagues over the past decade demonstrating the critical importance of marsh surface elevation in maintaining marsh plant communities in response to tidal flooding (Morris et al. 2002, Morris 2006, Morris 2007, Kirwan et al. 2009, Mudd et al. 2009, Mudd 2011).

Depth to groundwater was the other abiotic factor that correlated significantly with restoration and reference site plant assemblages – contributing to the highest correlation (r), along with elevation, at all sites where it was measured.

Our findings reinforce the known relationship between the saturation level of the marsh root zone and the associated plant community: i.e., some groups of marsh plants are more tolerant of longer periods of saturated soil conditions than others.

When the analysis was focused on restoration sites alone, this variable remained a significant correlate of the plant community at sites for 2 of the 3 Reserves where it was measured. For 3 of the Reserves the correlation (r) increased when reference sites were removed, a result of the influence of their dissimilarity with restoration sites on the strength of association between abiotic factors and plant communities.

Restoration site-only analyses at Narragansett RI and South Slough OR reduced the groundwater-plant community correlation somewhat, perhaps due to the large proportion of the complete data set contributed by reference sites for these Reserves (3 of 8 sites and 2 of 4 sites respectively). Interestingly, when only restoration sites were analyzed for Wells ME, soil factors replaced depth to groundwater as primary correlates of the plant community, with slightly increased correlations. This shift may be caused by the combined effect of: 1) the large number of soil cores in the data set (1 for each vegetation plot); and 2) the greater difference in groundwater depth at the restoration sites compared to the reference site (mean and standard error: reference; -23.7 cm ± 0.6, restoration; - 4.4 cm ± 0.8).

For South Slough OR, salinity becomes a primary correlate of the plant community when reference sites are excluded, emphasizing the large difference in groundwater salinity between the two restoration sites (mean: Kunz – 28 ppt, Y27 – 5 ppt); and for Narragansett, percent organic content of soil is no longer a correlate of the plant community, suggesting that variation in this parameter is reduced when reference sites are eliminated, and thus its ability to relate to variation in the plant community.

The significant correlation between RPI vegetation scores and both elevation and depth to groundwater across all Reserves reinforces the importance of these two abiotic factors in determining the plant community structure of restoring marshes.

Sampling transect at the Taskinas Creek marsh reference site, Chesapeake VA.

References Cited

Anisfeld, S.C., M.J. Tobin, G. Benoit. 1999. Sedimentation rates in flow-restricted and restored salt marshes in Long Island Sound. Estuaries 22, No. 2A: 231-244.

Bertness, M. D., P. J. Ewanchuk, and B. R. Silliman. 2002. Anthropogenic modification of New England salt marsh landscapes. Proceedings of the National Academy of Sciences. 99(3): 1395-1398.

Boumans, R.M., D.M. Burdick, and M. Dionne. 2002. Modeling habitat change in salt marshes after tidal restoration. Restoration Ecology 10(3): 543-555.

Bromberg Gedan, K., B.R. Silliman, and M.D. Bertness. 2009. Centuries of Human-driven change in salt marsh ecosystems. Annual Review of Marine Science 1: 117-451.

Burdick, D. M., M. Dionne, R. M. Boumans, and R. T. Short. 1997. Ecological responses to tidal restorations of two northern New England salt marshes. Wetland Ecology and Management 4:129-144.

Burdick, D.M., R. Buchsbaum, and E. Holt. 2001. Variation in soil salinity associated with expansion of Phragmites australis in salt marshes. Environmental and Experimental Botany 46: 247-261.

Burdick, D.M. and R. Konisky. 2003. Determinants of expansion for Phragmites australis, common reed, in natural and impacted coastal marshes.

Cahoon, D.R. and G.R. Guntenspergen. 2010. Climate change, sea-level rise, and coastal wetlands. National Wetlands Newsletter 32: 8-12.

Cahoon, D.R., D. J. Reed, and J.W. Day, Jr. 1995. Estimating shallow subsidence in microtidal salt marshes of the southeastern United States: Kaye and Barghoorn revisited. Marine Geology 128:1-9.

Cornu, C.E. 2005. Restoring Kunz marsh: a case history addressing marsh surface subsidence. South Slough NERR Coastal Resource Management Series. CRMS-2005-1. Coos Bay, Oregon.

Cornu, C.E., H. Harris, and A. Helms. 2011. NOAA Reference sites: measuring tidal marsh plant, soil and hydrologic response to restoration using performance benchmarks from local reference sites. South Slough National Estuarine Research Reserve, Coos Bay, OR. 58 pp.

Davy, A. J., M. J. H. Brown, H. L. Mossman, and A. Grant. 2011. Colonization of a newly developing salt marsh: disentangling independent effects of elevation and redox potential on halophytes. Journal of Ecology 99: 1350-1357.

Dionne, M. and C. Peter. 2011. Measuring salt marsh plant, soil and hydrologic response to restoration using performance benchmarks from a local reference system. Wells National Estuarine Research Reserve, Wells, ME. 31 pp.

Dionne, M., F. T. Short and D. M. Burdick. 1999. Fish utilization of restored, created, and reference salt-marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22:384-404.

Dionne, M. 2011. Drakes Island marsh restoration final report. Submitted to RAE/NOAA Restoration Center. Wells National Estuarine Research Reserve. 13 pp.

Ewanchuk, P.J.and M.D. Bertness. 2003. Recovery of a northern New England salt marsh plant community from winter icing. Oecologia 136: 616-626.

Ewanchuk, P.J. and M.D. Bertness. 2004. Structure and organization of a northern New England salt marsh plant community. Journal of Ecology 92: 72-85.

Ewanchuk, P.J. and M.D. Bertness. 2004. The role of waterlogging in maintaining forb pannes in northern New England salt marshes. Ecology 85(6): 1568-1574.

Fear, J. 2011. Measurement and assessment of restored and reference Spartina alterniflora marsh ecosystems in North Carolina. North Carolina National Estuarine Research Reserve, Beaufort, NC. 26 pp.

Friedrichs, C.T. and J.E. Perry. 2001. Tidal wetland restoration: physical and ecological processes. Journal of Coastal Research, special issue 27: 7-37.

Griffin, P.J., T. Theodose, and M. Dionne. 2011. Landscape patterns of forb pannes across a northern New England salt marsh. Wetlands 31:25-33

Godinez-Alvarez, H., J. E. Herrick, M. Mattocks, D. Toledo, and J. Van Zee. 2009. Comparison of three vegetation monitoring methods: their relative utility for ecological assessment and monitoring. Ecological Indicators 9: 1001-1008.

Kennish, M.J. 2001. Coastal salt marsh systems in the U.S.: a review of anthropogenic impacts. Journal of Coastal Research 17(3): 731-748.

Kirwan, M. L., G. R. Guntenspergen, and J. T. Morris. 2009. Latitudinal trends in Spartina alterniflora productivity and the response of coastal marshes to global change. Global Change Biology. 15: 1982-1989.

Konisky, R., D. M. Burdick, M. Dionne, and H. A. Neckles. 2006. A regional assessment of salt marsh restoration and monitoring in the Gulf of Maine. Restoration Ecology 14:516-525.

Lerberg, S. and W. G. Reay. 2011. Measurement and assessment of restored and reference salt marsh structural and functional performance indicators in the southern Chesapeake Bay. Chesapeake Virginia National Estuarine Research Reserve, Gloucester Point, VA. 96 pp.

Moore, G.E., D.M. Burdick, C.R. Peter, A. Leonard_Duarte, and M. Dionne. 2009. Regional assessment of tidal marsh restoration in New England using the restoration performance index. Final Report submitted to NOAA Restoration Center. 237 pp.

Moreno-Mateos, M.E. Power, F.A. Comin, and R. Yockteng. 2011. Structural and functional loss in restored wetland ecosystems. PLoS Biology 10(1): e1001247. Doi:10.1371./journal.pbio.1001247.

Morlan, J.C. 1991. Ecological status and dynamics of a salt marsh restoration in the Salmon River Estuary, Oregon. M.S. Thesis, Oregon State University, Corvallis, OR.

Morris, J.T. 2006. Competition among marsh macrophytes by means of geomorphological displacement in the intertidal zone. Estuarine and Coastal Shelf Science 69:395-402.

Morris, J.T. 2007. Ecological engineering intertidal saltmarshes. Hydrobiologia 577:161-168.

Morris, J.T., P.V. Sundareshwar, C.T. Nietch, B. Kjerfve, D.R. Cahoon. 2002. Responses of coastal wetlands to rising sea level. Ecology 83:2869-2877.

Mudd, S.M., S.M. Howell, J.T. Morris. 2009. Impact of dynamic feedbacks between sedimentation, sea-level rise, and biomass production on near-surface marsh stratigraphy and carbon accumulation. Estuarine, Coastal and Shelf Science 82:377-389.

Mudd, S. M. 2011. The life and death of salt marshes in response to anthropogenic disturbance of sediment supply. Geology 39(5): 511-512.

National Estuarine Research Reserve System (NERRS). 2009. Bioregions. Retrieved from http://nerrs.noaa.gov/BGDefault.aspx?ID=65)

Orr, M., S. Crooks, W.P. Williams. 2003. Will restored tidal marshes be sustainable? San Francisco Estuary and Watershed Science 1(1): 1-33.

Pennings, S.C. and M.D. Bertness. 2001. Salt marsh communities. In Marine Community Ecology. Edited by M.D. Bertness, S.D. Gaines and M.E. Hay. Sinauer, Sunderland, MA. pp. 289-316.

Pete, R.K., T.R. Wentworth, and P.S. White. 1998. A flexible, multipurpose method for recording vegetation composition and structure. Castanea 63(3):262-274.

Phillip Williams & Associates, Ltd. and P.M. Faber, P.M. 2004. Design guidelines for tidal wetland restoration in San Francisco Bay. The Bay Institute and California State Coastal Conservancy, Oakland, CA. 83 pp.

Portnoy, J.W. and A.E. Giblin. 1997. Biogeochemical effects of seawater restoration to diked salt marshes. Ecological Applications 7(3): 1054-1063. Estuaries 20(3): 569-578.

Portnoy, J.W. and I. Valiela. 1997. Short-term effects of salinity reduction and drainage on salt-marsh biogeochemical cycling and Spartina (cordgrass) production.

Raposa, K.B. and Weber, R. 2011. NERRS reference sites project: final report from the Narragansett Bay Research Reserve. Narragansett Bay Research Reserve, Providence, RI. 67 pp.

Roegner, G.C., H.L. Diefenderfer, A.B. Borde, R.M. Thom, E.M. Dawley, A.H. Whiting, S.A. Zimmerman, and G.E. Johnson. 2008. Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary. PNNL-15793. Report by Pacific Northwest National Laboratory, National Marine Fisheries Service, and Columbia River Estuary Study Taskforce submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Society for Ecological Restoration International (SER). 2004. The SER International Primer on Ecological Restoration. Retrieved from http://www.ser.org/content/ecological_restoration_primer.asp#6

Thayer, Gordon W.; Teresa A. McTigue; Ronald J. Salz; David H. Merkey; Felicity M. Burrows; and Perry F. Gayaldo. Science-Based Restoration Monitoring of Coastal Habitats. Volume Two: Tools for Monitoring Coastal Habitats. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, National Centers for Coastal Ocean Science, Center for Sponsored Coastal Ocean Research. April, 2005.

Wilson, K.R., J.T. Kelley, A. Croitoru, M. Dionne, D. Belknap, and R. Steneck. 2009. Salt pools are secondary and dynamic features of the Webhannet Estuary, Wells, Maine, USA. Estuaries and Coasts 33: 855-870.

Appendix A: Methods Detail

Vegetation

Plant community percent cover was measured using the point intercept method (Godinez-Alvarez et al. 2009) using one meter by one meter quadrats (50 points per quadrat). The identity of every species that touched each vertical point (using a 3 mm diameter dowel) was recorded (Image 2). Note that the point – intercept method measures plants in vertical as well as horizontal space, allowing more than 100% cover, since canopy plants often overhang subcanopy plants. In most uses of this method, the total percent cover values are corrected so that the maximum value is 100%. In this study, however, we have used the raw percent cover scores, as they contain more information about the horizontal and vertical structure of each species within the overall plant community found in each quadrat.

Vegetation data were collected in August (period of maximum aboveground biomass) during 2008, 2009, and 2010. Vegetation plots one meter on a side were offset by one meter perpendicular to the transect line and two diagonally opposite corners outside the boundary of each plot were marked with stakes. At Wells NERR and Narragansett NERR shallow groundwater wells were located one meter perpendicular to the transect line on the opposite side from the plot (Figure 10).

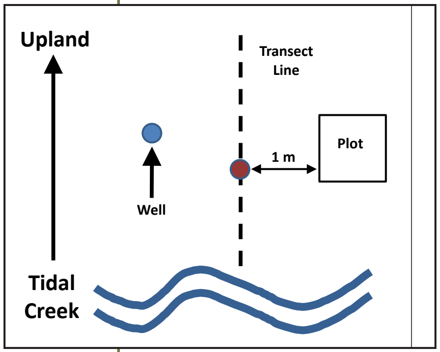

Figure 10. Basic vegetation transect layout and groundwater well location (diagram after Moore 2009).

As noted in the recommendations section, vegetation sampling design methods need to be different for west coast sites than those used in this study. Vegetation transects in west coast emergent tidal wetlands should be oriented parallel to intertidal zonation (e.g., Roegner et al. 2008) (Figure 11). For higher diversity west coast tidal wetland plant communities, we also recommend that a power analysis be conducted to determine the minimum number of vegetation plots needed to detect a specific level of yearly change in percent cover data in.

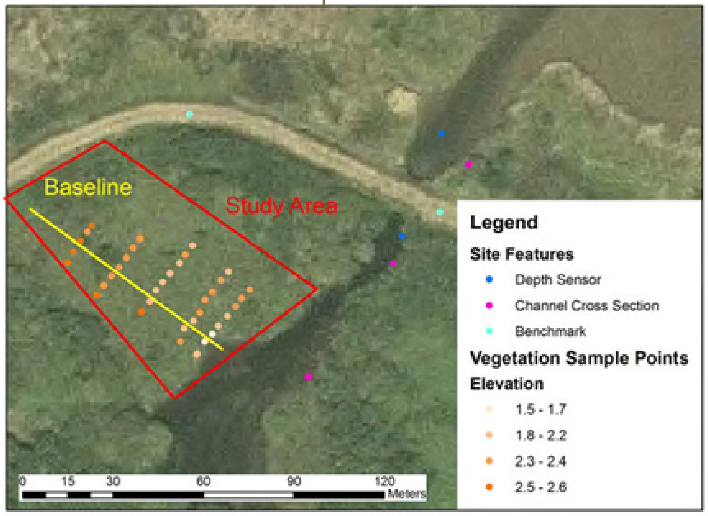

Figure 11. Example of baseline and transect sampling design in an Oregon coast herbaceous tidal wetland (from Roegner et al. 2008).

We also measured (for all participating Reserves for at least one year of the study) plant density and plant height in addition to percent cover in each permanent vegetation plot. Plant density for typical tidal wetland species were measured in 0.25 m^2 or 0.625 m^2 quadrats within the larger 1 m^2 permanent plot, with an exception for the high density species *Spartina patens, Distichlis spicata*, and *Juncus gerardii*, which were counted often in 0.01 m^2 quadrats. Species of concern (e.g. invasive vegetation), were measured directly in the 1 m^2 plots. This was not difficult as these species are large and do not achieve extreme densities in a 1 m^2 area. Plant height was measured for the dominant and subdominant species in the reference marsh, as well as for species of concern. Height was measured for the three longest stems for each species within the 1 m^2 sampling plot.

Salinity

Up to five types of salinity measurements were made (depending on the Reserve:

1) For shallow groundwater wells (installed up to 45 cm depth) water samples were retrieved with a metal tube (perforated at the lower end and fitted with a syringe at the upper end) and measured with a hand-held refractometer.

2) Adjacent to the shallow groundwater wells, pore water was sampled using the perforated metal tube inserted directly into the marsh substrate, to a depth within the top 20 cm (usually six to 16 cm), depending on soil wetness, and salinity measured with a refractometer (measures parts per thousand (ppt) NACL).

3) Adjacent to the deeper groundwater logging wells, porous PVC sippers installed to 20 cm depth in the substrate were used to extract fresh pore water samples. Samples were extracted by clearing the chamber and applying a vacuum using a syringe, and read with a refractometer, or a handheld YSI-85 salinity probe, which measures salinity as Practical Salinity Units (PSU), a dimensionless ratio of conductivity of the sample to an international calibration standard.

4) At groundwater logging wells (installed to one meter depth), salinity was measured as PSU at six- minute intervals during a two week spring-neap tide cycle, using In Situ Aquatroll 200™ instruments.

5) At each vegetation plot, three replicate soil cores, approximated 3.4 cm in diameter, were cut approximately 10-15 cm into the soil. A small section of marsh soil was removed from the bottom of each soil core. Drops of pore water were extracted from the base of the sample using the garlic press and coffee filter method, and salinity was measured with a refractometer (ppt).

Wells and sippers were sampled within 2 hours of low tide, on several dates throughout the June-September sampling period.

Groundwater Level

Spot checks of water level were measured in shallow and deep groundwater wells using a water level probe to locate the water surface during times when Aquatrolls were deployed, as well as for several additional dates throughout the June-September sampling period. Groundwater level was measured at 6 minute intervals in the 1 m deep logger wells using the Aquatroll™ loggers. Percent inundation time for each deep groundwater well was calculated as the percent of time that the water level was higher than the substrate.

Soils

Soil cores were collected by hand with a sharpened, thin-walled, stainless steel tube (3.5 cm diameter) inserted to 20 cm depth. Cores were sectioned longitudinally or horizontally. These sections were used to measure bulk density and organic content by loss on ignition, following standard procedures (Ball 1964, Burt 2004).

Elevation

The position and elevation (NAVD88) of each vegetation quadrat was recorded using survey grade leveling, GPS, or total survey station instruments. Plot elevations were measured as the mean of up to 4 points located within each 1 m^2 plot. Elevations and positions of all wells were measured as single points. Transect profiles marked position and elevation of vegetation zone transitions, channel creek and pool edges, and channel bottom, and points at regular intervals (approximately 10 m) on the marsh platform.

Data Methods

Data Management

Monitoring data collected across five NERRs using standardized data templates were received by the data consultant for series of similar parameters (Vegetation, Pore Water, Groundwater, Soils, and Elevation). Data sheets (Microsoft Excel®) from each Reserve were checked and formatted when necessary to match existing templates. Databases were created for parameters that were collected using similar methodologies. For vegetation data, the data template was repeatedly modified to include newly recorded species, consistency of recorded plant densities and heights, and better overall organization. Once all data sets were standardized to the latest version template, data from each Reserve were combined and housed in an Excel file to create a national database of restoration and reference marsh data. These databases were created for each series of parameters (e.g., vegetation, soils) except for groundwater data collected through Aquatrolls™, which were too extensive to practically combine into one national database. Therefore, groundwater databases remained in files by Reserve.

Data were summarized into means and standard error for each monitored site, yearly, both by marsh zone, and the average of all marsh zones. Summarized data were also housed in Excel® files for each Reserve and sorted by restoration site, along with its paired reference (to facilitate comparison), in separate worksheets within each Reserve file. In instances where several restoration sites shared the same reference site, reference data was duplicated on multiple worksheets. The majority of analyses involved comparing restoration to reference data. These summary databases were intended to provide performance benchmarks for both restoration and reference sites that would be easily transferable to NOAA's Restoration Monitoring Planner.

Performance benchmarks (means and standard error) were summarized for each site (all data pooled, and also by zone – low (L), high (M – for mid-marsh platform), and high marsh/upland transition (H – for high marsh perimeter) for the standard suite of performance variables based on all reference site data collected for each NERR, by year, and for all years combined. These benchmarks are housed in separate data sets by restoration site including paired restoration data designed to easily transfer into 1) NOAA's Habitat Restoration Planner and 2) the Restoration Performance Index (RPI). In addition, summary databases were intended to automatically format annual means by marsh zone for instant input into a custom format designed to compute RPI scores by using a series of linking cells.

Prior to generating the performance benchmarks, raw data for each parameter was defined in the metadata and in some cases manipulated (e.g., averaged to eliminate pseudoreplication – the use of multiple, non-independent measures of the same sampling unit as though they were replicate samples).

Hydrologic parameters include: marsh inundation, groundwater level, and maximum tide. Marsh surface inundation (percent) is defined as the percentage of recorded units (or time) during which water levels were at or above the marsh surface using the continuous groundwater level data. Groundwater level (m) is the average groundwater level and maximum tide data (m) is simply the highest observed water level obtained using that same data set over that same discrete time period.

Soils data include bulk density (mg/m^3) and percent organic matter.

Salinity data were collected using steel or PVC 'sippers' inserted directly in the substrate or shallow groundwater wells. Shallow well parameters included both salinity and groundwater level (m) while pore water sipper collected only information on salinity. Salinity from these spot checks was averaged to station over multiple dates annually. Groundwater levels were also averaged annually and were only utilized in the MDS (multidimensional scaling) analyses (described below).

Vegetation parameters include plant cover, species richness, and height and density. Since point intercept data were collected for 50 points, it was converted into plant species cover by multiplying the values by 2 to convert values to 100% cover. Plant cover for the 5 most abundant species were chosen based on the specific restoration/reference marsh comparison. Percent cover included invasive species to provide the total percent cover for all invasive species. Species richness was the mean of the number of unique species per plot.

Plant heights (cm) utilized in the database represented the two dominant native species and also species of concern, determined from the paired reference marsh using 2010 data. The species for plant density (# m^2) data were chosen based on several factors including regional dominance, species of concern, and local Reserve monitoring protocols. For all sites throughout each of the 5 participating Reserves, the following designated species (if present and monitored) were averaged (mean + SE): *Carex lyngbyei, Distichlis spicata, Juncus gerardii, Phragmites australis, Spartina alterniflora, Spartina alterniflora-short form, Spartina patens, Typha angustifolia*. Species richness is defined as the average number of species per 1 m^2 quadrat.

Data Analyses

Data were analyzed using Analysis of Variance (ANOVA), Regression Analysis, Difference analysis, and non-metric multi-dimensional scaling (MDS) with biota-environment analyses (BEST), analysis of similarity (ANOSIM) and similarity percentage analysis (SIMPER). ANOVA and Regression tests were performed using JMP 9.0.1 © 2010 SAS. MDS, BEST, ANOSIM and SIMPER analyses were performed with PRIMER v.6.1.9 (PRIMER-E Ltd). Our general approach to data synthesis was to combine data by Reserve, and compare variables measured across Reserves to provide a regional picture of restoration performance that allowed for the influence of frequently unique features of individual sites. For some variables we combined data from all restoration sites by restoration type to better understand differences in marsh restoration response to altered hydrology and excavation/fill.

Difference Analyses

Differences between reference and restoration sites for vegetation and hydrology parameters were compared directly using Analysis of Variance (ANOVA), using annual means from 2008-2010. ANOVA is used to determine whether mean values from different groups of data are statistically different at a predetermined level of probability. In this case, the probability value chosen was, $p <= 0.05$, so that a significant difference detected by the ANOVA had at most a 5% chance of being incorrect (this is the standard used in ecological research). ANOVA compares the amount of variation within a group of data to the variation in the means between different groups of data, to determine whether the groups come from the same or different populations or data distributions.

Tukey's HSD was used as the post-hoc means comparison test to adjust the significance level for multiple means comparisons. Data were transformed where necessary to meet assumptions of data distributions (normality, homogeneous variance) required by ANOVA. When assumptions could not be met through data transforms, alternative non-parametric tests requiring no such assumptions were used (Kruskal-Wallis).

In the difference analyses, if a parameter for a restoration site was greater than for its paired reference site, the difference was set to zero, indicating that the site was fully restored for that particular parameter. If the restoration site parameter value was lower than the reference value, this difference was reported as a positive value. The one exception is for parameters related to invasive species, where a positive value indicates that the restoration site has a higher value for that parameter than the reference site.

In addition to difference analyses ANOVAs were completed for soils parameters, plant height and density, and Restoration Performance Index scores (see below for a description of the RPI).

Non-metric Multidimensional Scaling (MDS)

MDS analyses provide two-dimensional plots showing similarities between species assemblage groups (species presence and abundance) through the distance between their locations in the plot. The more separated in space two groups are (e.g., plant communities for restoration and reference sites for a particular Reserve), the less similar they are. The more scattered plant community sample points are within a group, the higher the plant community variability within that group (see Figs. 6-9 and captions for examples and explanations). Similarity values were assigned on a scale of 1-5, with 5 being the lowest similarity. Variation values were assigned on a scale of 1 – 3, with 1 being lowest variation. We are interested in similarity between groups to determine the level of convergence between reference and restoration sites for both abiotic (i.e. hydrologic) and biotic (i.e. plant community assemblages) factors. We are interested in variation within groups to indicate the degree which individual abiotic and biotic variables exhibit a central tendency (mean value). Lower variation for a particular group provides a more discernible picture of its ecological state.

In addition to standard MDS analyses, we used several MDS-based analyses to further investigate species assemblage patterns and relationships. The BEST analysis (Biota-Environment Stepped Analysis) related plant community assemblage data to a suite of abiotic parameters (soil bulk density, soil percent organic content, soil pore water salinity, groundwater level, and elevation) that were collected in association with the stations where vegetation data were collected. This analysis identified the key abiotic correlates of the observed plant communities. The strength of the correlation is expressed as the square of r, the correlation coefficient. The value of r2 quantifies the amount of variation in the plant community that is explained by variation in abiotic parameters.

While MDS allows detailed examination of similarity patterns between variables, it does not provide statistical tests of these comparisons. ANOSIM (Analysis of Similarity) provides statistical tests by generating a large number randomly permuted similarity matrices of the species assemblage data to create a probability distribution for the R statistic, which is centered around zero, since randomly created similarity matrices will reflect the null hypothesis of no difference between groups. The created distribution determines the probability that the actually observed similarities will belong to the random (and therefore null) distribution. ANOSIM was used to determine significant differences between plant community assemblages for restoration and reference site pairs, and SIMPER (Similarity Percent) determined which species contributed the most to the observed differences. For the SIMPER analyses, species that, when ranked by percent cover, were not included in the 90% cumulative contribution, were not included in the analyses to prevent rare species from having undue influence on the similarity calculations between samples.

Data input to PRIMER software for all MDS analyses were the average of the 3 years of monitoring (2008-10) for both plant and abiotic parameters, and plant community assemblages, in the form of percent cover data for all species present. Groundwater level data associated with vegetation data for MDS were not available from South Slough and North Carolina, and soil bulk density was not available from North Carolina, so only the remaining abiotic parameters were used for these Reserves.

<u>Restoration Performance Index (RPI)</u>

The Restoration Performance Index (RPI: Moore et al. 2009) is a simple method to measure change over time in restoration sites relative to reference sites or reference benchmarks. Ideally, monitoring begins prior to restoration, but the RPI can be applied to any time series of data. For example, restoration site improvement may slow down as time progresses, and will be reflected as a smaller change from year to year in the RPI.

We calculated the Restoration Performance Index using structural and functional variables measured in more than one year (see above –hydro, vegetation). Since soils and elevation were measured only once during the course of this study, they could not be used in the RPI to measure change. The index is the weighted sum of RPI scores measured for each selected variable over the specified time interval, and can be used to describe restoration trajectories. The RPI score for a given variable, for example, pore water salinity, is described in the sidebar on page four.

The RPI value represents the percent similarity between the restoration and the reference site for each indicator variable. If an indicator variable has the same value in the restoration and the reference site at a given time point, the score will be 1. The lowest allowed RPI score is zero, such that negative scores (when restoration parameters values decline relative to their starting point) are reset to zero.

Indicator variable RPI scores were weighted by tidal wetland zone (low, high, and upland transition), by the number of parameters, and the number of component parameter scores to create a single overall RPI summary score. For example, to compute a component score for Vegetation component, the RPI for percent cover of 5 most common reference site species was averaged across zones (e.g. percent cover for low+high+upland transition÷3). Species richness was calculated for mid marsh plots only because of the extremely low richness in the low marsh and high variability of high marsh-upland transition plots. The scores for each parameter were then divided by two and summed to provide a component score with each parameter weighted equally. The same zone-weighting was done for Hydrology component (salinity, percent inundation time, ground water level, high tide level). Since there were four parameters contained in the Hydrology component score, each parameter RPI score was divided by 4 and then summed with the others. Each of the two component scores was divided by two. The maximum score for each of the 2 vegetation parameters would be 0.25, indicating parity with the reference site. The maximum score for each hydrology parameter would be 0.125, indicating full restoration for that parameter. If parameters were missing for a given year, then the RPI score would be weighted by the number of parameters available for that year. The summary RPI score was the simple sum of the two weighted component scores, with a maximum value of 0.5 for each, which would indicate full restoration for that suite of parameters.

Linear Regression Analysis

Linear regression tests the significance and strength of association of two variables, an independent causal variable, and a dependent response variable, by fitting a straight line to the paired independent-dependent variable pairs. RPI vegetation component scores (dependent variable) were regressed individually against two causal variables identified in the BEST analysis (elevation and depth to groundwater). Because the RPI is a proportion, the data were arcsine square-root transformed to meet assumptions of parametric statistics. The specifics of RPI data management are described below and in an overview in the following section. Regression results include the equation for the straight line describing the association, and the correlation coefficient (r), which when squared (r2) quantifies the amount of variation in the dependent variable, is explained by variation in the causal variable.

Appendix B: Results Detail

In this section we present the outcomes of the analyses describe above without interpretation. Interpretation of results is presented in the Project Discussion section.

Restoration Performance Index (RPI)

For this synthesis report, we used the Restoration Performance Index (RPI) data to compare parameters between the two restoration types, hydrologic and excavation/fill, represented in this study. When RPI total scores (vegetation and hydrology subcomponent scores combined for a maximum value of 1) were compared, there was no significant difference between excavation/fill and hydrologic restoration sites. Nor was there any significant difference between restoration types for the individual vegetation or hydrology component scores, either by year (2009, 2010), or by yearly average (Tables 5 and 6; Figures 12-14).

The same was true for pore water salinity difference analyses (Figure 15), although the difference from the reference trended higher for hydrologic compared to excavation/fill restoration sites, and is in a negative direction (i.e. lower than the reference). Salinity data from deep groundwater loggers were not used, as data were only available from three locations, and generally not collected on same dates for restoration-reference site pairs (most sites only had three to four data loggers available).

The difference in percent cover of invasive species (primarily Phragmites) was greater than the reference only for hydrologic restoration sites (Figure 16).

RPI hydrology subcomponent scores (Table 7) from restoration sites are generally similar to the values obtained at their paired reference sites (less than 10 percent difference), with pore water salinity and marsh surface inundation showing the most frequent differences greater than 10

Table 5. RPI component scores for Hydrology and Vegetation, and Total scores. Maximum value for component scores is 0.5, unless only one component used, then maximum value is one.

Reserve	Reference Sites	Restoration Sites	Rest. Type	YEAR 1			YEAR 2			AVERAGE		
				Hydro	Veg	Total	Hydro	Veg	Total	Hydro	Veg	Total
Wells, ME	Webhannet Marsh	Cascade Brook	H	0.3	0.28	0.58	0.24	0.3	0.54	0.27	0.29	0.56
		Drakes Island	H	0.29	0.18	0.47	0.26	0.06	0.32	0.275	0.12	0.395
		Spruce Creek	H	0.25	0.15	0.4	0.35	0.32	0.67	0.3	0.235	0.535
		Wheeler Marsh	H	0.41	0.33	0.74	0.37	0.35	0.72	0.39	0.34	0.73
Narragansett, RI	Nag Marsh	Potter Pond	H		0.69	0.69	0.5	0.37	0.87	0.5	0.53	0.78
		Silver Creek	H	0.25	0.32	0.57	0.2	0.36	0.56	0.225	0.34	0.565
		Walker Farm	H	0.5		0.5	0.4	0.09	0.49	0.45	0.09	0.495
	Coggeshall Marsh	Gooseneck Cove	H	0.44	0.32	0.76		0.23	0.23	0.44	0.275	0.495
	Jacobs Point	Jacobs Point	H				0.14	0.28	0.42	0.14	0.28	0.42
Chesapeake VA	Goodwin Islands	Naval Weapons	E	0.25	0.33	0.58	0.34	0.16	0.5	0.295	0.245	0.54
		Hermitage	E	0.37	0.2	0.57	0.34	0.2	0.54	0.355	0.2	0.555
	Taskinas Creek	Chaetham Annex	E	0.38	0.22	0.6	0.39	0.08	0.47	0.385	0.15	0.535
North Carolina	Middle Marsh	DUMarineLab	E	0.5	0.38	0.88	0.5	0.38	0.88	0.5	0.38	0.88
		NC Marine	E		0.33	0.33	0.5	0.17	0.67	0.5	0.25	0.5
		Pine Knoll	E	0	0.48	0.48	0.33	0.43	0.73	0.165	0.455	0.605
South Slough OR	Danger Point Marsh	Kunz Marsh	H, E		0.11	0.11	0.17	0.03	0.2	0.17	0.07	0.155
	Yaquina 28	Yaquina 27	H		0.11	0.11	0.5	0.14	0.64	0.5	0.125	0.375

RESTORATION TYPE	N	YEAR 1						YEAR 2						AVERAGE					
		Hydro		Veg		Total		Hydro		Veg		Total		Hydro		Veg		Total	
		X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE
Excavation	7	0.34	0.05	0.25	0.05	0.54	0.08	0.3	0.09	0.29	0.05	0.51	0.09	0.37	0.04	0.2	0.04	0.57	0.08
Hydrologic	11	0.33	0.04	0.25	0.04	0.5	0.05	0.35	0.04	0.28	0.06	0.49	0.07	0.31	0.04	0.23	0.04	0.52	0.06
t Ratio		0.09		0.08		0.42		-0.58		0.2		0.12		0.89		-0.35		0.54	
P>|t|		0.93		0.94		0.68		0.57		0.84		0.91		0.39		0.73		0.6	

Table 6 Mean, standard errors, and p values for RPI scores for restoration type comparisons.

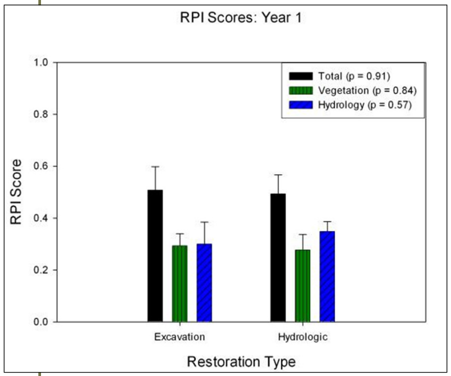

Figure 12. Comparisons of RPI scores for 2008-2009 by restoration type, showing total and component scores (vegetation and hydrology). Restoration types were not significantly different. @ p <= 0.05.

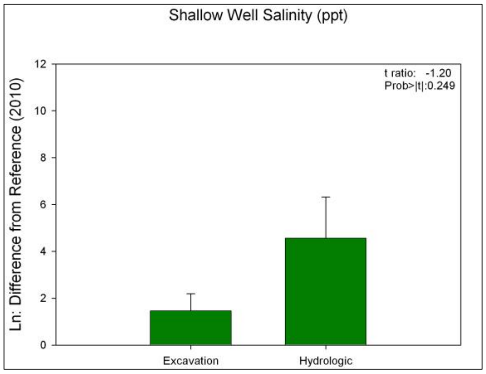

Figure 15. Comparisons of pore water salinity differences between reference and restoration sites by restoration type. Restoration types were not significantly different @ p <= 0.05.

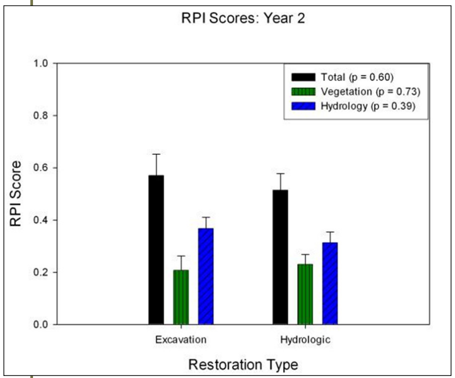

Figure 13 Comparisons of RPI scores for 2009-2010 by restoration type, showing total and component scores (vegetation and hydrology). Restoration types were not significantly different @ p <= 0.05.

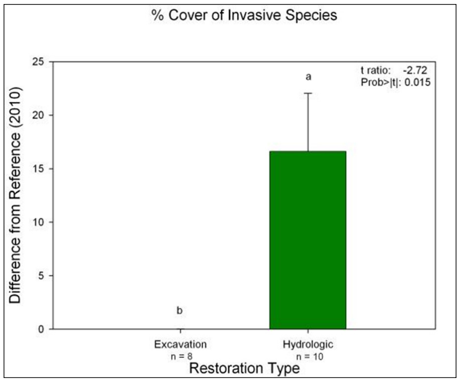

Figure 16. Comparisons of differences in percent cover of invasives between reference and restoration sites by restoration type. Restoration types were significantly different @ p <= 0.05.

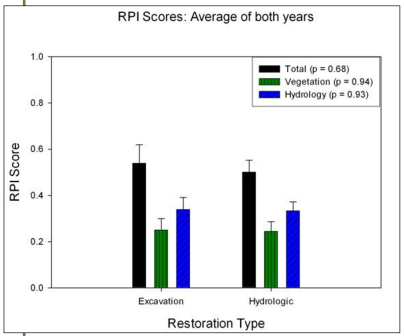

Figure 14 Comparisons of RPI scores for 2008-2010 by restoration type, showing total and component scores (vegetation and hydrology). Restoration types were not significantly different @ p <= 0.05.

Table 7 RPI parameter differences between restoration and paired reference sites (reference minus restoration). Negative values (where restoration site value greater than reference) are converted to zeros, indicating that the restoration site has achieved or exceeded the reference value. Note: Percent invasive cover was not an RPI parameter, but is included as a parameter of great interest. Negative values for differences in percent cover were converted to positive values rather than to zero for this variable, as in this case, exceeding the reference value is not a desired outcome. Light blue cells indicate 10-20% difference from reference value. Light green cells indicate > 20% difference from reference value.

Reserve	Restoration Sites	Rest. Type	RPI PARAMETER DIFFERENCES (Reference minus Restoration)							
			Year	PORE-WATER (PSU)	INUNDATION MARSH SURFACE (%)	GROUNDWATER LEVEL (m)	MAX HIGH TIDE (m)	5 DOMINANT PLANT COVER (%)	INVASIVE COVER (%)	SPECIES RICHNESS (# m^{-2})
Wells, ME	Cascade Brook	H	2008	12.22	0	0	0	10	20.13	0
	Drakes Island	H	2008	8.68	0	0	0.12	7.15	11.73	1.11
	Spruce Creek	H	2008	3.44	0	0	0.22	6.69	6.13	0.44
	Wheeler Marsh	H	2008	6.72	0	0	0.16	5.15	0	0
Narragansett, RI	Gooseneck Cove Marsh	H	2008	1.93				4.12	16	0.09
	Jacob's Point Restoration	H	2008	18.23				20.76	75.04	0.69
	Potter Pond	H	2008					9.74	22	0.27
	Silver Creek Marsh	H	2008	8.1				8.02	31.52	0
	Walker Farm	H	2008	9.57				18.7	74.48	0
Chesapeake VA	Chaetham	E	2008	5.37	5.05	0	0	14.84	0	0.6
	Hermitage	E	2008	3.42	0	0.19	0.21	4.02	0	0.77
	Naval Weapons	E	2008	6.91	49.49	0.63	0.63	11.23	1.6	0.8
North Carolina	DUMarineLab	E	2008	0				19.31	0	0
	NC Marine	E	2008	0				4.67	0	0
	Pine Knoll	E	2008	0				23.96	0	0
South Slough OR	Kunz Marsh	H	2008					23.5	2.61	3.51
	Kunz Marsh	E	2008					23.5	0	3.51
	Yaquina 27	E	2008	0				15.17	0	1.71
Wells, ME	Cascade Brook	H	2009	17.39	0	0	0	9.07	53.2	0
	Drakes Island	H	2009	4.83	0	0	0.25	8.45	18.13	0.44
	Spruce Creek	H	2009	7.22	0	0	0.17	3.97	6.67	0.44
	Wheeler Marsh	H	2009	0	0	0	0	5.39	0	0
Narragansett, RI	Gooseneck Cove Marsh	H	2009	0				4.9	9.04	0
	Jacob's Point Restoration	H	2009	24.02						
	Potter Pond	H	2009	0	0	0.03	0.29	8.52	19.21	0
	Silver Creek Marsh	H	2009	5.12				7.23	26.64	0
	Walker Farm	H	2009	3.23	47.52	0.15	0.34			
Chesapeake VA	Chaetham	E	2009	5.68	0	0	0	10.97	0	0.33
	Hermitage	E	2009	4.66	0	0	0	3.79	0	0.47
	Naval Weapons	E	2009	6.15	7.36	0.13	0.22	8.92	2.2	0
North Carolina	DUMarineLab	E	2009	0				12.91	0	0
	NC Marine	E	2009	0				3.39	0	0.12
	Pine Knoll	E	2009	0				13.27	0	0
South Slough OR	Kunz Marsh	H	2009		0	0	0	27.26	2.28	4.31
	Kunz Marsh	E	2009		0		0.06	27.26	0	4.31
	Yaquina 27	E	2009	0	0	0	0	15.2	0	1.4
Wells, ME	Cascade Brook	H	2010	13.58	15.37	0	0.09	12.03	39.33	0
	Drakes Island	H	2010	4.47	16.19	0	0.34	5.84	0	0.67
	Spruce Creek	H	2010	5.17	7.62	0	0	3.55	7.2	0
	Wheeler Marsh	H	2010	0	18.36	0	0	2.4	0	0
Narragansett, RI	Gooseneck Cove Marsh	H	2010		0	0	0	14.39	5.48	0.52
	Jacob's Point Restoration	H	2010	12.11				23.49	47.29	0.63
	Potter Pond	H	2010	0	0	0.01	0	7.12	18	0.02
	Silver Creek Marsh	H	2010	5.72	0	0	0	7.21	30.73	0
	Walker Farm	H	2010	0	0	0	0.02	17.74	16.22	
Chesapeake VA	Chaetham	E	2010	4.87	0	0	0	3.24	0	0.78
	Hermitage	E	2010	3.4	0	0	0	0	0	0.3
	Naval Weapons	E	2010	3.4	20.92	0.11	0.07	0.32	0.1	0.65
North Carolina	DUMarineLab	E	2010	0	0	0.05	0.3	17	0	0
	NC Marine	E	2010	0	0	0	0	16	0	0.09
	Pine Knoll	E	2010	0	0	0	0.25	23.8	0	0
South Slough OR	Kunz Marsh	H	2010	0	0	0	0.24	25.36	1.84	3.76
	Kunz Marsh	E	2010	0	0	0.28	0.62	25.36	0	3.76
	Yaquina 27	E	2010	0	0	0	0	15.71	0	1.19

percent (six of 54 comparisons or 11 percent, the same for both parameters).

Plant community parameters differed from reference values much more frequently. For percent cover of the five dominant reference plant species, restoration sites differed by at least 10-20 percent for 30 percent of comparisons, and by more that 20 percent for 19 percent of comparisons. Species richness at restoration sites did not differ from the paired reference values by 10 percent or more in any case.

Results of individual RPI analyses can be found in each Reserve's site report and will not be presented here. Graphical results from these analyses are included in the data appendices for this synthesis report.

Difference Analyses

When the difference between reference and restoration sites for each variable measured in this study is statistically compared between excavation/fill and hydrologic restoration types (Table 8), only a few parameters differ significantly. In addition to groundwater salinity and invasive percent cover (see above under RPI), the differences in invasive stem density (analyzed for 2010 only) between reference and restoration sites were greater for hydrologic restoration than for excavation/fill sites, with stem densities higher in the restoration sites than in the paired reference sites.

Results of individual difference analyses can be found in each Reserve's site report and will not be presented here. Graphical presentations of results from these analyses are accessible in a Data Appendix submitted to the NOAA Restoration Center.

Table 8. Means, standard errors, and significance levels for parameter value differences (reference minus restoration) by restoration type. Light blue cells indicate significant differences ($p < 0.05$)

			Parameter Differences between Reference and Restoration by Restoration Type												
	N		2008				2009				2010				
	Excavation	Hydrologic	Excavation		Hydrologic		Excavation		Hydrologic		Excavation		Hydrologic		
	N	N	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	
Hydrology															
Salinity	8	9	2.24	1.12	8.61	1.8	2.36	1.12	6.87	2.81	1.46	0.73	4.56	1.76	
Inundation Marsh Surface	8	9	18.18	15.72	0	0	1.47	1.47	6.79	6.79	2.61	2.61	6.39	2.7	
Ground Water Level	8	9	0.27	0.19	0	0	0.03	0.03	0.03	0.02	0.05	0.03	0	0	
Max High Tide	8	9	0.28	0.18	0.13	0.05	0.06	0.04	0.15	0.06	0.16	0.08	0.08	0.04	
Vegetation															
5 Dominant Plant Cover	8	10	14.59	2.71	11.38	2.2	11.96	2.66	9.35	2.64	12.68	3.6	11.91	2.58	
Invasive Cover	8	9	0.2	0.2	25.97	8.67	0.28	0.28	16.9	6.1	0.01	0.01	16.61	5.42	
Species Richness	7	10	0.81	0.47	0.71	0.33	0.75	0.6	0.73	0.47	0.8	0.51	0.68	0.37	
Native Stem Density	7	10	-	-	-	-	-	-	-	-	183.2	87.11	143.2	54.37	
Invasive Stem Density	2	8	-	-	-	-	-	-	-	-	0.11	0.11	9.48	2.64	
Dominant Stem Height	7	7	-	-	-	-	-	-	-	-	6.45	5.49	0.47	0.47	
Soils															
Bulk Density	5	10	-	-	-	-	-	-	-	-	1.04	0.43	0.12	0.05	
Organic Matter	8	10	-	-	-	-	-	-	-	-	14.83	4.85	14.42	4.84	

Multidimensional Scaling (MDS) of Abiotic Factors by Zone and Site

Similarity

Marsh zone abiotic factors (soil bulk density and percent organic content, salinity, depth to groundwater, and marsh surface elevation) were less similar for excavation/fill sites than for hydrologic sites (Table 9-13). Reference restoration site pairs were most similar at Narragansett, with Jacobs Point showing greatest similarity (level 2), the three Nags Marsh pairs showing intermediate similarity (level 3), and Coggeshall showing least similarity to Gooseneck Cove (level 4). Other site pairs showing high similarity included Taskinas Creek-Naval Weapons Station (level 1), Goodwin Islands-Heritage (level 2), both at Chesapeake; and Y-28 - Y-27 associated with South Slough OR (level 2). The degree of similarity between restoration and reference pairs at Chesapeake and South Slough sites pairs is similar to that of Narragansett. Wells and North Carolina showed the least degree of similarity between reference-restoration site pairs (nearly all at level 4 and level 5).

When similarity scores were totaled for each Reserve, and the Reserves ranked, Wells had the greatest similarity among marsh zones, followed by Narragansett, Chesapeake and South Slough (tied), and North Carolina (Table 3). Restoration at Narragansett and Chesapeake emphasized hydrologic restoration; Wells, South Slough and North Carolina focused on excavation/fill. Similarity rankings by reference-restoration site pairs, from high similarity to low similarity, were: Chesapeake, South Slough, Narragansett, Wells, and North Carolina (Table 3).

Table 9. Top: Similarity and variation of abiotic factors by zone and site (based on resemblance of Euclidian distances). Levels were assigned based on visual observation of sample patterns projected on 2-dimensional plots. Bottom: Similarity and variation of plant communities by zone and site (based on resemblance of Bray-Curtis similarities). For variation by site and zone (lower right corner of panel) P represents an assessment for pooled zone data. For both top and bottom panels, similarity and variation levels were assigned based on visual observation of sample patterns projected on 2-dimensional plots. All plots are included in a Data Appendix submitted to the NOAA Restoration Center. Example plots and explanation of pattern interpretations are presented in Figures 19-22.

	Wells ME								
	SIMLARITY						VARIATION		
ABIOTIC	1	2	3	4	5		1	2	3
Zone (low,mid,high)						Zone (low,mid,high)			
L - M		■				L		■	
L - H		■				M		■	
M - H		■				H		■	
Site (ref-rest)						Site			
WB - CB				■		WB	■		
WB - DI				■		CB	■		
WB – SC			■			DI	■		
WB - WM				■		SC	■		
						WM			■

	Wells ME																	
	SIMILARITY					VARIATION												
Community	1	2	3	4	5		1				2				3			
Zone						Zone												
L - M	■					L						■						
L - H					■	M						■						
M - H				■		H										■		
Site																		
L					■													
M			■															
H					■													
							Zone											
							P	L	M	H	P	L	M	H	P	L	M	H
Site (Ref-Rest)						Site												
WB - CB				■		WB		■					■		■			■
WB - DI			■			CB							■	■	■			
WB - SC		■				DI	■		■	■		■						
WB - WM	■					SC		■					■	■	■			
						WM		■						■	■		■	

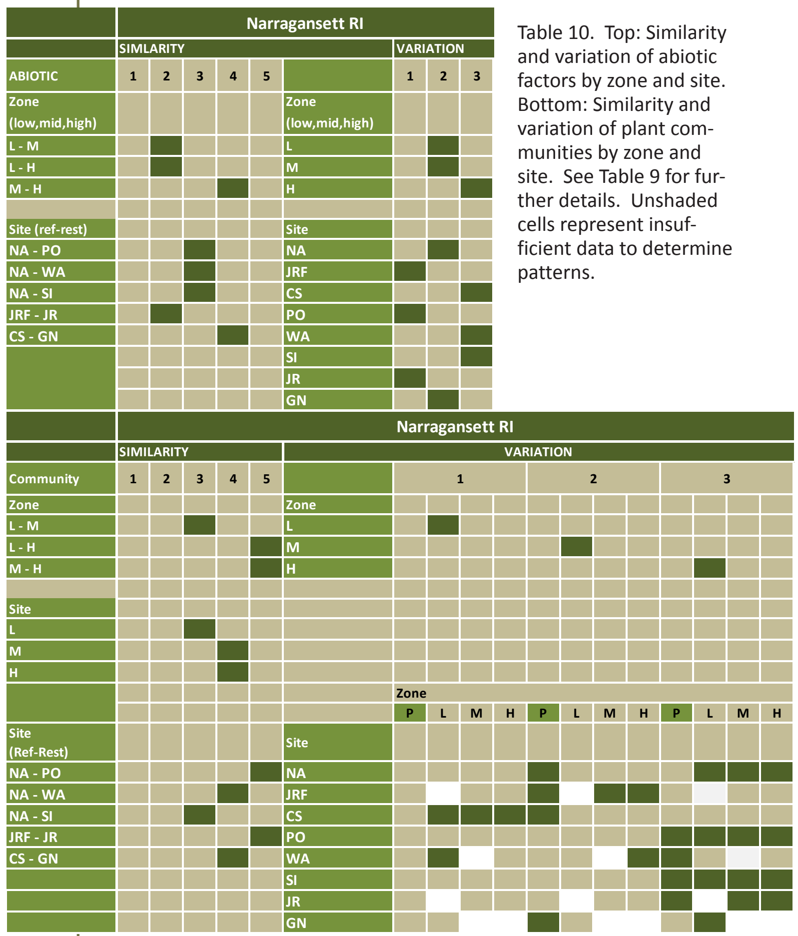

Table 10. Top: Similarity and variation of abiotic factors by zone and site. Bottom: Similarity and variation of plant communities by zone and site. See Table 9 for further details. Unshaded cells represent insufficient data to determine patterns.

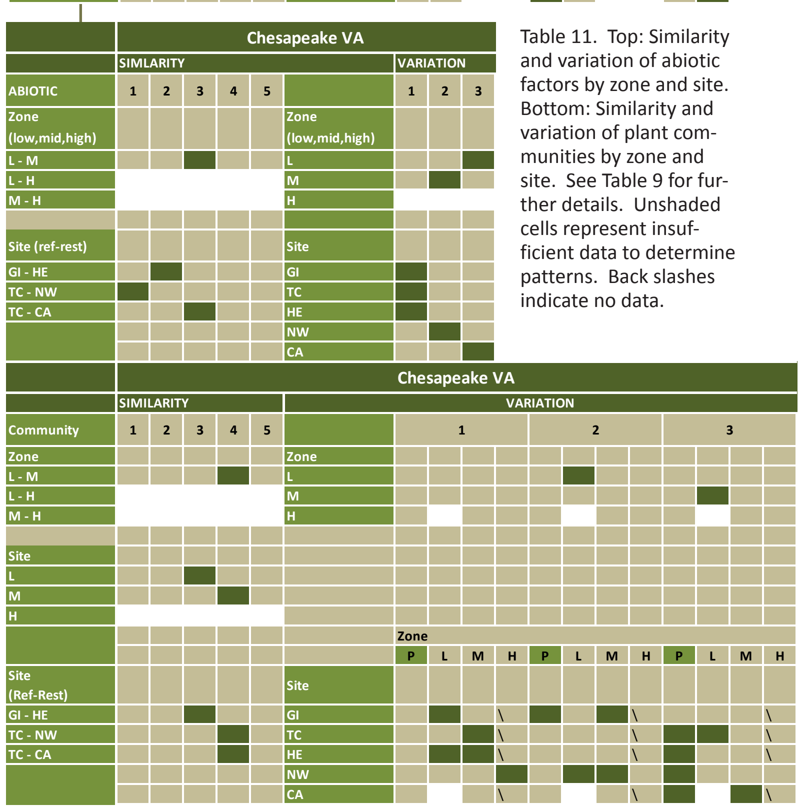

Table 11. Top: Similarity and variation of abiotic factors by zone and site. Bottom: Similarity and variation of plant communities by zone and site. See Table 9 for further details. Unshaded cells represent insufficient data to determine patterns. Back slashes indicate no data.

	North Carolina								
	SIMILARITY						VARIATION		
ABIOTIC	1	2	3	4	5		1	2	3
Zone (low,mid,high)						Zone (low,mid,high)			
L - M						L			
L - H						M			
M - H						H			
Site (ref-rest)						Site			
MM - PK						MM			
MM - DU						PK			
MM - NC						DU			
						NC			

Table 12. Top: Similarity and variation of abiotic factors by zone and site. Bottom: Similarity and variation of plant communities by zone and site. See Table 9 for further details. Unshaded cells represent insufficient data to determine patterns. Back slashes indicate no data.

	North Carolina																	
	SIMILARITY						VARIATION											
Community	1	2	3	4	5		1				2				3			
Zone						Zone												
L - M						L												
L - H						M												
M - H						H												
Site																		
L																		
M																		
H																		
							Zone											
							P	L	M	H	P	L	M	H	P	L	M	H
Site (Ref-Rest)						Site												
MM - DU						MM												
MM - NC						DU				\				\				\
MM - PK						NC												
						PK												

	South Slough OR								
	SIMLARITY						VARIATION		
ABIOTIC	1	2	3	4	5		1	2	3
Zone (low,mid,high)						Zone (low,mid,high)			
L - M						L			
L - H						M			
M - H						H			
Site (ref-rest)						Site			
Y28 – Y27						Y28			
DP – KM						DP			
						Y27			
						KM			

Table 13. Top: Similarity and variation of abiotic factors by zone and site. Bottom: Similarity and variation of plant communities by zone and site. See Table 9 for further details. Unshaded cells represent insufficient data to determine patterns. Back slashes indicate no data.

	South Slough OR																	
	SIMILARITY						VARIATION											
Community	1	2	3	4	5		1				2				3			
Zone						Zone												
L - M						L												
L - H						M												
M - H						H												
Site																		
L																		
M																		
H																		
							Zone											
							P	L	M	H	P	L	M	H	P	L	M	H
Site (Ref-Rest)						Site												
Y28 – Y27						Y28		\		\		\		\		\		\
DP – KM						DP												
						Y27		\				\				\		
						KM		\				\				\		

Variation

Low and mid marsh zones displayed intermediate variation at most sites across Reserves (Table 9-13). Highest variation (level 3) was observed (for low marsh) at Chesapeake and North Carolina (excavation/fill), and (for high marsh) at Narragansett (hydrologic) and South Slough (excavation/fill). Lowest variation (level 1) was observed for the mid-marsh platform in North Carolina and South Slough.

Abiotic variation was lowest (level 1) for the majority of sites at Wells, Chesapeake, and North Carolina (all sites at level 1). All reference sites at these Reserves showed low (level 1) variation.

Narragansett displayed the widest range of variation for both reference and restoration sites (level 1 to level 3), and South Slough sites were the most uniform (all level 2).

When variation scores were totaled for each Reserve and the Reserves ranked, Wells, North Carolina and South Slough were tied for the lowest variation within marsh zones, followed by Narragansett and Chesapeake. Individual sites showed lowest variation in North Carolina, followed by Wells, Chesapeake, Narragansett and South Slough.

Multidimensional Scaling of Plant Communities by Zone and Site

Similarity

Observed similarities among plant communities across zones were intermediate to low (level 3 to level 5) among Reserves (Table 9-13). The few exceptions were high similarity (level 1) between low- and mid marsh plots at Wells, and high to intermediate similarity (level 2) between mid-marsh platform and high marsh (upland transition) at North Carolina and South Slough.

Similarity within zones across sites followed a comparable pattern, with all but one Reserve showing intermediate to low similarity (level 3 to level 5). The one exception was for low marsh at North Carolina, with high to intermediate similarity (level 2) across sites. Similarity for restoration-reference pairs ranged from level 3 to level 5 for the most part. The most similar site pairs occurred in Wells, for Wheeler Marsh (level 1), and Spruce Creek (level 2); in North Carolina for NC Maritime (level 2); and in South Slough for Kunz Marsh (level 2).

When similarity scores were totaled for each Reserve and the Reserves ranked, Chesapeake showed the highest similarity across zones, followed by South Slough and North Carolina (tied), Wells, and Narragansett. Reference and restoration site pairs were most similar in Wells, followed by North Carolina, South Slough, Chesapeake, and Narragansett.

For individual sites, greatest similarity occurred in North Carolina, then Chesapeake and South Slough (tied), Narragansett and Wells.

Variation

Variation within low and mid marsh zones was mostly at the intermediate level, with the high marsh/upland transition zone at all sites showing high variation (Table 9-13). The one instance of low variation occurred for low marsh at Narragansett Bay.

Variation within sites (pooled across zones) was generally high (level 3) for both reference and restoration sites. However, Narragansett reference sites all showed intermediate variation, as did Goodwin's Island reference site at Chesapeake, and middle marsh reference site at North Carolina. Danger Point reference marsh at South Slough showed the lowest variation. Sites showing low variation included Drakes Island (level 1) at Wells; those showing intermediate variation (level 2) were Gooseneck Cove at Narragansett, NC Maritime at North Carolina, and Kunz Marsh at South Slough.

When variation scores were totaled for each Reserve and the Reserves ranked, Narragansett showed the lowest variation within zones, followed by North Carolina and Wells (tied), Chesapeake, and South Slough (Table 3). Individual sites were least variable at South Slough, then higher in Wells, Narragansett and North Carolina (tied), and Chesapeake.

Analysis of Similarity (ANOSIM) and Similarity Percentage (SIMPER) of Plant Communities

Analysis of similarity for all reference-restoration pairs revealed significant differences in plant communities, based on the complete percent cover data set, and with species not included in the 90 percent cumulative cover eliminated. There were two exceptions. The Wheeler Marsh restoration site was not significantly different from the paired Webhannet Marsh reference site at Wells, and the Hermitage restoration site was not significantly different from the paired Goodwin Islands reference site at Chesapeake (Table 4).

The number of species contributing to the 90 percent cumulative cover in each reference-restoration site assemblage varied considerably between the Reserves. Mean species number across reference and restoration site pairs for each Reserve (from north to south, east to west) was Wells (18 species), Narragansett (11), Chesapeake (6), North Carolina (10), and South Slough (11).

Average percent dissimilarities indicate the total contribution from each species in the combined species assemblage to the difference between the reference-restoration site pairs, and ranged from 51 percent to 89 percent. The five species contributing the most to the dissimilarity for each reference-restoration site pair totaled more than 50 percent of the dissimilarity for each comparison, with two exceptions of 41 percent and 48 percent (Tables 14-18).

Of the 85 species, the top five identified contributors to dissimilarity between 17 restoration sites and their reference pairs were: *Spartina*

WELLS ME		Percent Dissimilarity and Abundance					Cum %
Reference	Restoration	Species 1	Species 2	Species 3	Species 4	Species 5	
Webhannet	Cascade	SPAPAT	PHRAUS	SPAALT*	DISSPI*	SPAALS	
		6.88 ref	6.79 res	6.42 ref	5.86 res	5.86 ref	42
	Drakes	SPAALT*	SPAALS	SPAPAT*	BARE	DEAD	
		8.43 res	8.30 res	7.85 ref	5.71 ref	4.28 res	55
	Spruce	SPAPAT*	SPAALT	SPAALS	BARE*	DISSPI	
		8.63 res	8.21 ref	7.44 ref	6.18 ref	5.00 res	51
	Wheeler	SPAPAT*	SPAALT	SPAALS	BARE*	JUNGER	
		7.92 ref	7.63 ref	7.52 ref	5.45 ref	4.94 res	48

Table 14. Dissimilarity percent contributions for top 5 species at Wells NERR that distinguish restoration sites from paired reference sites at Wells NERR. Comparisons where the species abundance was greater for the reference site are designated “ref”, and where greater for the restoration site by “res”. The cumulative contribution to total dissimilarity is also indicated. Species codes: SPAPAT – Spartina patens, PHRAUS – Phragmites australis, SPAALT – Spartina alterniflora, DISSPI – Distichlis spicata, SPAALS – Spartina alterniflora short, JUNGER – Juncus gerardii.

NARRAGANSETT RI		Percent Dissimilarity and Abundance					Cum %
Reference	Restoration	Species 1	Species 2	Species 3	Species 4	Species 5	
Coggeshall	Gooseneck	SPAPAT*	SPAALT	DISSPI	BARE*	PHRAUS	
		12.72 ref	10.6 ref	8.21 ref	7.03 ref	5.86 ref	70
Jacobs Point	Jacobs Point	DISSPI*	PHRAUS*	SPAPAT	JUNGER	IVAFRU	
		18.25 ref	17.13 res	11.54 ref	7.03 ref	4.95 ref	74
Nag Marsh	Potters Pond	SPAPAT*	SPAALT	DISSPI*	PHRAUS	BARE	
		14.09 ref	11.67 ref	9.16 ref	6.57 res	5.77 res	71
	Silver Creek	SPAALT*	SPAPAT*	DISSPI*	PHRAUS	IVAFRU	
		12.57 ref	12.31 ref	8.71 res	8.09 res	5.71 res	65
	Walker Farm	PHRAUS*	SPAPAT*	SPAALT	DISSPI	SALEUR	
		17.04 res	15.25 ref	13.2 ref	8.94 ref	4.23 res	73

Table 15. Dissimilarity percent contributions for top 5 species at Narragansett Bay NERR that distinguish restoration sites from paired reference sites at Wells NERR. Comparisons where the species abundance was greater for the reference site are designated “ref”, and where greater for the restoration site by “res”. The cumulative contribution to total dissimilarity is also indicated. Species codes: SPAPAT – Spartina patens, PHRAUS – Phragmites australis, SPAALT – Spartina alterniflora, DISSPI – Distichlis spicata, SPAALS – Spartina alterniflora short, JUNGER – Juncus gerardii, IVAFRU – Iva frutescens, SALEUR – Salicornia europaea.

CHESAPEAKE VA		Percent Dissimilarity and Abundance					Cum %
Reference	Restoration	Species 1	Species 2	Species 3	Species 4	Species 5	
Goodwin Isld	Hermitage	SPAALT*	SPAPAT*	DISSPI	ATRPAT	BACHAM	
		18.47 res	17.98 ref	15.10 ref	2.23 res	1.55 ref	92
Taskinas Crk	Cheatham Anx	SPAPAT	DISSPI*	SPAALT*	SCIAME	SCIROB	
		16.30 ref	14.51 ref	14.39 res	11.03 res	4.62 ref	92
	Naval Wpns	SPAPAT	SPAALT*	DISSPI*	SCIROB	SCIAME	
		15.21 ref	15.17 res	12.71 ref	5.50 res	3.7 ref	79

Table 16. Dissimilarity percent contributions for top 5 species at Chesapeake VA NERR that distinguish restoration sites from paired reference sites at Wells NERR. Comparisons where the species abundance was greater for the reference site are designated “ref”, and where greater for the restoration site by “res”. The cumulative contribution to total dissimilarity is also indicated. Species codes: SPAPAT – Spartina patens, PHRAUS – Phragmites australis, SPAALT – Spartina alterniflora, DISSPI – Distichlis spicata, ATRPAT – Atriplex patula, BACHAM – Bacharris halmiifolia, SCIAME – Scirpus americanus (now Schoenoplectus americanus), SCIROB – Scirpus robustus (now Schoenoplectus robustus), SPAALS – Spartina alterniflora short.

alterniflora (14 sites), *Spartina patens* (12), *Distichlis spicata* (11), bare ground (8), and *Phragmites australis* (7). These five species account for 61 percent of the species contributing to dissimilarity, and 77 percent of the best indicator species identified in Table 5.

For *S. alterniflora*, *S. patens, D. spicata*, and bare ground, abundance was greater in reference sites for the majority of cases, while the opposite was the case for *Phragmites*.

NORTH CAROLINA		Percent Dissimilarity and Abundance					Cum %
Reference	Restoration	Species 1	Species 2	Species 3	Species 4	Species 5	
Middle Marsh	Duke Marine	SPAALT*	OYSTER	BARE	DEAD*	WRACK	
		10.95 ref	6.94 res	6.43 res	5.38 ref	4.83 res	59
	NC Museum	SPAALT*	OYSTER	BARE	WRACK	DEAD*	
		9.7 ref	8.64 res	7.58 ref	5.88 res	5.12 ref	71
	Pine Knoll	SPAALT	SALSP	BARE*	WATER	DEAD*	
		11.27 ref	8.67 res	8.14 ref	6.36 res	5.69 ref	67

Table 17. Dissimilarity percent contributions for top 5 species at North Carolina NERR that distinguish restoration sites from paired reference sites at Wells NERR. Comparisons where the species abundance was greater for the reference site are designated "ref", and where greater for the restoration site by "res". The cumulative contribution to total dissimilarity is also indicated. Species codes: SPAPAT – Spartina patens, SPAALT – Spartina alterniflora, SALSP – Salicornia species.

SOUTH SLOUGH OR		Percent Dissimilarity and Abundance					Cum %
Reference	Restoration	Species 1	Species 2	Species 3	Species 4	Species 5	
Danger Point	Kunz Marsh	TRIMAR*	AGRSTO*	DESCAE	DISSPI	CARLYN	
		8.19 res	8.11 res	7.82 res	6.02 res	4.20 ref	53
Yaquina 28	Yaquina 27	CARLYN	AGRSTO*	PHAARU	ELEPAL	ARGEGE*	
		11.14 res	11.09 res	7.79 ref	7.53 res	6.23 ref	49

Table 18. Dissimilarity percent contributions for top 5 species at South Slough NERR that distinguish restoration sites from paired reference sites at Wells NERR. Comparisons where the species abundance was greater for the reference site are designated "ref", and where greater for the restoration site by "res". The cumulative contribution to total dissimilarity is also indicated. Species codes: TRIMAR – Triglochin maritimum, AGRSTO – Agrostis stolinifera, DESCAE – Deschampsia caespitosa, DISSPI – Distichlis spicata, CARLYN – Carex lyngbyei, PHAARU – Phalaris arundinacea , ELEPAL – Eleocharis palustris , ARGEGE –Argentina egedii .

Plant Community-Abiotic Factor Correlations

Associations between plant communities and abiotic factors were explored with Spearman rank correlations (note – groundwater data collected in association with plant community data not available for South Slough or Chesapeake). Correlations were carried out for all sites at each Reserve (both reference and restoration), and then again just for the restoration sites. R values were low to modest, but the combination of factors contributing to the highest correlations, groundwater level and elevation, were consistent across Reserves (Table 5). Preliminary screening with bivariate plots and resemblance matrices ensured that these factors were not auto-correlated—that is, they were not duplicating the same information (correlation between all paired variables < 0.95).

Linear regression of RPI vegetation component score against mid-marsh elevation was significant, with a correlation r = 0.41, and a non-significant linear relationship of RPI = 0.20 + 0.07 □ elevation (in) (Figure 17). Linear regression of the RPI vegetation component score against depth to groundwater was significant (p = 0.04), with a correlation r = 0.45, and a linear relationship of RPI = 0.17 + 0.009 □ groundwater depth (cm) (Figure 18).

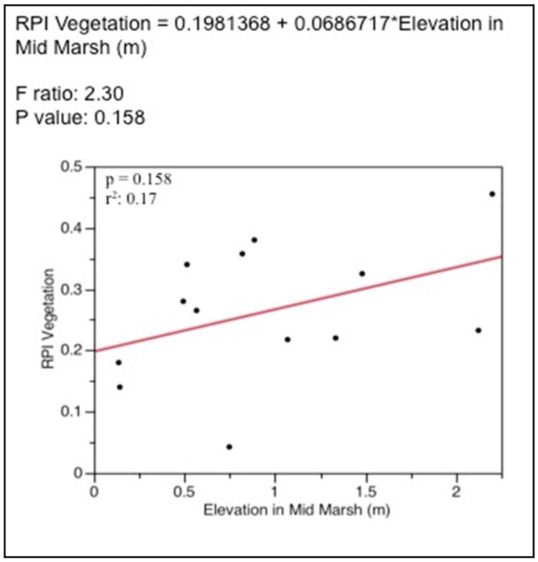

Figure 17. Linear regression of RPI vegetation component score against mid-marsh elevation across all restorations sites.

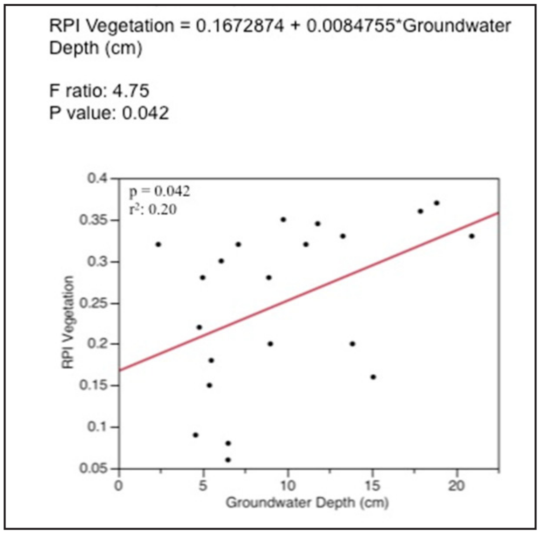

Figure 18 Linear regression of RPI vegetation component score against groundwater depth across all restorations sites.

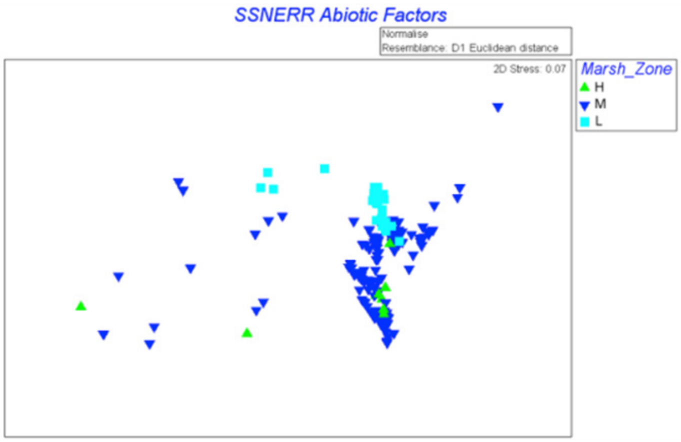

Figure 19. Example of similarity and variation patterns (based on resemblance matrix of Euclidean distance) for marsh zone abiotic factors at South Slough NERR study sites. Due to overlap of mid (M) and high marsh/upland transition zones (H) for many of the samples, a similarity level of 2 (out of 5, with 5 being lowest similarity) was assigned. Low (L) to mid marsh points (M) showed separation, but were spatially adjacent, so these zones were assigned an intermediate similarity level of 3. Low (L) and high marsh -upland transition zones (H) show intermediate separation, so received a similarity level of 4. Variation levels (from 1 being low to 3 being high) were assigned based on the level of clustering (taking into account the number of data points). Here the mid-marsh (M) showed the tightest clustering (variation level 1), followed by low marsh (level 2), and high marsh (H) (level 3).

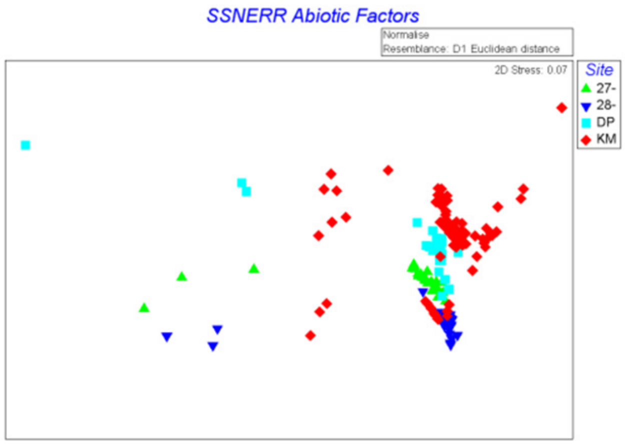

Figure 20. Example of similarity and variation patterns (based on resemblance matrix of Euclidean distance) for reference and restoration site abiotic factors at South Slough NERR. Many samples within each site were tightly clustered and directly adjacent, so the reference – restoration pairs were assigned similarity levels of 3 – intermediate (DP reference vs. KM restoration), and 2 – intermediate/high (Y28 reference - Y27 restoration). Here, all 4 sites displayed a similar pattern of spatial variation, with outlying points at intermediate distance from the main clusters, and were assigned a variation level of 2 - intermediate.

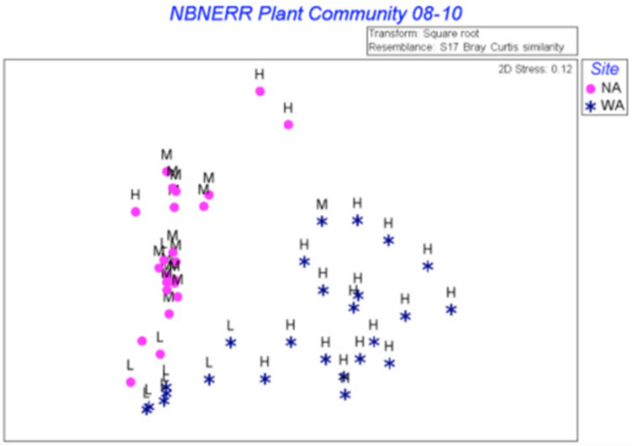

Figure 21. Example of similarity and variation patterns (based on rank order resemblance matrix) for plant communities from the Nag Marsh-Walker Farm reference-restoration pair at Narragansett Bay NERR. Due to the separation between the points from the two sites, a similarity level of 4 was assigned. Pooled variation (all zones combined) was intermediate (level 2) for Nag Marsh, and high (level 3) for Walker Farm.

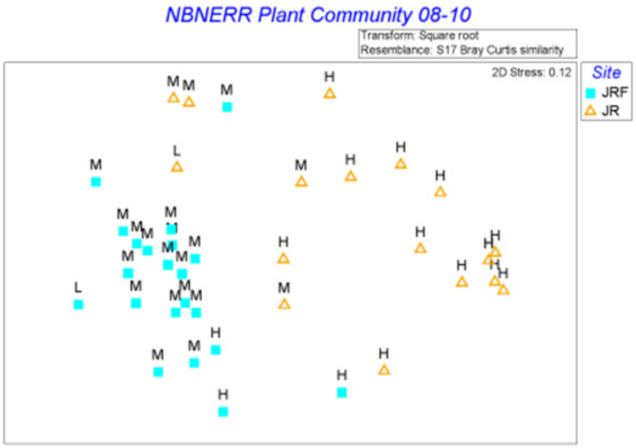

Figure 22. Example of similarity and variation patterns (based on rank order resemblance matrix) for plant communities from the Jacobs point reference-restoration pair at Narragansett Bay NERR. Due to the greater separation of the points between the two sites, relative to other reference-restoration site pairs, a similarity of 5 (low) was assigned. Variation across zones (Low, Mid, High) was intermediate (2) for Jacobs Point reference site, and high (3), for Jacobs Point restoration site.

Appendix C: Data Management

A Data Appendix is provided as a series of digital files and has been submitted to the NOAA Restoration Center.

In the Data Appendix, reference site benchmark values for all parameters and for all sites are provided, including:

Hydrology
Salinity (shallow and deep wells, pore water sippers),
Groundwater Level (shallow wells)
    Groundwater Level (deep wells, continuous)
Channel Tide Level (continuous)
Vegetation
% Cover all plant species and other cover types
Stem Density (by species)
Stem Height (by species)
% Invasives
Soils
    % Organic Carbon, Bulk Density
Elevation and Location
    Vegetation plots
    Sampling wells
    Transects
Data Templates with Metadata
Graphics
Restoration Performance Index Figures
Difference Analyses Figures
    Multidimensional Scaling Plots
    Plant Height and Density Figures