The Study

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

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.

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).

Reserve	Reference Sites	Restoration Sites				
Wells, ME	**Webhannet Marsh**	**Site**	**Cascade Brook**	**Drakes Island**	**Spruce Creek**	**Wheeler Marsh**
	25 ppt	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**	**Site**	**Potter Pond**	**Walker Farm**	**Silver Creek**	
	23.14 ppt	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	**Site**	**Gooseneck Cove**			
	26.75 ppt	Rest type	Hydrologic			
		Rest date	2005			
		Area (ha)	22.8			
		Prox to ref (km)	21.69			
		Salinity (ppt)	29.85			
	Jacobs Point	**Site**	**Jacob's Point**			
	27.82 ppt	Rest type	Hydrologic			
		Rest date	2010			
		Area (ha)	6.7			
		Prox to ref (km)	0.0			
		Salinity (ppt)	11.28			
Chesapeake VA	**Goodwin Islands**	**Site**	**Hermitage Living**			
	16-23 ppt	Rest type	Excavation/Fiill			
		Rest date	2007			
		Area (ha)	0.2			
		Prox to ref (km)	35			
		Salinity (ppt)	17-23			
	Taskinas Creek	**Site**	**Naval Weapons Stn.**	**Cheatham Annex**		
	6-16 ppt	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**	**Site**	**Duke Marine Lab**	**NC Maritime Museum**	**Pine Knoll Shores**	
	15-38 ppt	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**	**Site**	**Kunz Marsh**			
	5-18 ppt	Rest type	Hydrologic-Ex/Fill*			
		Rest date	1996			
		Area (ha)	2.8			
		Prox to ref (km)	0.36			
		Salinity (ppt)	28			
	Yaquina 28	**Site**	**Yaquina 27**			
	0.5-5 ppt	Rest type	Hydrologic			
		Rest date	2002			
		Area (ha)	3.2			
		Prox to ref (km)	1.1			
		Salinity (ppt)	5			

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.

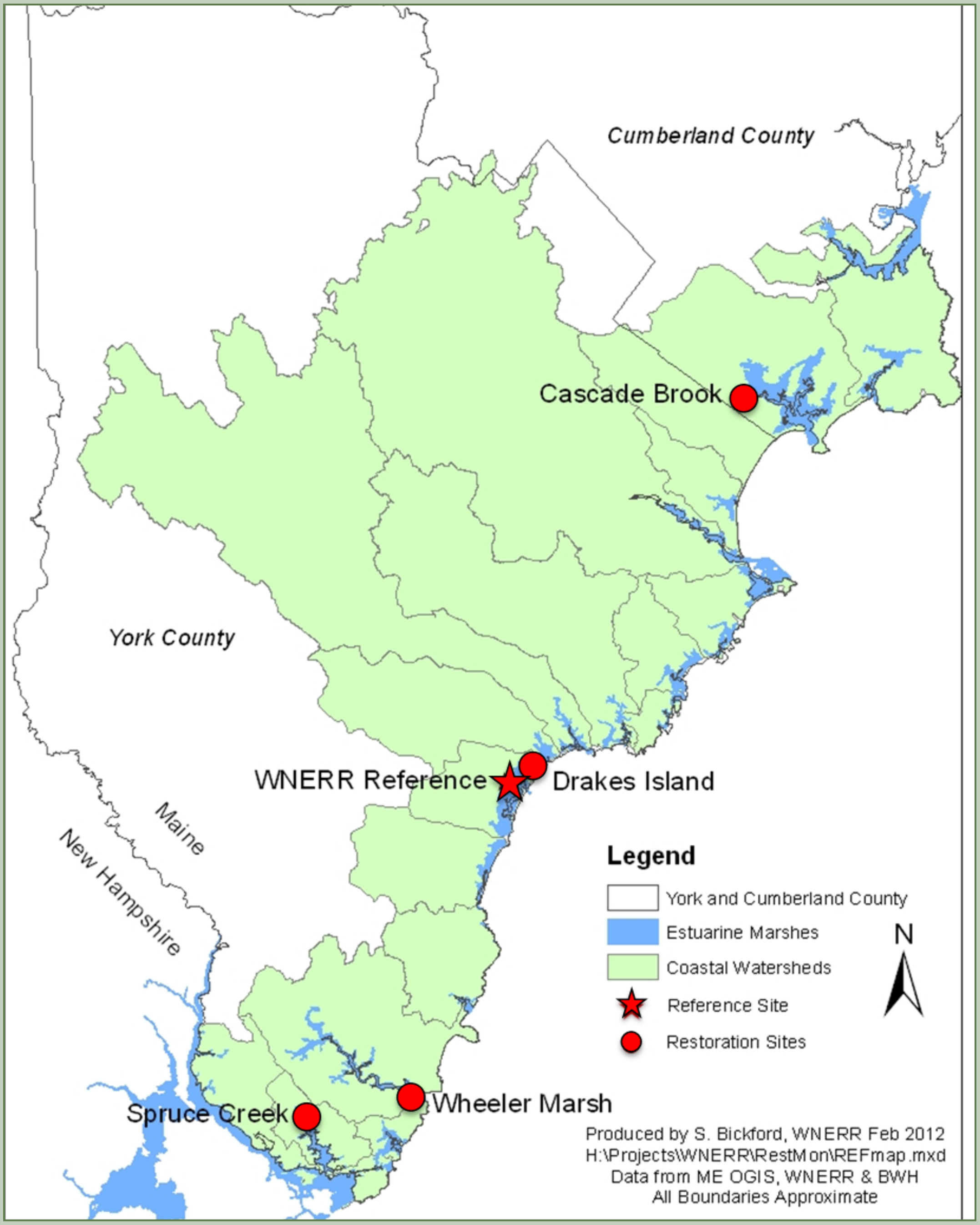

Figure 5. Location of reference site and four restoration sites monitored by the Wells NERR in southeast Maine.

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.

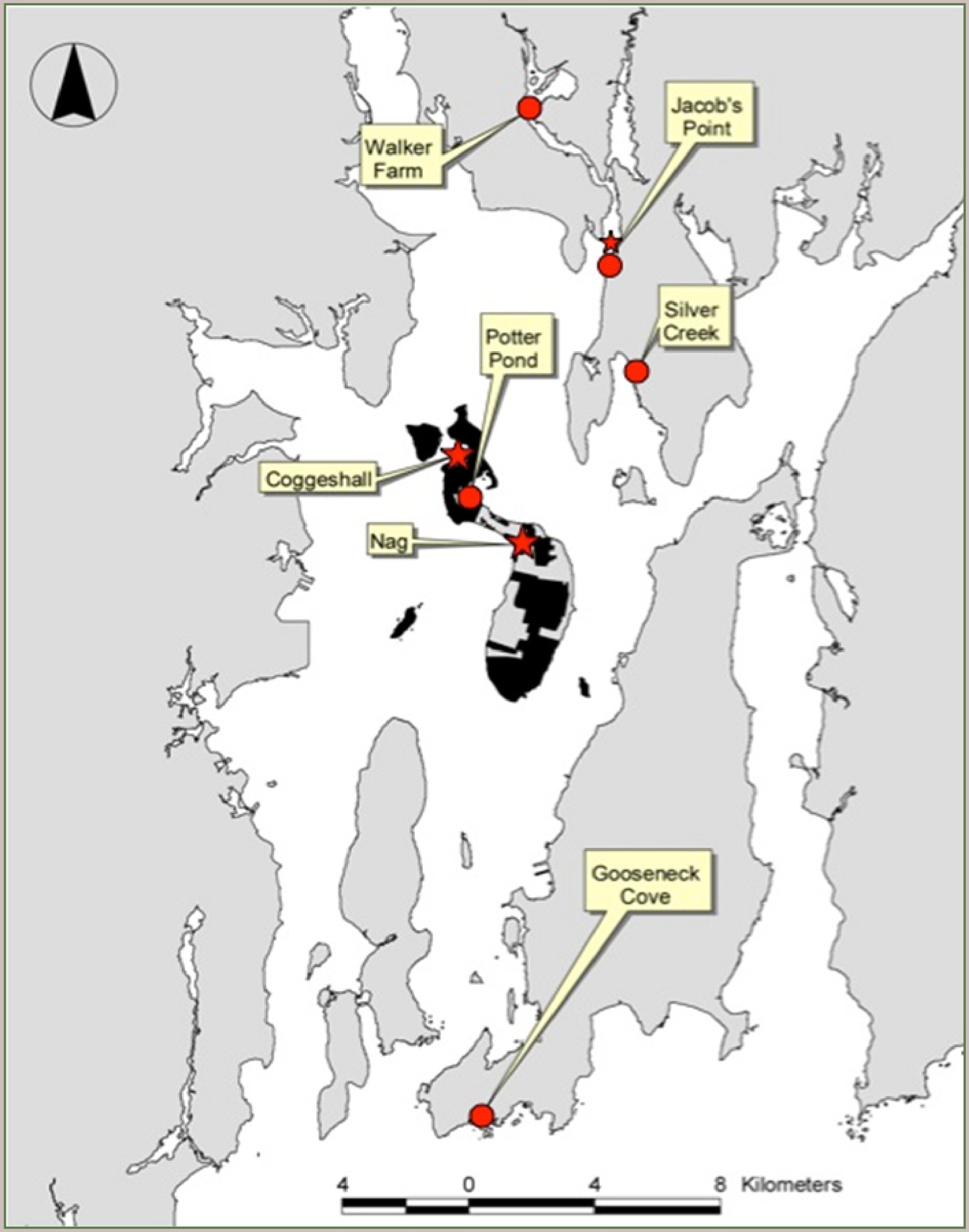

Figure 6. Location of three reference sites (red stars) and five restoration sites (red circles) monitored by the Narragansett Bay NERR in Rhode Island.

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.

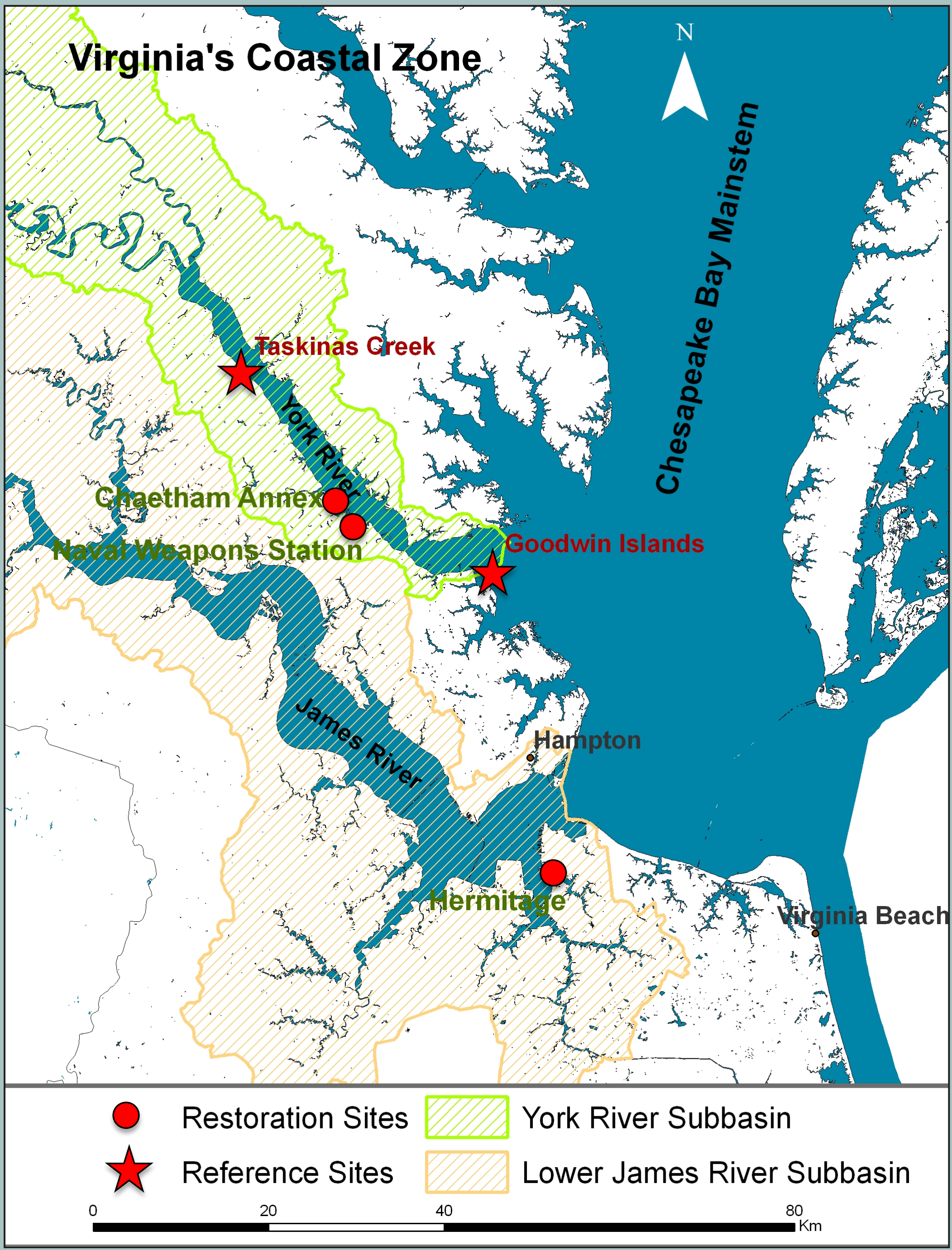

Figure 7. Location of two reference sites and three restoration sites monitored by the Chesapeake Bay VA NERR in Virginia.

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.

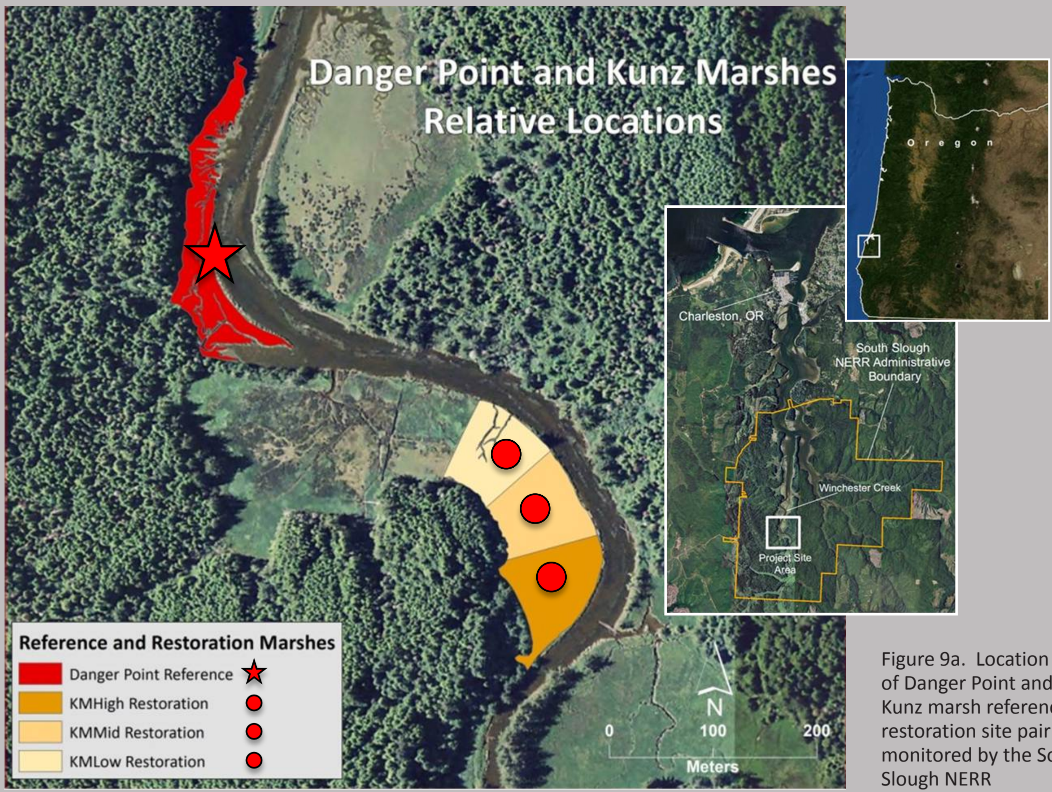

Figure 9a. Location of Danger Point and Kunz marsh reference-restoration site pair monitored by the South Slough NERR

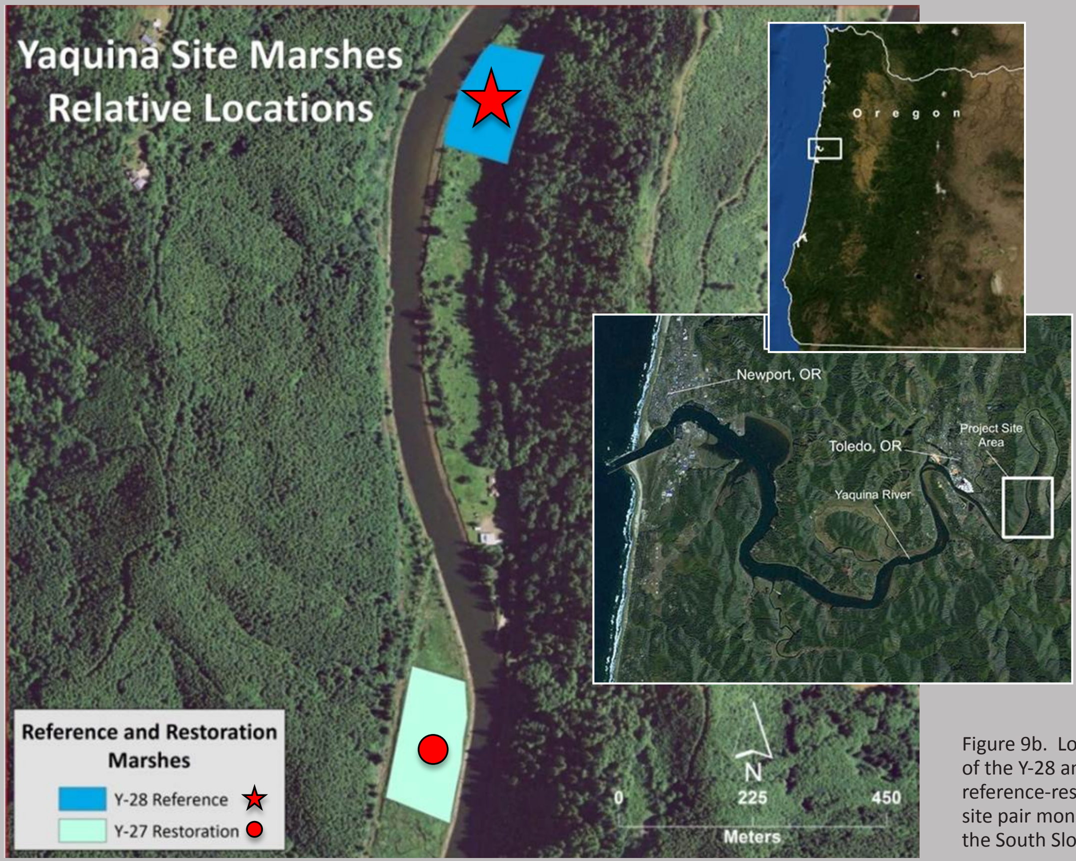

Figure 9b. Location of the Y-28 and Y-27 reference-restoration site pair monitored by the South Slough NERR

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.

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