Project Title: Measurement and Assessment of Restored and Reference *Spartina alterniflora* marsh ecosystems in North Carolina.

Final Report

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1) Overview

a. Rational:

Coastal marshes sit at the interface between the land and water. They provide many beneficial functions including erosion protection, fisheries and bird habitat, and carbon sequestration. They are also one of the most vulnerable habitats to impacts of shoreline development, storm damage and sea level rise. Nationwide, much effort is put toward protecting remaining marshes and restoring lost ones. At the same time the amount of money available for protection and restoration projects is decreasing. Consequently, the projects that are undertaken need to be extremely efficient and provide the highest return possible in terms of benefit for each dollar spent. Thus, understanding how best to conduct restoration activities across the various geographic provinces of the United States is a high priority need for the coastal management community. This project examined several restoration projects located within 4 different biogeographic provinces to quantify which restoration methods worked best in terms of creating a marsh that most mimicked the function of natural analogues.

This project was conducted by five National Estuarine Research Reserves (NERRS). The NERRS system is ideally suited to conduct this type of work as they have protected properties within all biogeographic provinces of the Continental United States, are nationally coordinated so methods are standardized and results can be broadly disseminated. Each NERRS also has a local State level tie in so regional issues can be accommodated. The five NERRS that conducted this study and their represented biogeographic provinces are: the Wells NERR in Wells, Maine representing the Acadian province; the Narragansett Bay NERR in Prudence Island, Rhode Island and the Chesapeake Bay NERR in Gloucester Point, Virginia representing the Virginian province; the North Carolina NERR in Beaufort, NC representing the Carolinian province, and the South Slough NERR in Charleston, Oregon representing the Columbian province.

b. Study Design:

The study was designed as a field based assessment of the health and location of the restoration marshes in the tidal frame compared against natural marshes. For each participating Reserve one or more restoration sites were monitored and compared against one or more natural marsh controls. The marshes within the five NERRs differed dramatically, however similar methodology was utilized in all sites. At each site the following parameters were quantified: vegetation percent cover, species presence and abundance, plant height, marsh elevation, marsh inundation, groundwater and porewater salinity and level, soil type and organic content. This was a three year project with all of the parameters except for the soil analysis being quantified each year. The soil analysis was a one-time assessment conducted in year 1. Data from each of the Reserves was combined into a centralized database coordinated by the Wells NERR and analyzed for trends of interest.

c. Study Sites:

As part of this project, NCNERR monitored and will report below on the following restoration sites (Table 1).

Table 1: Restoration sites monitored.

Site Name	Site ID #	Type of Restoration	Restoration Method	Year permitted	Length
Duke Marine Lab Shoreline Restoration (DUML)	536	Shoreline Restoration	Marsh Sill	2002	300
NC Maritime Museum Shoreline Restoration (NCMM)	232	Shoreline Restoration	Marsh Sill	2001	315
Pine Knoll Shores Aquarium Shoreline Restoration (PKS)	356	Shoreline Restoration	Marsh Sill	2002	400

As a reference site for these restoration projects, the Middle Marsh portion of the Rachel Carson component of NCNERR was monitored. All three restoration sites and middle marsh are located within 20 km of each other and thus, are within similar environmental settings (Figure 1). Middle marsh is a roughly 400 acre intertidal *Spartina alterniflora* marsh that sits on top of a relict flood tide delta (Figure 2).

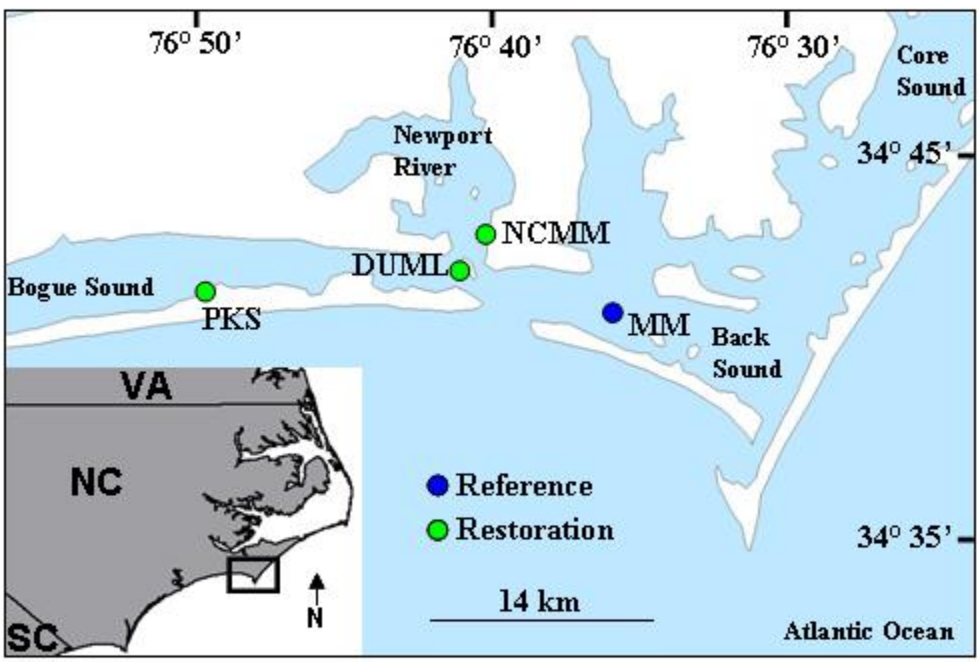

Figure 1: Restoration and reference site locations.

Figure 2: Middle Marsh portion of the Rachel Carson Reserve. Note the multiple marsh islands and tidal creeks.

The DUML site was constructed to replace a failing bulkhead. Prior to the project, there were no wetlands present. The goal of the project was to provide bank stabilization without using a bulkhead. The project site has three critical elements, an offshore granite rock sill, a low marsh area dominated by *Spartina alterniflora*, and an upper marsh area containing *Spartina patens*. Figure 3 shows a picture of this restoration site with these three critical elements labeled. The salinity range at this site is usually between 20 to 30ppt. Diurnal tides occur at this site with a typical range of 0.9m.

Figure 3: DUML restoration site with features labeled. Style of old bulkhead can be seen in distance.

The NCMM site was constructed to provide shoreline stabilization. The site originally was the location of a menhaden processing facility. Long since abandoned, at the time of the restoration all that remained of the original factory were the chimneys and failing waterfront bulkheads/piers. The property at the time of the restoration contained failing bulkheads, natural shoreline, rip rap revetment, and piers. The restoration project removed the failing bulkheads and piers and replaced them with a marsh sill. The marsh sill at this site consists of several granite rock breakwaters, a low marsh area dominated by *Spartina alterniflora*, and an upper marsh area containing *Spartina patens*, *Salicornia sp.* and *Borrichia frutescens* (Figure 4). The salinity range at this site is usually between 20 to 30 ppt. Diurnal tides occur at this site with a typical range of 0.9m.

Figure 4: NCMM restoration site with features labeled.

The PKS site was constructed to provide shoreline protection against erosion. Prior to the project, a natural eroding saltmarsh was present. The goal of the project was to protect the existing marsh from erosion. The restoration project consisted of installed a marsh sill to protect the existing marsh while at the same time replanting some of the areas that had been lost to erosion. The marsh sill at this site consists of an offshore granite rock wall, a low marsh area dominated by *Spartina alterniflora*, and an upper marsh area containing *Spartina patens*, *Juncus romerianus*, *Salicornia sp*. *Distichlis spicata*, and *Borrichia frutescens* (Figure 5). The typical salinity range for this site is 20 to 30 ppt. The tidal signal at this site is muted due to its distance from the closest inlet. Diurnal tides in the range of 0.5m do occur but can be altered by wind forcings.

Figure 5: PKS restoration site with features labeled.

2) Methods

Transect and vegetation plot layout:

NCNERR had the added benefit of working in marshes that had previously been monitored through another restoration center project headed by Dr. Carolyn Currin, NOAA-NOS. As such, NCNERR sampled the existing transects and vegetation plots established by Dr. Currin's project. This means that the results from NCNERR's project can be directly compared to those from the previous work doubling the sampling period from 3 years to 6 without any additional field work. Coupling the datasets would require a small amount of funding to support a research technician to accomplish this work.

Dr. Currin's group established transects and vegetation plots within each of NCNERR's study sites based on the following criteria. Within each study site, transects were established that went perpendicular from the marsh-water interface back to the marsh upland transition. The start and end of each transect was marked using rebar reinforced PVC pipe. Transect locations were selected at random within 10m blocks. At the time of sampling, reel tapes were placed between the front and back markers. One meter square vegetation quadrats were located at -1m from the front marker (this is the first meter waterward of the front marker), 0m, 5m, 10m, 15m, 20m, 30m, 40m, and 50m (Figure 6). Quadrats were located by placing a $1m^2$ PVC square along the reel tapes at the appropriate locations.

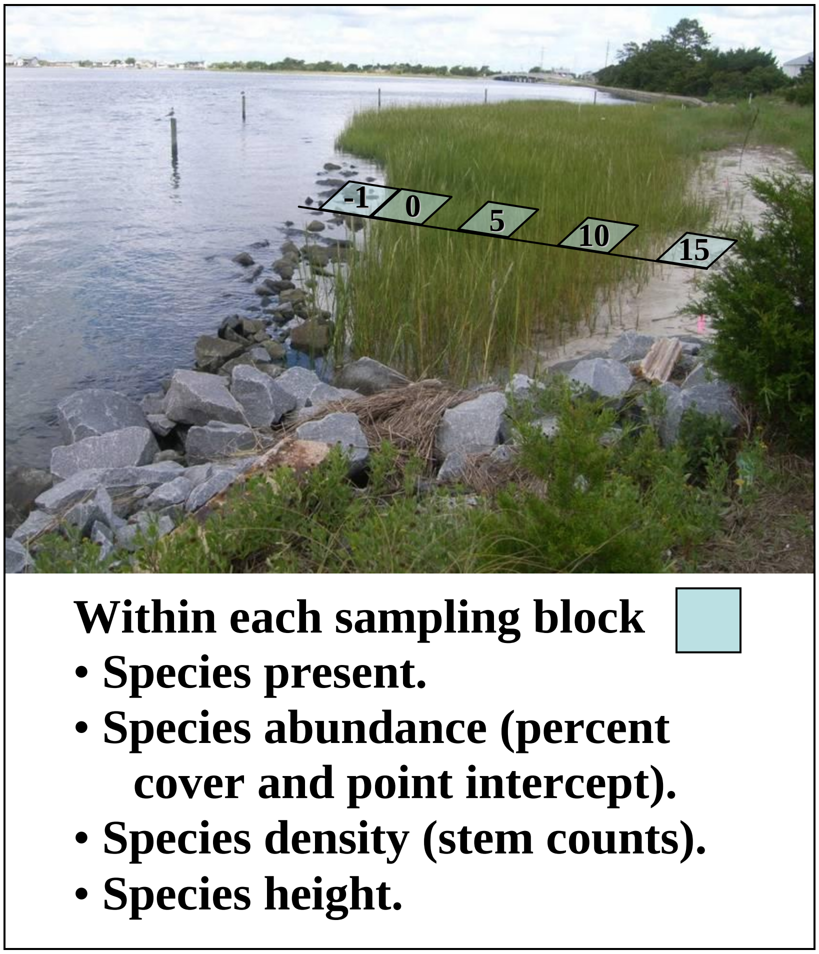

Figure 6: Transect and quadrat layout design. Example is from the DUML restoration site.

Vegetation:

The vegetation within each quadrat was quantified using both the visual percent cover method (Pete et al. 1998) as well as the point intercept method (Romen et al. 2001). Within each quadrat, stem counts for *Spartina alterniflora* were obtained as was the height in meters of the three tallest representatives of the dominant species present. Ten random *Spartina alterniflora* stems were also counted to allow us to calculate a biomass estimate. The biomass estimate was derived from prior work by Dr. Currin's group in these marshes that found a relationship between *Spartina alterniflora* stem heights and dry weight (Currin 2011). Based on this, we were able to estimate marsh biomass in dry weight equivalents without destructive harvesting methods by multiplying average stem height by the stem count.

Pore Water:

Porewater samples were obtained from shallow piezometers installed in the restoration marshes along one transect. The transects that contained the porewater piezometers and the groundwater wells (see below) were labeled as primary transects. The piezometers were made by placing 1.25in diameter PVC well pipe to a depth of 18cm below the surface of the marsh. This distance represents the typical root zone for the *Spartina* marshes in North Carolina. A 19 cm hole was created using a 3in core liner (see soils section). The piezometer was placed in the hole and clean sand used to back fill around the piezometer. The piezometers extended about 12 cm above the marsh surface and were covered with a loose fitting cap to prevent debris from entering without restricting water flow. These devices were often overtopped by tidal inundation. Sampling was always conducted at low tide. The sampling procedure involved removing the water in the piezometer present when the cap was removed and then sampling the water that refilled the pipe. This prevented us from sampling tide water that may have entered the piezometer during the most recent high tide and gave us a much clearer porewater sample. Three piezometers were installed in each restoration marsh, one in the low marsh zone, one in the upper marsh zone at the upland transition, and one half-way between these two endpoints. The piezometers were sampled every three-six months throughout the project for salinity and temperature.

Hydrology:

Hydrology within the marshes were measured by a series of groundwater wells installed along the primary transect. The groundwater wells were installed within 0.5m of the porewater piezometers described above. As such each marsh had three groundwater wells, one in the low marsh zone within 2m of the marsh/water transition, one in the upper marsh zone at the upland transition, and one half-way between these two endpoints. The wells were constructed of 1.25in diameter PVC pipe that extended 1m below the surface of the marsh. The holes for the groundwater wells were created using a ratcheting 4 in hand auger. Well holes were drilled to ~ 1.05m. The PVC pipe was then placed in the hole and backfilled with clean sand. The wells had open slits along the entire distance from 18cm to 1m below the marsh surface, thus they represent an average of the groundwater along this entire depth gradient. The wells extended 1m above the marsh surface with solid PVC pipe and were sealed at the marsh surface with hydraulic cement and bentonite clay. This prevented surface water (rain and tidal) from infiltrating the well so long as the seal remained functional. The top of the wells were capped with loose fitting tops to allow air exchange and prevent rainwater intrusion. The tops of these wells were never topped by tidal waters. Salinity and temperature of the water in the groundwater wells were obtained every three months by dropping a YSI 85 into the well at low tide. Grab samples from these wells were also occasionally obtained via a portable peristaltic pump. These samples were evaluated for salinity using a handheld refractometer as a backup to the YSI method.

These wells were also used to deploy *In-situ aquatrolls* for 2-3 week continuous deployments. The aquatrolls obtained a temperature, salinity and vented water level datapoint every 30min while deployed. The aquatrolls were rotated from marsh to marsh providing two 2-3 week sample periods for each marsh per year. The aquatroll deployment schedule is presented in Table 2. After deployments the data from the aquatrolls was entered into an excel database.

Table 2: Aquatroll deployment dates.

Location	2008	2009	2010
DUML	10-13-08 to 10-27-08	5-20-09 to 6-11-09	6-18-10 to 7-2-10
NCMM	11-13-08 to 11-30-08	6-16-09 to 7-9-09	9-15-10 to 10-3-10
PKS	9-16-08 to 9-29-08	7-21-09 to 8-14-09	8-6-10 to 8-25-10
MM			7-6-10 to 7-22-10

This groundwater data was normalized to NAVD88 MSL. It was utilized along with the elevation data (see below) to calculate the amount of time that each marsh was under water. The NAVD88 standard was utilized by all reserve partners allowing the marshes from all five states to be accurately compared to each other in terms of placement within the tidal frame.

Soils:

Sediment cores were obtained from the root zone of each restoration marsh and the reference marsh in year 1 of the project. The sediment cores were obtained from the same locations along the primary transect where the piezometers were installed. In fact the core hole left from the sediment sample was used to install the piezometer. From each sediment core samples for organic matter content were obtained from the top of the root zone (0-2cm) and from the bottom (16-18cm). The sediment samples were dried for 3 days at 50°C and weighed. They were then combusted at 500°C for 5hrs and immediately reweighed. The difference in weight was assumed to be organic matter fraction. Percent organic matter was calculated for each sample.

Elevation:

Elevations were obtained through collaboration with Dr. Carolyn Currin's (NOAA-CCFHR) lab. Dr. Currin's lab obtained the elevation data. They utilized a laser level working from established temporary benchmarks to create a digital elevation model (DEM) for the study sites. The DEMs were constructed using ArdGIS v9.2, Spatial Analyst Tool, Natural Neighbor. The specific elevations for the vegetation plots relative to mean sea level in NAVD88 (NAVD88 MSL) were extracted from the DEMs using ArcGIS Spatial Analyst Tool based on X and Y coordinates of each vegetation plot obtained from a handheld Garmin 76. The elevations of the groundwater wells were obtained directly by laser leveling from the benchmarks to each of the wells. The temporary benchmarks were tied into a vertical datum using RTK GPS techniques.

Data Analyses:

Data was analyzed within each NERR to assess whether the individual sampling sites were different from each other. This was done using a set of one way ANOVAs. The dependent variables utilized in North Carolina were plant height, plant density, and calculated biomass. The independent variable was site location and sampling year. The analyses presented in this report are based on the data collected using the point intercept method. However, a comparison between point intercept and visual percent cover assessment was also conducted. The visual percent cover charts are included in this report to facilitate this comparison. The alpha level used for all statistical analyses was 0.05. It was also the goal of this project to pool all the data across all five project partners and look at the relative success of the restored marshes compared to natural reference marshes. To support this effort, all project partners submitted their data to the Wells NERR for consolidation into a single database. Project data was submitted using standardized data sheets. Project data can be obtained by contacting Dr. Fear, or the Wells NERR.

The data from the five project partners was used to create a restoration performance index (RPI). The RPI enables project managers and the regulatory community to gauge a diverse range of structural and functional parameters indicating relative restoration performance. The RPI achieves this by incorporating a wide variety of monitoring data into its formulation, regardless of the monitoring protocols used, number of variables, or sampling interval, by using calculated mean values and standardizing along a relative index scale from 0-1. The preliminary version of the RPI helps end users calculate the net benefits, present and accrued, of a system undergoing ecological change using monitoring data that they (or others) have collected. Objectives: (1) provide a relative index of restoration performance to date, (2) provide a means of comparing restoration performance at individual sites and across differing sites for local and regional comparisons, and (3) provide a basis upon which to demonstrate restoration trajectory and ultimately allow for opportunities to improve restoration outcomes (i.e., adaptive management). Because the RPI uses reference marsh data as a baseline for comparison, restoration performance is defined as its trajectory leads toward or intercepts the reference condition. The rate at which the trajectory achieves the desired outcome is expected to be widely variable, and dependent upon a variety of factors, including the factors chosen for measurement. The more factors (i.e., measurable parameters) incorporated into the RPI model, the stronger the predictive value of the output. For this project the RPI was calculated based on the following formula.

$$RPI = (T_{present} - T0) / (T_{ref} - T0)$$

The RPI scores range from 0 to 1, with 1 indicating identical conditions being found in the restoration site as compared to the natural reference site. For a successful restoration project, its RPI score will approach 1 as the project matures.

3) Results:

a. vegetation:

The marshes investigated as part of this project were dominated by *Spartina alterniflora* with *Salicornia spp*. the second most dominant. Other species and their contributions to the marsh flora are included in Table 3. Table 4 shows the species richness by year for all the sampled marshes together and then for each sampling site individually. Eight species were recorded in total: *Spartina alterniflora, Spartina patens, Salicornia spp., Borrichia frutescens, Distichlis spicata, Limonium spp., Juncus roemerianus,* and *Hydrocotyle spp.* The species richness remained stable for all marshes throughout the time period of the study.

Table 3: Species contributions to observed flora in sampled marshes.

	All Marshes	DUML	NCMM	PKS	MM
Spartina alterniflora	79%	77%	95%	49%	100%
Salicornia spp.	8%	5%	0%	24%	0%
Spartina patens	6%	16%	1%	8%	0%
Borrichia frutescens	3%	0%	3%	8%	0%
Distichlis spicata	2%	0%	0%	6%	0%
Limonium spp.	0.4%	0%	0%	1%	0%
Juncus roemerianus	1%	0%	0%	4%	0%
Hydrocotyle spp.	1%	3%	0%	0%	0%
* Percentages calculated from point-intercept data					

Table 4: Species richness by year for all sampled marshes

All marshes	2008	2009	2010	**NCMM only**	2008	2009	2010
Spartina alterniflora	X	X	X	*Spartina alterniflora*	X	X	X
Spartina patens	X	X	X	*Spartina patens*	X	X	X
Salicornia spp.	X	X	X	*Salicornia spp.*		X	
Borrichia frutescens	X	X	X	*Borrichia frutescens*	X	X	X
Distichlis spicata	X	X	X	*Distichlis spicata*		X	
Limonium spp.	X	X	X	*Limonium spp.*			
Juncus roemerianus	X	X	X	*Juncus roemerianus*			
Hydrocotyle spp.	X	X	X	*Hydrocotyle spp.*			
Total species count	8	8	8	Total species count	3	5*	3
DUML only	2008	2009	2010	**PKS only**	2008	2009	2010
Spartina alterniflora	X	X	X	*Spartina alterniflora*	X	X	X
Spartina patens	X	X	X	*Spartina patens*	X	X	X
Salicornia spp.	X	X	X	*Salicornia spp.*	X	X	X
Borrichia frutescens		X	X	*Borrichia frutescens*	X	X	X
Distichlis spicata	X			*Distichlis spicata*	X	X	X
Limonium spp.	**	X	X	*Limonium spp.*	X	X	X
Juncus roemerianus				*Juncus roemerianus*	X	X	X
Hydrocotyle spp.	X	X	X	*Hydrocotyle spp.*			
Total species count	5	6	6	Total species count	7	7	7
MM only	2008	2009	2010				
Spartina alterniflora	X	X	X	X = species present			
Total species count	1	1	1				

* One plant for each new species in 2009.

** *Limonium* was present in the DUML site in 2008, just was not captured in the quads.

The marsh flora percent cover also remained stable throughout the project. Figure 7 shows the percent cover based on the point intercept method for all species by year and marsh. No significant differences in percent cover were observed across the three years of the project for any of the marsh plant species. Significant differences were observed in percent cover between marsh sites. For the most dominant species, *Spartina alterniflora*, the MM percent cover was statistically different than the DUML site ($p = 0.049$). The percent cover for the second most dominant species, *Salicornia spp*., was significantly different between PKS and all other sites ($p < 0.001$ for all sites). The percent cover for the third most dominant species, *Spartina patens*, was significantly different between MM and both DUML and PKS ($p < 0.001$ for both), and between NCMM and both DUML and PKS ($p = 0.001$ and 0.019 respectively).

To facilitate the point intercept versus visual percent cover comparison, Figure 8 shows the same plots using data from the visual percent cover method. Comparing Figures 7 and 8 reveals that overall patterns remain unchanged, however, percent cover values are lower for the visual method.

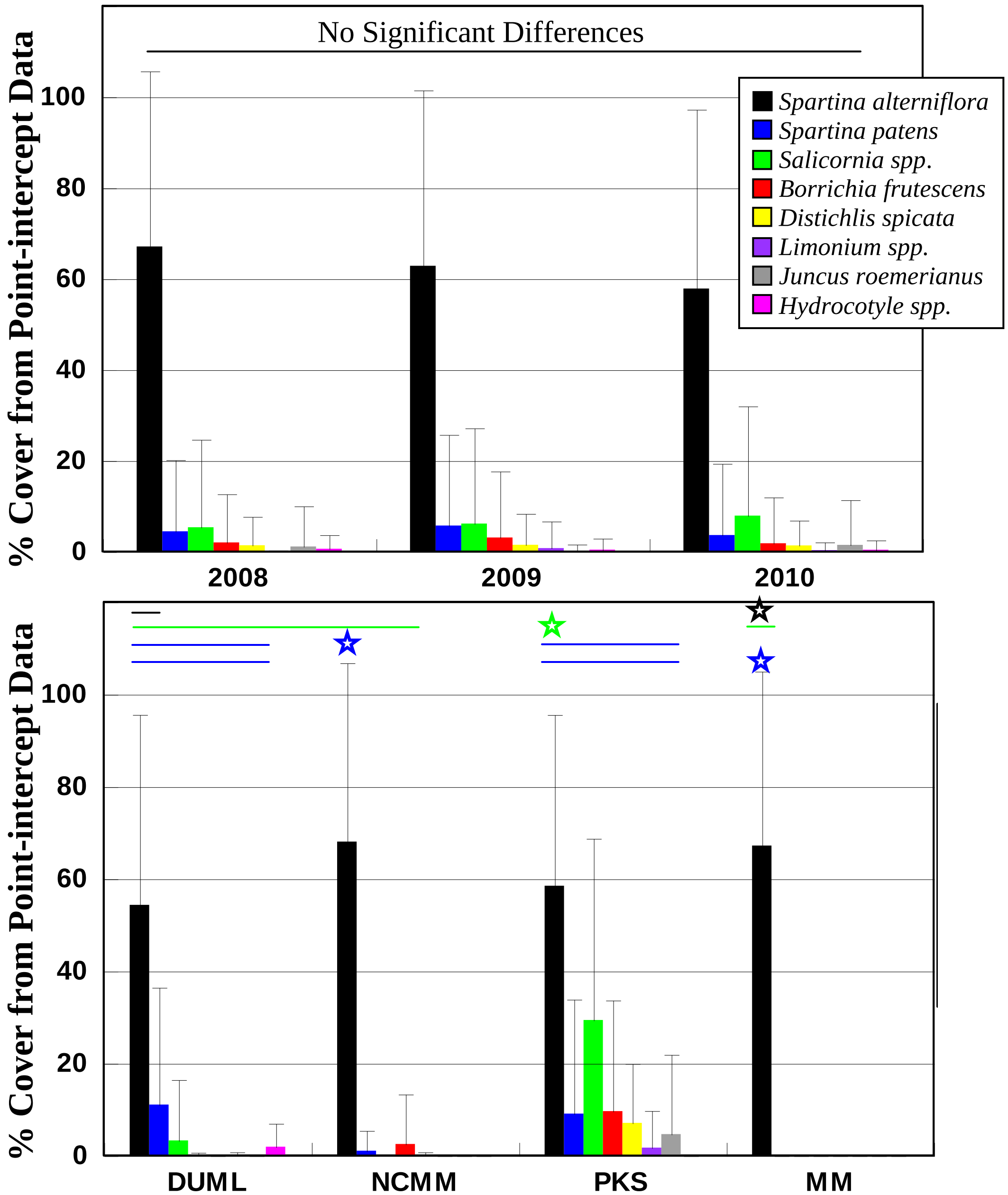

Figure 7: Top panel shows percent cover by species for each year. Bottom panel shows percent cover by species for each site. Error bars represent one standard deviation. Color coded stars and lines depict significant differences for the three most dominant species (bonferroni).

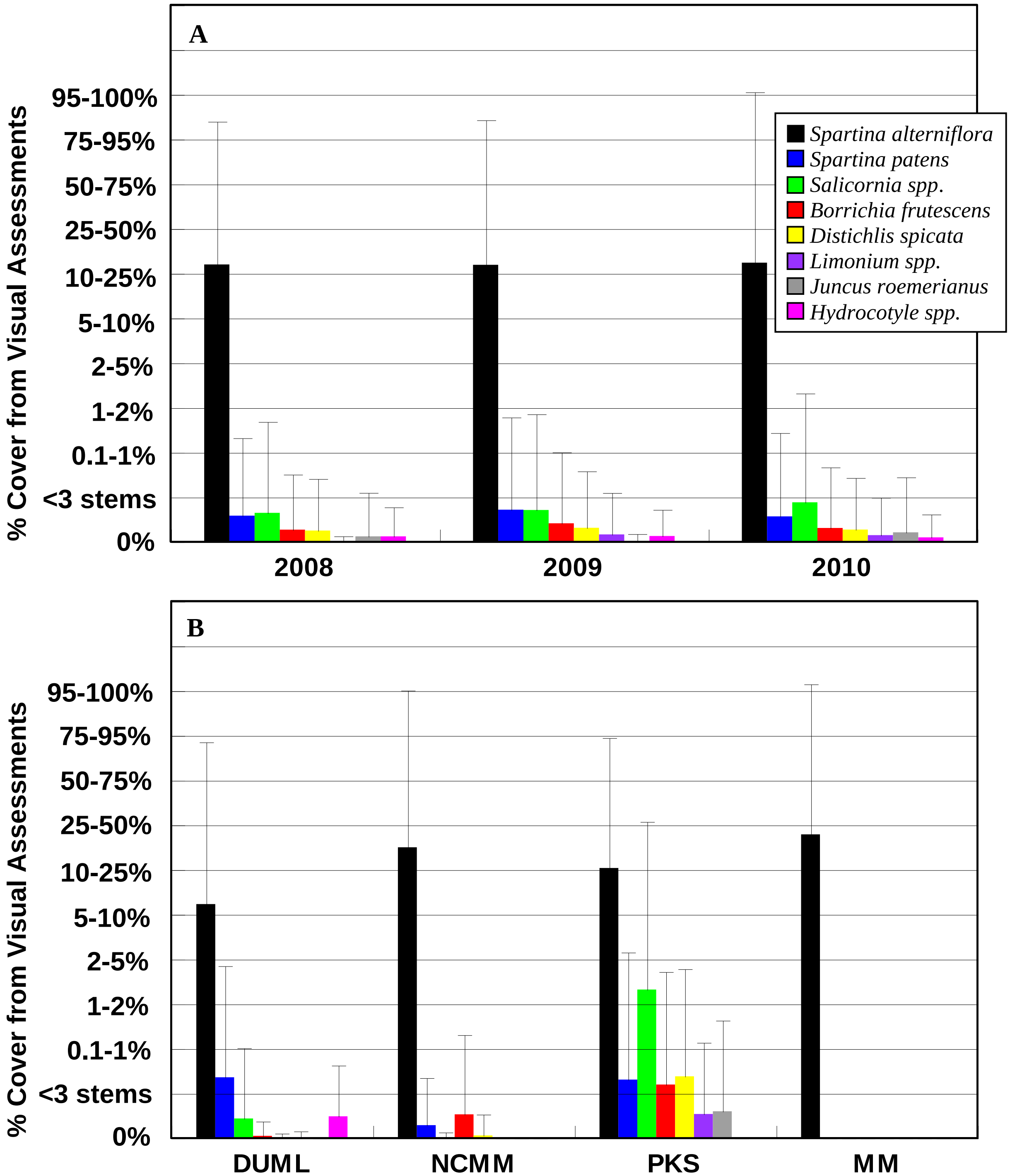

Figure 8: Percent cover by year (panel A) and by marsh (panel B) based on data from the visual assessment. Notice the non-linear scale on the y-axes. Error bars represent one standard deviation.

Figure 9 shows the measured plant metrics data for all marshes by year. Stem count, the 10 random *Spartina alterniflora* heights, and biomass data are available for 2009 and 2010. The data for the three tallest plant heights of the dominant species is available for all three years. No significant differences in stem count data or the 10 random *Spartina alterniflora* data were observed between the 2009 and 2010 data. The 2008 data for the 3 tallest plants was significantly different from the 2010 data ($p = 0.008$). The calculated biomass data for 2009 was significantly different from 2010 ($p = 0.009$).

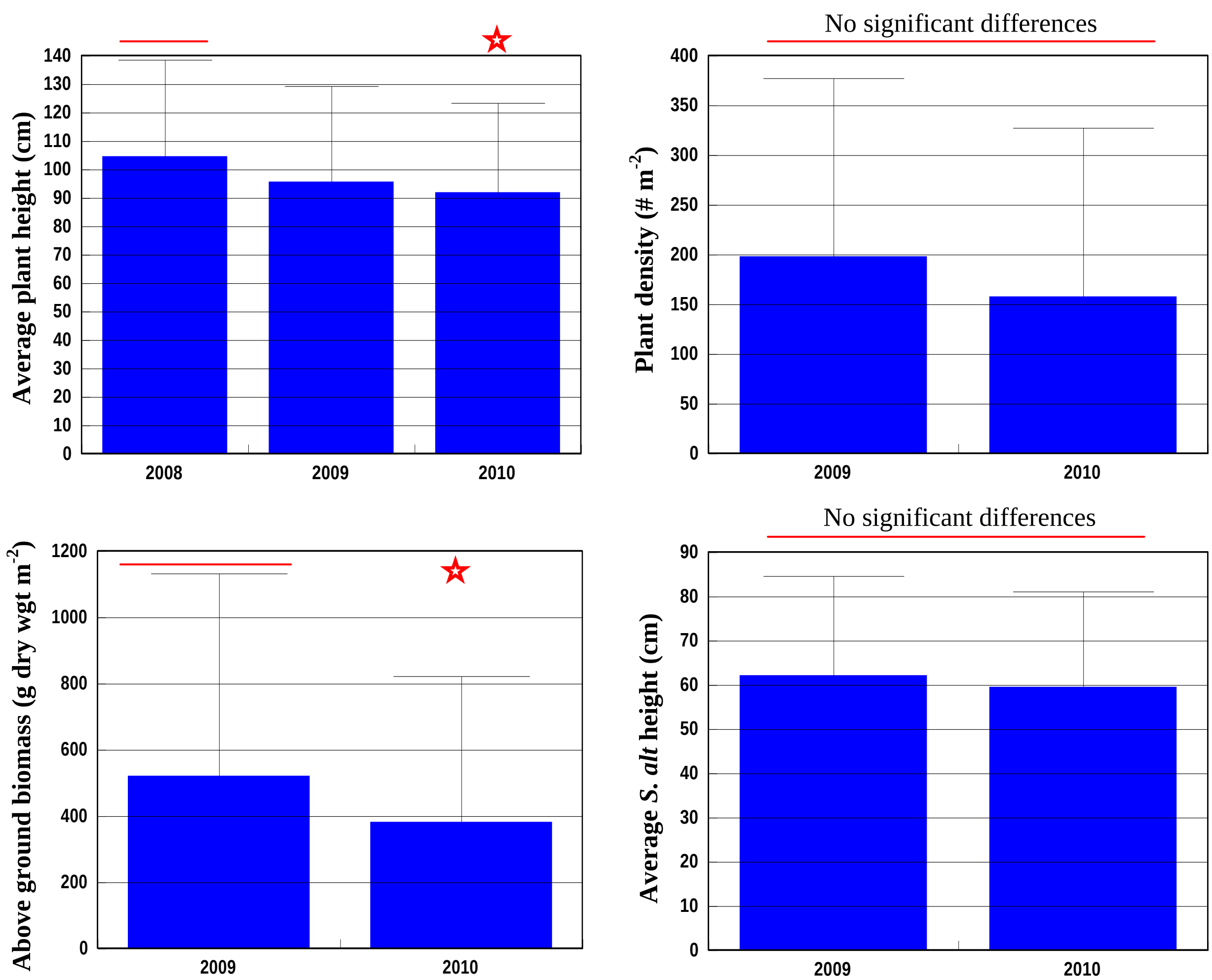

Figure 9: Vegetation metrics by year. 2008 data missing for plant density, average *S. alt* height, and *S. alt* aboveground biomass. Error bars represent 1 standard deviation. Significant differences are noted for each panel by the red stars and lines.

The inter-site comparisons are presented in Figures 10-13. Figure 10 shows the average of the 3 tallest members of the dominant species by marsh. The PKS had significantly shorter plant heights compared to the other three marshes ($p < 0.001$ for all comparisons). The NCMM site had the tallest plants out of all the sites, but the difference was not significantly different from the other marshes except for the PKS marsh as noted above.

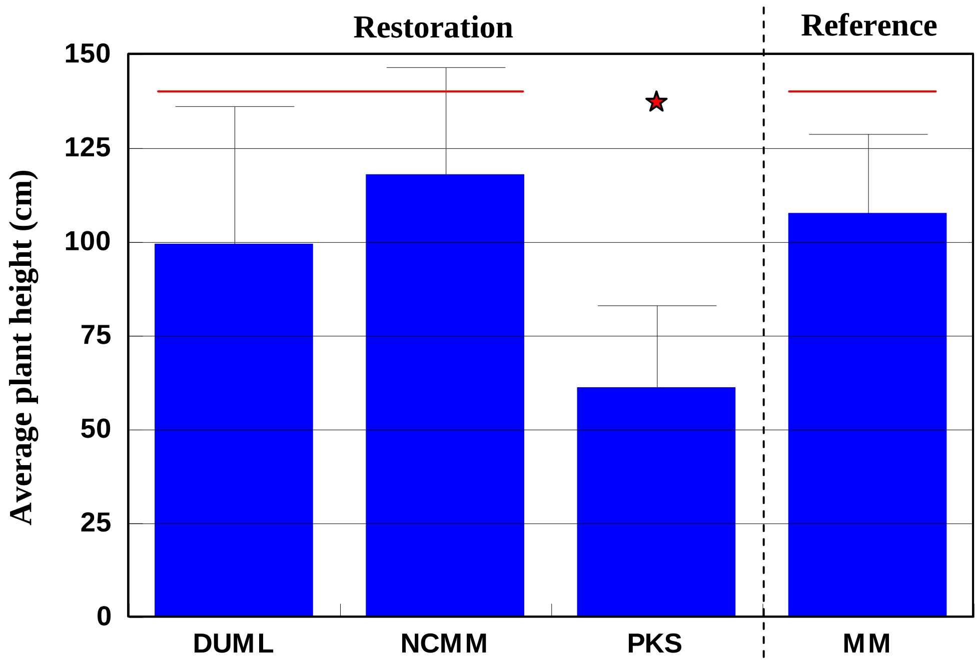

Figure 10: Average height of the three tallest dominant plant species. Error bars represent 1 standard deviation. The PKS site is significantly different from the other locations (bonferroni).

Figure 11 shows the plant density (stem counts) by marsh site. The PKS site had significantly higher stem counts than all the other sites ($p = 0.001$ for the NCMM comparison and < 0.001 for the MM and DUML comparisons). No differences were observed between any of the other marshes.

Figure 12 shows the average height of 10 randomly selected *Spartina alterniflora* stems. Overall, MM had the tallest *Spartina alterniflora* stems and PKS had the shortest. The DUML and NCMM sites were intermediate. Similar to the results from Figure 9 for the three tallest plants, the PKS site had significantly shorter *Spartina alterniflora* stems compared to the other marshes ($p < 0.001$ for all comparisons). A significant relationship between DUML and MM was also observed. The DUML *Spartina alterniflora* stems were significantly shorter than those from MM ($P < 0.001$).

The calculated above ground *Spartina alterniflora* biomass for the four marshes ranged from 0 (plots with no plants in them) to 3.8 kg dry weight m^{-2}. Figure 13 shows the biomass data for each marsh normalized to meters squared. The NCMM site had the highest calculated above ground *Spartina alterniflora* biomass, while the PKS site had the lowest. The DUML and MM sites were intermediate. PKS was significantly different than MM and NCMM ($p < 0.001$), and DUML was significantly different from NCMM ($p = 0.004$).

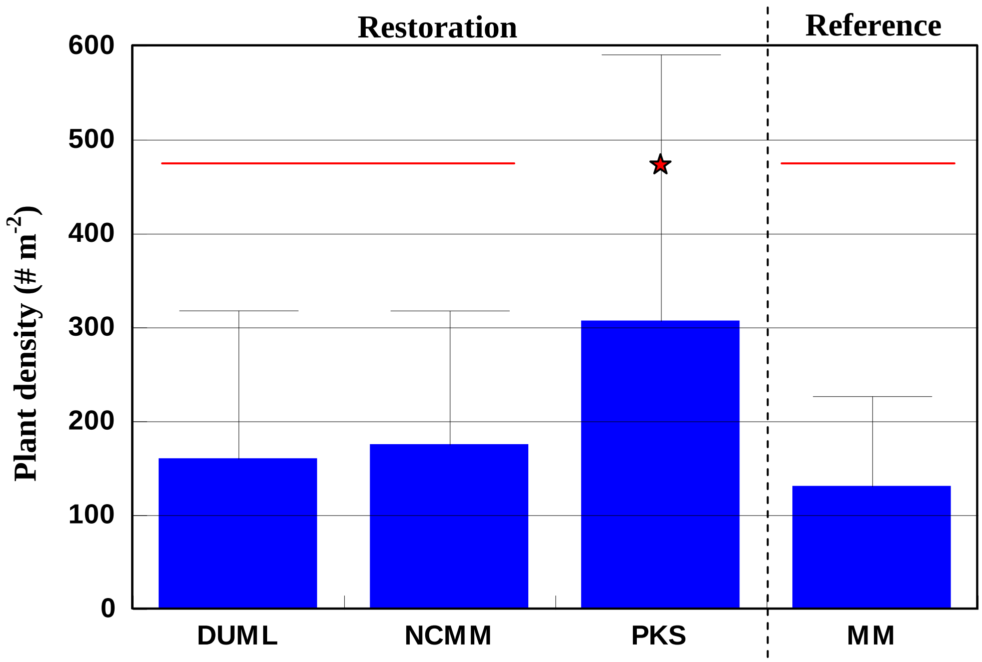

Figure 11: Live *Spartina alterniflora* stem counts for each marsh. Error bars represent 1 standard deviation. The PKS site is significantly different from the other locations (bonferroni).

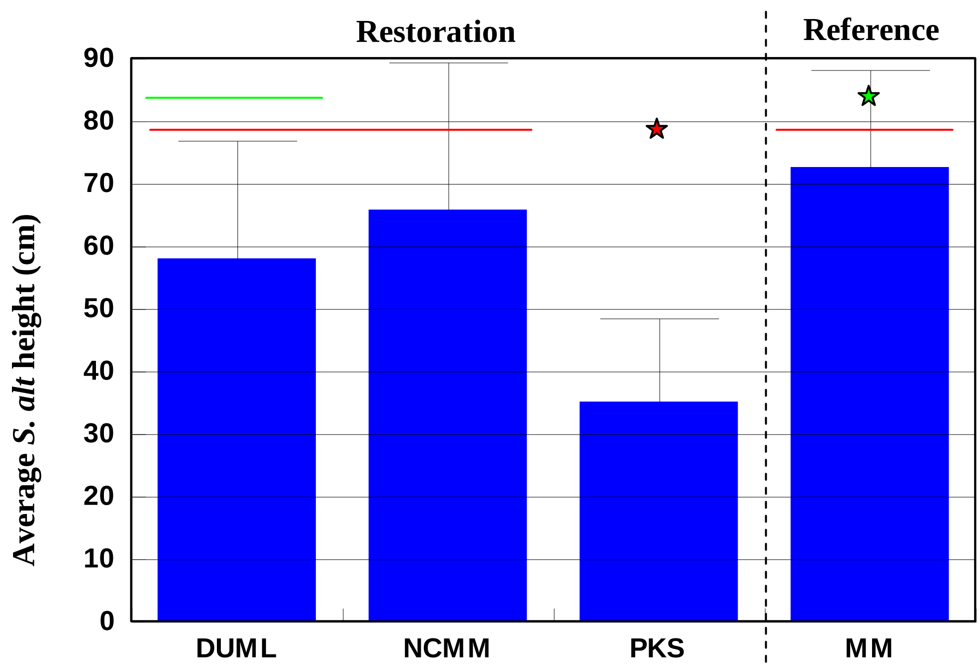

Figure 12: Average height of 10 randomly selected *Spartina alterniflora* stems. Error bars represent 1 standard deviation. PKS was significantly different from the other three sites. MM was significantly different from DUML (bonferroni).

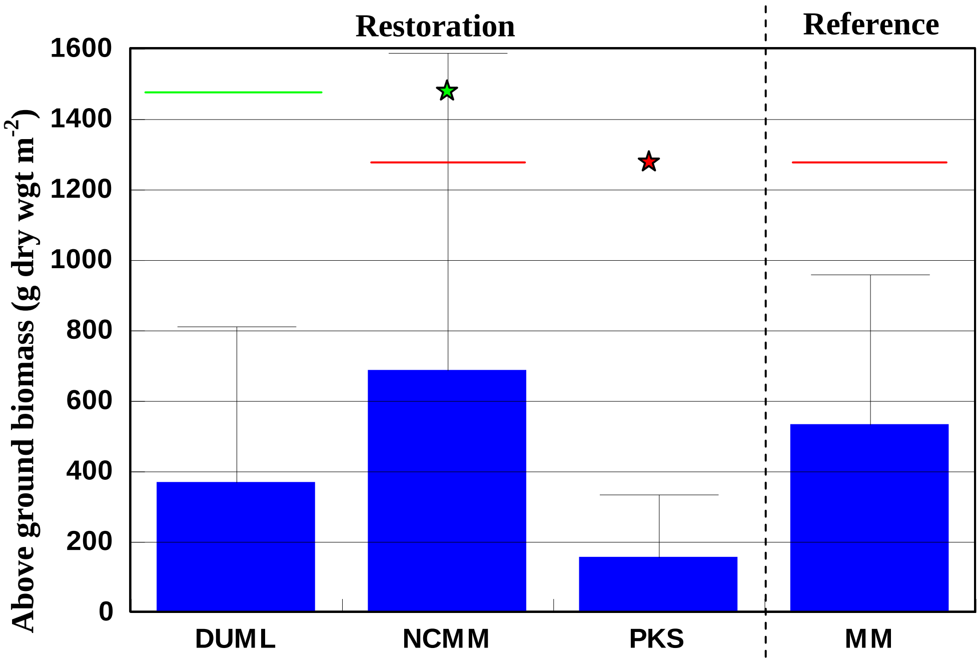

Figure 13: Calculated *Spartina alterniflora* above ground biomass for each marsh. Error bars represent 1 standard deviation. PKS was significantly different than MM and NCMM. DUML was significantly different from NCMM (bonferroni).

b. soils and porewater:

The marsh soils were analyzed during year 1 of the project. Table 5 contains the sediment percent organic matter data. Sediment organic matter ranged from 0.5 to 17.9%. The PKS had the highest average sediment organic matter content, middle marsh the second highest, then the NCMM site and finally the DUML site. The PKS site average was influenced by the very high values obtained from the center of that marsh.

Table 5: Marsh soil percent organic matter for root zone (0-18cm).

Site	Low Marsh	Middle	High Marsh	Average
DUML	5.4	0.7	0.5	2.2
NCMM	3.1	3.4	2.9	3.1
PKS	4.9	17.9	3.7	8.8
MM	6.6	8.3*	8.9*	7.9
* Middle Marsh is all low marsh. These points are located most interior and half way between the interior and edge.				

The porewater salinity values obtained from the grab samples are included as Table 6. Porewater data from MM was not collected. The lowest porewater salinity value recorded during the study was 7.9ppt at the NCMM marsh. The highest value of 43.5ppt was recorded at the PKS site. The upper porewater piezometer at the DUML marsh was always dry. The porewater data show that the PKS marsh had significantly higher porewater salinity values compared to the NCMM site ($p = 0.025$). The DUML site fell between these two (Figure 14). Porewater values did not vary significantly based on marsh zone with data from all marshes pooled together (Figure 15).

Table 6: Porewater data collected from piezometers.

Date	Site	Transect-Quad	Salinity (ppt)	Date	Site	Transect-Quad	Salinity (ppt)
Sept 2008	PKS	13-1 13-50 13-70	43.5 42.2 42.6	July 2009	PKS	13-1 13-50 13-70	33.9 37.5 28.5
Sept 2008	DUML	5-1 5-7 5-14	34 37 dry	Aug 2009	PKS	13-1 13-50 13-70	26.8 36.7 26.9
Nov 2008	NCMM	4-1 4-7 4-15	32 30 29	Feb 2010	PKS	13-1 13-50 13-70	18.1 20.6 20.3
Feb 2009	PKS	13-1 13-50 13-70	dry dry dry	Feb 2010	DUML	5-1 5-7 5-14	19.5 21.1 dry
Feb 2009	DUML	5-1 5-7 5-14	33 dry dry	Feb 2010	NCMM	4-1 4-7 4-15	20.9 13.9 7.9
Feb 2009	NCMM	4-1 4-7 4-15	29.1 17.9 dry	June 2010	DUML	5-1 5-7 5-14	29.9 34.3 dry
May 2009	DUML	5-1 5-7 5-14	29.4 32.7 dry	Aug 2010	PKS	13-1 13-50 13-70	dry 37.4 dry
June 2009	NCMM	4-1 4-7 4-15	22.6 24.8 28.8	Sept 2010	NCMM	4-1 4-7 4-15	27.1 26.9 22.4
July 2009	NCMM	4-1 4-7 4-15	23.7 29.5 28.8				

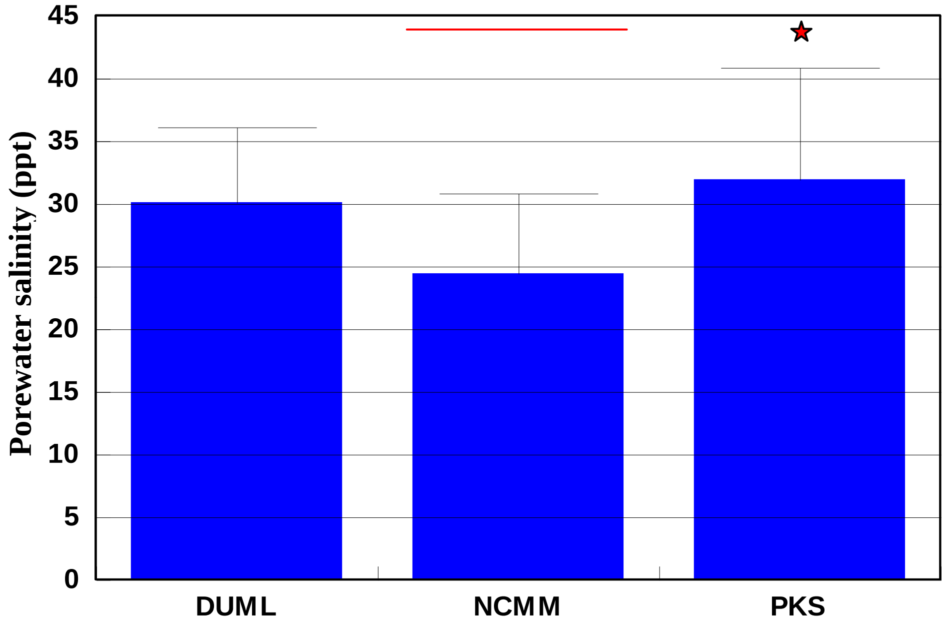

Figure 14: Average porewater salinity by marsh site. Error bars represent 1 standard deviation. The PKS site is significantly higher than the NCMM site (bonferroni).

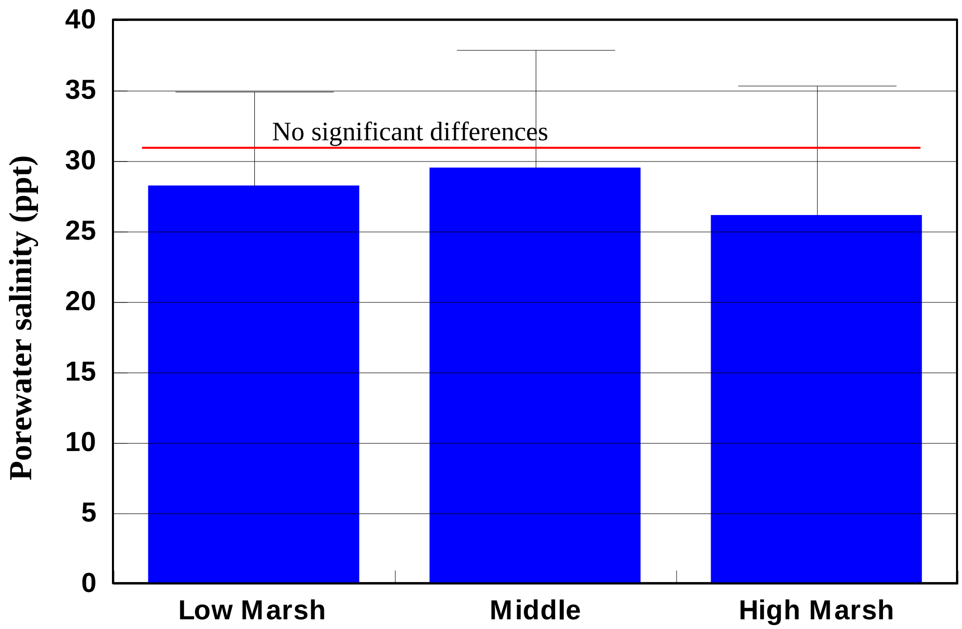

Figure 15: Average porewater salinity by marsh zone. Error bars represent 1 standard deviation. No significant differences were observed among marsh zones.

c. elevation and groundwater:

The elevation of the marsh surface for the primary transects is presented in Figure 16. Data is available for all assessed transects but the primary transects are representative for each marsh and allow the differences to be clearly seen. From Figure 16 it is clear that the DUML site has the most elevation change, 1.40m, and the steepest marsh slope (elevation change/distance from water to upland transition) 0.07. The NCMM site was a close second with 0.91m of elevation change with a slope of 0.06. Both the PKS and MM reference site had much smaller elevation changes and much shallower slopes. The PKS site had a total elevation change of 0.51m and a slope of 0.005. A true slope calculation is not possible for MM as there is no upland transition and the elevation data for the two lower quadrats was not obtainable, but the available data suggest it similar to the PKS marsh.

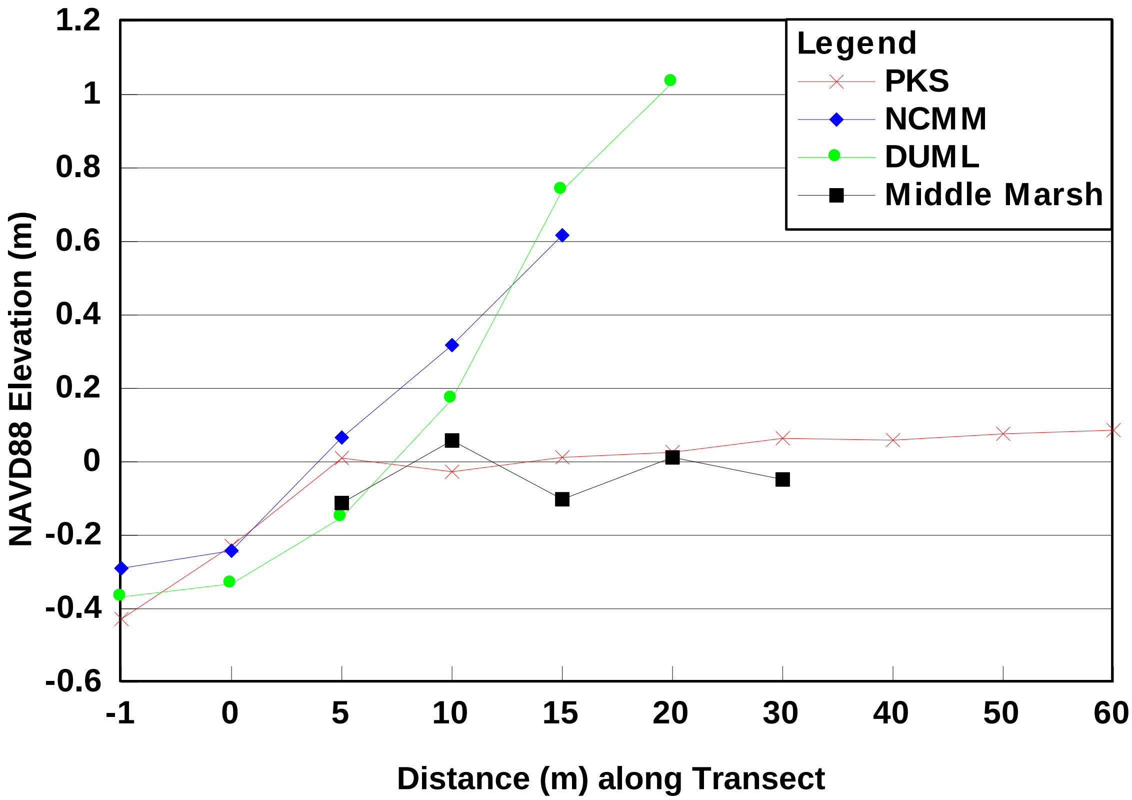

Figure 16: Elevation of primary transects in all sampled marshes relative to NAVD88 MSL. Slopes were calculated as linear regressions of these plots.

The elevation data and water level data from the aquatroll deployments were used to calculate the percent of the time that the marshes were inundated. Figure 17 shows this calculation. The figure shows the calculation for each of the three years and then an average for all the data combined. Middle Marsh only had aquatroll data available from 2010. The elevation of the marsh surface at the well locations relative to NAVD88 are also shown. As expected by the slope differences in the marshes, the DUML and NCMM marshes had the most variation in inundation time between the upper marsh area and lower marsh area. Both these sites lower edges were almost always flooded, while their upper regions were typically dry. The much lower sloped PKS and MM reference site showed more of a tidal pattern with the entire marsh being flooded during high tide and the entire marsh being dry at low tide.

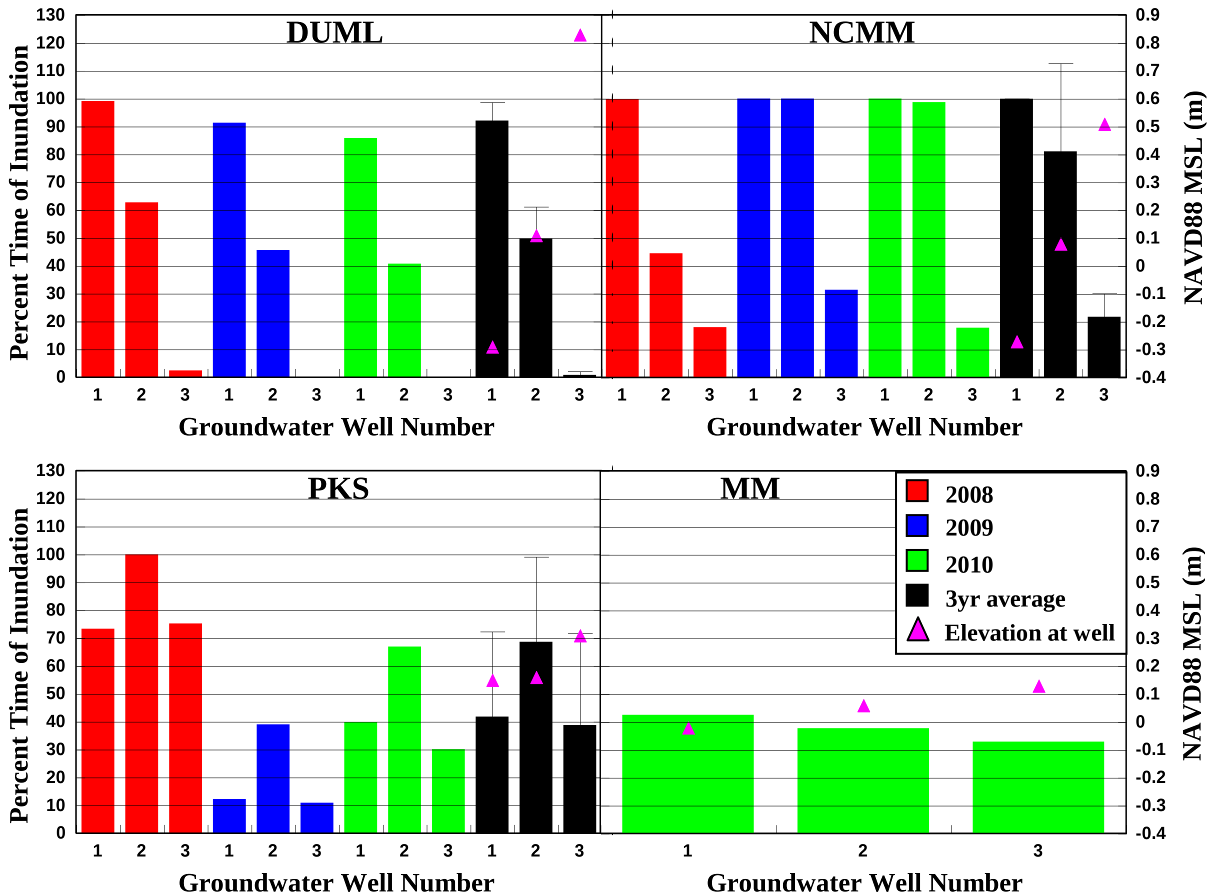

Figure 17: Calculated inundation time for the sampled marshes based on annual 2 week deployments with aquatrolls (see Table 2 for deployment schedule). Middle Marsh only had one year of data collected. Error bars represent standard deviation of the mean. Pink triangles represent the elevation of the marsh at the location of the groundwater well. Well 1 was located at the marsh/water transition, well 3 was located at the marsh/upland transition, well 2 was located halfway between the other two.

d. RPI results:

The vegetation, elevation and groundwater data were used as variables to calculate the RPI for the North Carolina marshes. The RPI results are presented in Figure 18.

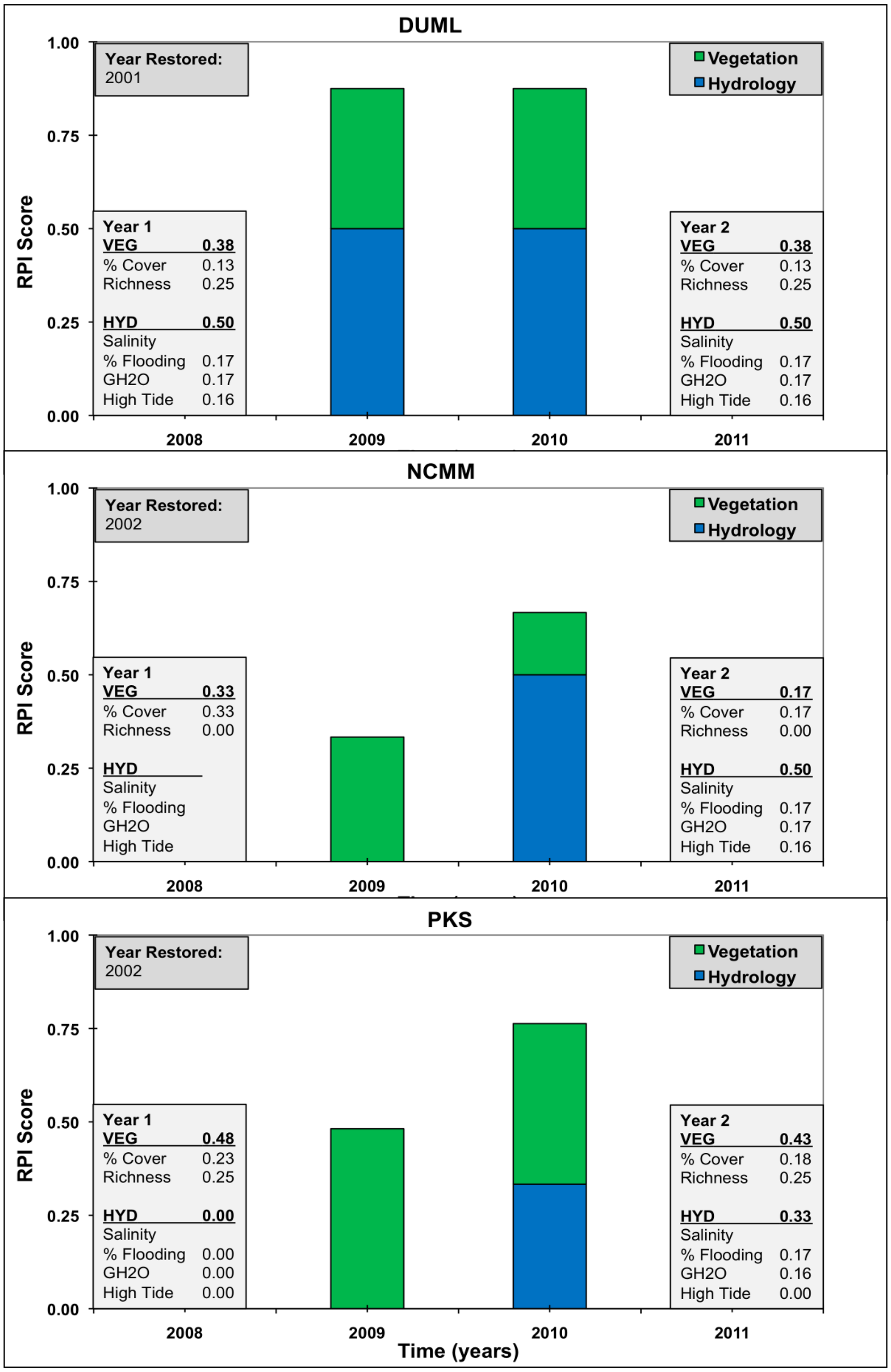

Figure 18: RPI assessments for DUML, NCMM, and PKS.

4) Discussion:

a. soils:

The porewater soils indicate that the restored marshes sampled as part of this study are very mature. The organic matter content of restored marshes is often much lower than a natural marsh. It takes many years for a restored marsh to build up sediment organics. With the exception of the DUML site, the restored marshes that NCNERR sampled had degraded marsh present before the restoration. Thus, the soils likely already had higher levels of organic matter than most restoration projects. The DUML site is typical of restored sites in that fill was used to create the needed grade. The fill material used at the DUML site was clean sand. Clean sand has very little organic matter in it and this explains this sites lower organic content. However, even the DUML site especially in the lower portions has started to accumulate organic matter. This is indicative of a healthy marsh and a successful restoration. Using MM as the natural marsh benchmark, the restored sites sampled during this project appear to be moving more toward natural marsh sediment organic matter levels. One of the restored sites, PKS, has even accumulated more sediment organic matter content (8.8 versus 7.9) than our reference marsh (MM) (Table 5).

b. vegetation:

The vegetation data indicates that the PKS site is performing differently than the other two restored marshes and the reference marsh. This is supported by all measured vegetation metrics and also the calculated biomass estimate. The PKS site had both significantly shorter plants and significantly higher stem densities than the other sites (Figures 10, 11, and 12). It also had significantly less above ground *Spartina alterniflora* biomass than both NCMM and MM. Compared to DUML, the biomass was also less however the trend was not statistically significant (Figure 13). The difference in the inundation time and slope between the PKS site and the other two restoration sites offer some explanation for the observed differences. The PKS site is flatter, wider, and has less slope (Figures 16 and 17). These factors increase the inundation time and penetration into the marsh of tidal waters. This could decrease the plants ability to exchange gases with the atmosphere compared to the other two restoration sites leading to reduced growth. This argument does not work for the PKS to MM comparison as both marshes have similar slopes and elevations. Consequently, some other factor must be causing the observed differences between PKS and the reference marsh. Possible factors include differences in the magnitude of the tidal signal (slightly muted at PKS compared to MM), competition between plant species at PKS, difference in grazing, etc. The underlying cause/s for the observed differences between PKS and MM at present time remains unknown. What is clear is that the PKS restoration project seems to be on a different trajectory compared to the other restoration projects and the natural reference marsh.

The inter-annual comparisons did show a few significant differences. The plants heights were significantly shorter in 2010 compared to 2008 for the 3 tallest measured stems, and the above ground biomass was significantly less in 2010 compared to 2009. These findings are not unexpected given the interannual variability that occurs in natural systems. The sea level anomaly described in Sweet et al. (2009) is one such example that could have potentially impacted the sampled marshes in 2009. The inundation times also varied from year to year (Figure 17) especially for the PKS site which also could have impacted the plant metrics. During the 2010 growing season, N.C. experienced a substantial drought which could have impacted these systems as well. The best way to account for interannual variability is to increase the length of time that the marshes are sampled. The interannual differences that showed up in the NCNERR data, while significant were small in magnitude and did not impact the marsh plant percent cover (Figure 7), or the species richness (Table 4). The best lesson for the Restoration Center is to continue to fund long term (>3 year) projects to help average out the inherent interannual variability that exist within these systems. This is especially critical at more mature restoration projects as the rapid period of change is no longer occurring and the changes that are occurring due to marsh maturation are more likely to be of similar magnitudes as those that occur from interannual variability. In essence you need more data to separate out the changes due to interannual variability from actual trends associated with the restoration project progressing towards a more natural system.

c. elevation and inundation:

The marshes showed dramatically different levels of inundation both within marsh zones (low marsh versus high marsh) and among the various marsh sites. The DUML and NCMM sites were similar in slope and elevation change. Both tended to have permanently wet low marsh portions with permanently dry high marsh areas. The interior marsh zones at these sites tended to have a more tidal pattern. The PKS and MM sites tended to have a more tidal pattern for the entire marsh. These marshes elevation and slope are such that the entire marsh platform is submerged and exposed during the tidal exchanges. It should be noted that North Carolina often has seasonal differences in water levels. Care should be exercised in extrapolating the inundation patterns based on the two - three week aquatroll data periods up to an entire year. Ideally more data points are needed. The multiyear approach helps alleviate this concern slightly, but water level from all four seasons would have been advantageous. Despite these shortcomings, the inundation patterns were fairly consistent and seem to be driven primarily by the slope of the marsh and the tidal exchange. There was not much suggestion of a large hydrologic connection to upland groundwater sources.

The only location where the inundation deviated from what would be expected given marsh slope and tidal inundation occurred at Well 2 in the PKS marsh. At this site there did seem to be more water coverage than can be explained by tidal inundation. A reasonable explanation for this is that well 2 in the PKS marsh has upwelling occurring from subterranean groundwater. Salinity data from the aquatroll deployments partially support this hypothesis as during both the July 2009 and August 2010 deployment the salinity values at well 2 decrease rapidly during potions of the deployment while the other wells remained fairly stable (Figure 19). This could indicate the influence of groundwater discharge which would be expected to have lower salinity values. The influence of groundwater within the marsh is an interesting avenue that will be investigated during future sampling efforts.

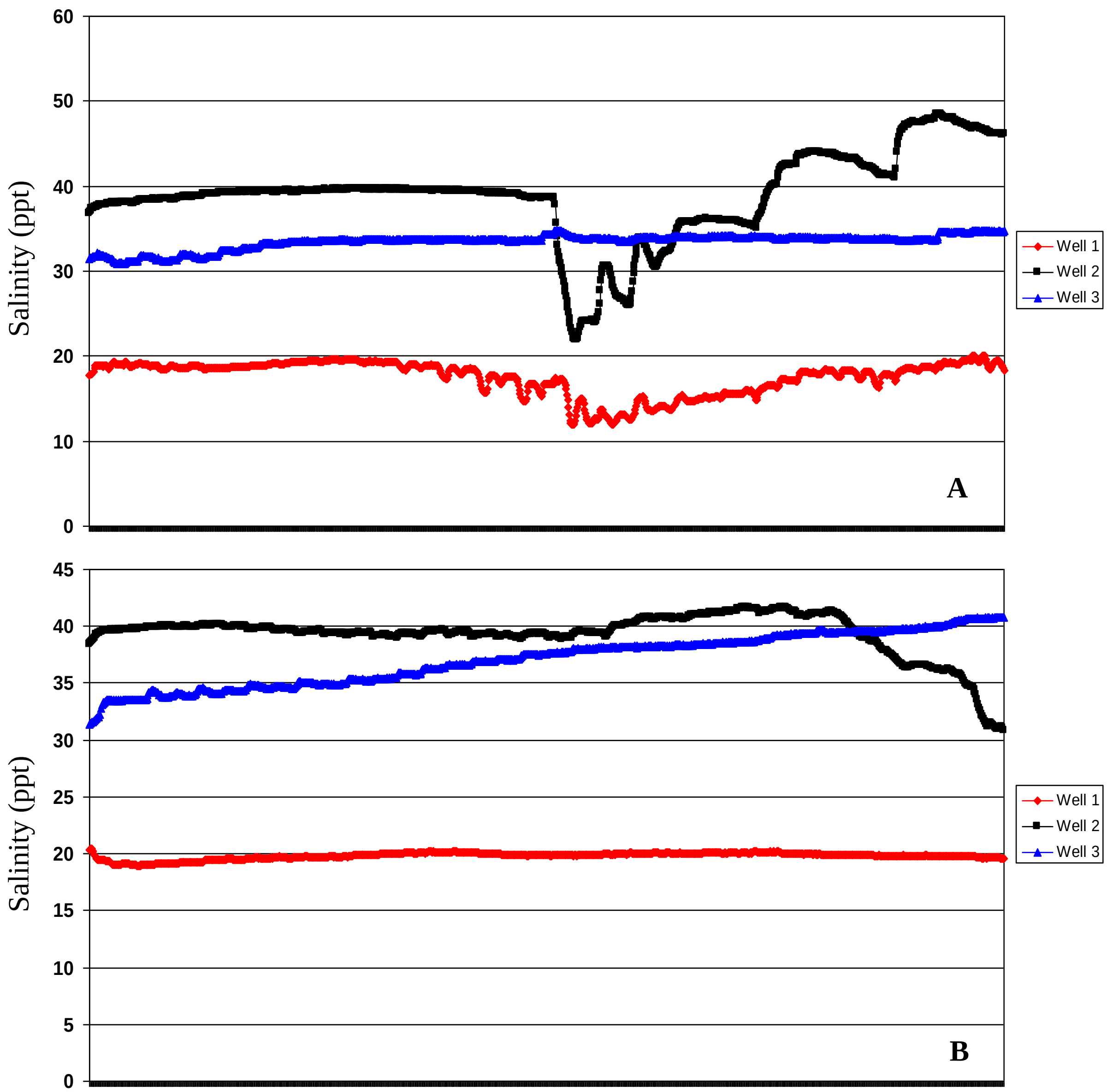

Figure 19: Salinity data from the aquatroll deployment starting in July 2009 (A) and August 2010 (B) at the PKS marsh. X axis is unlabeled, but represent time since deployment (See table 2 for deployment dates). Note dip in salinity values at well 2 during both deployments.

d. point-intercept versus visual percent cover method:

The point intercept method was more labor intensive than the visual observation method. The vegetation surveys in our marshes took three times longer using the point intercept method than if just the visual observation method was utilized. The point intercept method however was observed to be less subjective. Many times individual members of the field team had different opinions on which visual cover class should be recorded. This type of subjectivity was not present in the point intercept method, however, there were some differences in how individuals interpreted what was/was not touching the rod. The point intercept method also 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 (Figures 7 and 8). This may be due to the fact that the visual method typically is based on the top layer of the marsh (what can be seen while looking down from the top), while the point intercept method provides a more three dimensionally assessment as anything the rod touched from the top of the plants down to the marsh surface was recorded. The cover classes used for the visual method also may explain some of the difference between the two methods. The cover classes used are based on the North Carolina Vegetation Survey protocols which are described in Pete et al. (1998) (Table 7). As can be seen the cover classes are not linear and are very broad. They also include large breaking points where a marsh could be 25-50% or 50-75%. This is a large difference and could certainly lead to lower estimates if recorders consistently went with the lower category for a marsh that was right at the 50% level. Despite the difference in magnitude, the overall trends for the data in Figures 7 and 8 are essentially mirror images. We would have reached the same conclusions regarding our marsh comparisons if we had utilized the visual percent cover method instead of the point intercept method.

Table 7: Visual Cover Classes Utilized.

Cover Class	Cover Range
0	0
1	<3 stems
2	0.1-1
3	1-2%
4	2-5%
5	5-10%
6	10-25%
7	25-50%
8	50-75%
9	75-95%
10	95-100%
Classes based on North Carolina Vegetation Survey Protocols.	

e. RPI discussion:

The use of the RPI analyses for the North Carolina marshes is problematic. Because most project partners did not have pre-restoration data, the data from the first year of the project (2008) was used as the pre-restoration condition. For North Carolina this is especially challenging. The restoration projects in North Carolina were completed in 2001 and 2002. As such the data from the first year of this project was not collected until six years after the restoration projects were completed. A period of rapid change in a restored marsh often occurs within the first few years. After that, the marsh often plateaus and changes become smaller in magnitude and occur over a much longer time scale. Given this, the use of the 2008 data as the pre-restoration condition for the North Carolina marshes is a poor substitute for the actual pre-restoration condition. The measured differences in the RPI score for North Carolina are probably more related to inter-annual variability, than to changes along the progression from restored to natural. RPI is highly valuable, but should be applied with caution if pre-restoration data is not available. The North Carolina RPI assessment could be greatly improved if first year of data from the Currin et al. dataset was used as a proxy for the pre-restoration condition instead of the 2008 data from this project.

f. Variable rankings:

The data collected by NCNERR indicates that soil organic matter content and marsh above ground biomass (requires stem count and plant heights) were critical variables needed to assess the performance of restored marshes to natural reference marshes. Both these variables are easily obtainable and require no special equipment. They should be standard metrics required for future marsh assessment projects funded by the NOAA Restoration Center.

Water level and marsh elevation are also critical variables needed, but for different questions. These variables are needed to compare marshes regionally and to assess the longer term success of restored marshes relative to climate change impacts (sea level rise and storm impacts). These variables require specialized equipment and trained specialist to obtain. Thus, these variables should be highly encouraged for Restoration Center funded marsh assessment projects, but not necessarily required.

The point intercept method seemed to be the better method in terms of providing non-biased percent cover data. While the visual method in our case provided similar results, the subjectivity in which cover class to use and the large cover categories and associated breaking points are disadvantageous. This issue becomes especially problematic if a rotating volunteer corps is being used to collect data.

5) Conclusions:

The restored marshes in North Carolina sampled as part of this project were very mature and based on metrics measured as part of this project, two (NCMM and DUML) seem to be functioning very similarly to the project reference site. The PKS site seems to be less far along the progression from restored to natural compared to the DUML and NCMM sites. All the restored marshes sampled as part of this project were built for the purpose of protecting shorelines from erosion, and all utilized similar construction methods (marsh sill design). Given that, no comparison between excavation and hydrologic can be conducted using our data. Future Restoration Center funded projects should assess above ground marsh biomass and should be of sufficient length that annual anomalies do not confound findings.

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