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Natural Resource Stewardship and Science

Salt Marsh Vegetation Monitoring Report, Cape Cod National Seashore

A summary of monitoring data from 2003, 2008, and 2013

Natural Resource Report NPS/CACO/NRR —2015/920

ON THE COVER
Photograph of Nauset marsh (photo taken by Stephen Smith)

Salt Marsh Vegetation Monitoring Report, Cape Cod National Seashore

A summary of monitoring data from 2003, 2008, and 2013

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Abstract

Seven salt marshes within Cape Cod National Seashore were surveyed for their plant communities and a number of physicochemical variables in 2013. This effort was part of CACO's long term Inventory and Monitoring program and represented the third time within 10 years that these marshes had been monitored in order to document temporal change. The marshes differed substantially with respect to soil organic matter content and particle size fractionation, which were the most important environmental variables influencing plant heights and biomass. For salinity and soil hardness there were few large differences among marshes. Survey to survey variability in all environmental variables was evident, but there were no major changes in the above variables that suggested a significant change in conditions. With respect to plant communities, four and two marshes exhibited statistically significant community-level vegetation changes between 2003 and 2013 and 2008 and 2013, respectively. Differences in *S. alterniflora* (4 marshes) and *S. patens* (one marsh) cover contributed most to the community dissimilarities between years. In this regard, *S. alterniflora* cover decreased in five marshes between 2003 and 2013 and increased in one between 2008 and 2013. *S. patens* declined in two marshes between 2003 and 2013 and in one marsh between 2008 and 2013. The apparent decline in *S. alterniflora* may be related to the different methodologies used to estimate cover. Alternatively, it may be the result of increasing mean high water elevations since 2003 (change of +12 cm). The cover of other, less common species both increased and decreased but collectively there were no consistent trends.

For future monitoring of these systems, accurate estimates of each plot elevation should be acquired using Real Time Kinematic GPS (RTK-GPS), With this data, the flooding frequency (and temporal changes in) of each plot can be tracked over time and correlated with vegetation variables.

Introduction

Salt marsh ecosystems are an important natural resource within Cape Cod National Seashore (CACO). In addition to their aesthetic value, their role in supporting a wide variety of flora and fauna has been well documented (Nixon and Oviatt 1973, Roman et al. 2001). Salt marshes also provide recreational activities, reduce coastal erosion, attenuate nutrient inputs to the marine environment, and protect shorelines by dissipating energy from storm surges (Bertness 1999).

At CACO, salt marshes comprise nearly 10% of the total landcover. Some salt marshes within CACO have been directly impacted by hydrologic restrictions to tidal flow (e.g., Hatches Harbor, Provincetown; East Harbor, Truro; Herring River, Wellfleet). These tidal restrictions cause severe physical, chemical and biological degradation of the wetland (Roman et al. 1984, Portnoy and Giblin 1997, Roman and Burdick 2012). However, most of CACOs marshes are hydrologically unimpaired. Hydrologically unimpaired (hereafter – unrestricted) salt marshes – though not burdened with restrictions to tidal flow may be influenced by a variety of other factors including accelerated sea level rise, nutrient inputs, herbivory, and climate change. The salt marsh vegetation of three restricted and seven unrestricted systems is being monitored at CACO in order to better understand how these ecosystems function and change over time and how they may be managed in the future. This report summarizes data from the unrestricted marshes that was collected in 2013 as part of this monitoring effort and compares it with previous sampling done in 2003 and 2008. It also includes a brief section on recommendations for future sampling. Previous reports on CACO's unrestricted salt marshes can be found on the North Atlantic Coastal Laboratory (biolab) server at:

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The reports are also hosted online on CACO's Cape Cod Ecosystem Monitoring website at:

http://www.nps.gov/caco/naturescience/cape-cod-ecosystem-monitoring-program-reports-and-publications.htm#CP_JUMP_190678

Methods

Study areas

In 2003, a network of 183 1-m^2 plots (along randomly placed transects oriented perpendicular to the long axis of the marsh) in five unrestricted CACO salt marshes was established following Roman et al (2001) and their vegetation surveyed, along with a number of physico-chemical variables (Smith and Portnoy 2004). The plots spanned the entirety of the marsh from the seaward edge to near the upland edge. Plots were placed at uniform distance from each other (e.g., every 20 meters) but this distance varied between 20 and 100 m depending on the size of the marsh. These marshes were Hatches Harbor (HH; Provincetown), West End marsh (WE; Provincetown), Middle Meadow (MM; Wellfleet), Nauset marsh (island portion = NI; mainland portion = NM; Eastham), and Pleasant Bay marsh (PB; Orleans and Chatham). In 2004, the Gut (GU; Wellfleet) was added to the monitoring network. In 2008 the network was expanded to include Jeremy marsh (JM; Wellfleet) and more transects/plots were added to the existing marsh sites to bring the total to 340 monitoring plots in seven marshes (Smith et al. 2009) (Figure 1). The plot network currently has coverage in every major salt marsh system within CACO. In 2013, all marsh plots within the network were re-visited to assess vegetation abundance and selected environmental variables.

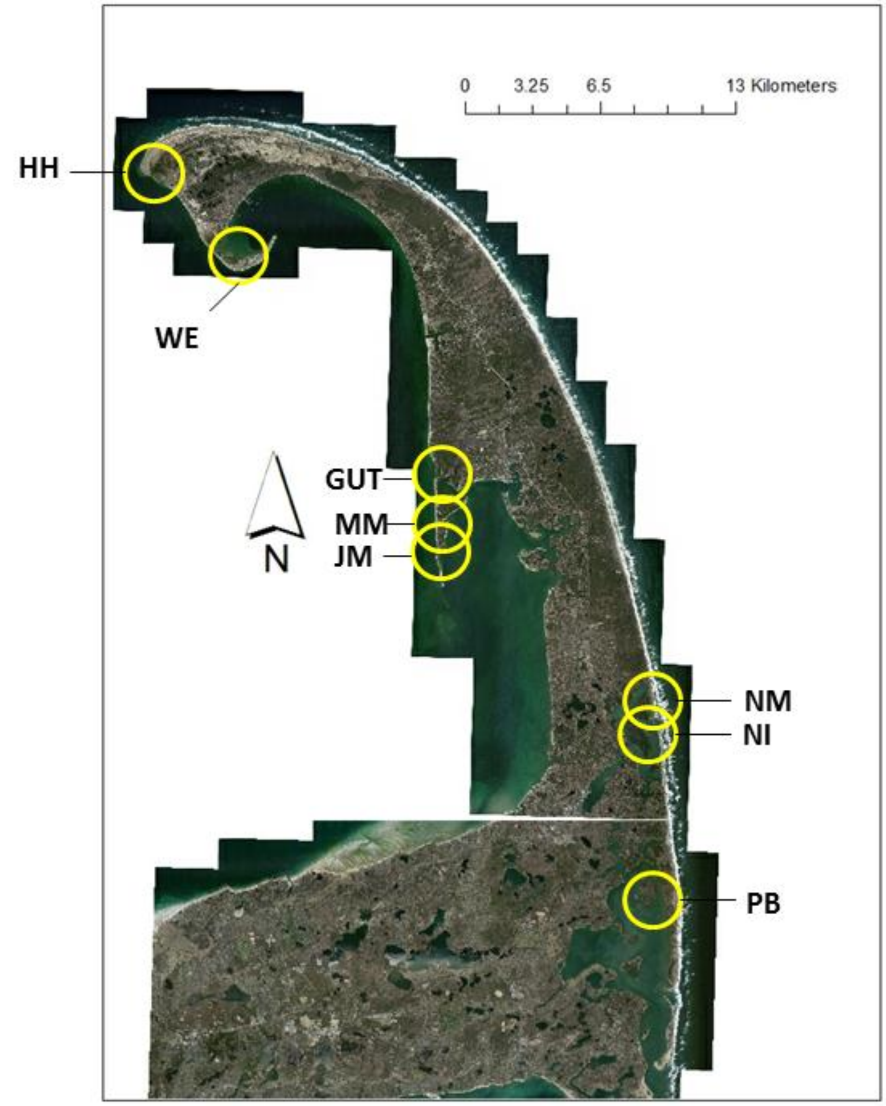

Figure 1. Map of all unrestricted marsh monitoring sites (HH-UR=Hatches harbor (unrestricted portion), WE=West End, GUT=The Gut, MM=Middle meadow, JM=Jeremy marsh, NI = Nauset marsh (island), NM = Nauset marsh (mainland), PB=Pleasant Bay marsh).

Vegetation

Species composition

In 2008 and 2013 vegetation cover by species was visually assessed based on a modified Braun-Blanquet cover scale (0=0%, 1=<1%, 2=1-5%, 3=6-10%, 4=11-25%, 5=26-50%, 6=51-75%, 7=76-100%). This differs from 2003, when cover was assessed by point counts (Smith and Portnoy 2004). For data analysis, percent cover for the 2003 data were converted to corresponding cover class values. The advantages of the visual method over point counts in conducting large vegetation monitoring programs are numerous and justification for its use can be found in Appendix I of Smith et al. (2009). The visual-estimate method captured many more species and has been found to be more consistent among observers (Symstad 2008). For 2003 vs. 2013 comparisons, only the plots in the original network (2003) are used. For 2008 vs. 2013 comparisons, all additional plots are included (applies to PB, WE, GU, and HH where additional plots were installed in 2008).

Spartina alterniflora heights

In plots where *Spartina alterniflora* (smooth cordgrass) was present, the heights of the five tallest plants were measured to the nearest cm. In 2013, the data was collected twice – once during July-August and once during late August-September (unlike in previous years when it was only collected in July-August). This repeated sampling was conducted to evaluate how much growth occurs between these times and to assess whether error due to the different sampling dates among individual marshes can be reduced.

As part of a separate project, biomass samples of *S. alterniflora* were collected once during July by coring adjacent to 122 plots (total) in the 7 marshes and this data is also presented in this report. This was done to examine the amount and relative proportions of above- and belowground biomass within each separate marsh. To collect the sample, an individual or cluster of plants that was representative of the vegetation within the plot was selected from just outside of the plot (so as not to disturb the permanent plot). The aboveground portion was then cut off at the sediment surface, and a 3-inch polycarbonate pipe corer was used to extract a 30 cm core of the below ground portion. The above- and belowground samples were individually bagged, labeled, and brought back to the lab for processing. There, the samples were rinsed of all soil, sorted into aboveground and belowground fractions, dried to a constant weight at 60°C and weighed.

Environmental variables

Porewater salinity

Porewater salinity was collected in 2003/2004, 2008, and 2013. Soil organic matter and particle size data was collected in 2003 and 2013. Soil hardness data was collected in 2013 only. Porewater was withdrawn from the sediment using a 2-mm inner-diameter stainless steel probe with a slotted point. The probe was inserted ~10 cm into the sediment, within the active root zone, and water was drawn into a syringe fitted onto the probe's upper end. The sample contained in the syringe was then discharged onto a refractometer and the salinity read to the nearest parts per thousand (ppt).

Soil organic matter and particle size analysis (PSA)

Soil organic matter content influences the production of H2S, which at high concentrations is deleterious to Spartina growth (Howarth and Teal 1979). Particle size reportedly influences the growth of *S. alterniflora* (Osgood and Zieman 1993). Samples of sediment from an area adjacent to each plot were obtained by coring to a 20-cm depth with a 5-cm diameter butyrate tube. Before coring, a serrated knife was used to cut around the outside of the tube to prevent compaction. The cores were placed in zippered bags, transported back to the laboratory, and dried in a convection oven at 105°C for 48 hours. For organic matter determination, a ~10 ml subsample of the dried sediment was placed in a pre-weighed ceramic dish and weighed. The dish was then placed in the muffle furnace set to 500°C for 5 hrs. After letting the dish and sample cool down for at least 1 hr., the dish was weighed again to determine the amount of weight loss after burning (which equals the amount of organic matter).

Particle size fractions were determined by sieving dried samples first by hand through a 2 mm brass sieve. The material that passed through this screen was then sieved through 1 mm, 0.5 mm, 0.25 mm, 0.1 mm, 0.05 mm, and < 0.05 mm stacked sieves placed on a shaker for 5 min. Each fraction was then weighed and these weights were converted to % of the total sample.

Soil hardness

A type of soil penetrometer was constructed to assess the relative hardness of the substrate among plots and marshes. Soil hardness has been shown to influence *S. alterniflora* productivity (Bertness 1988). The device consisted of a hollow PVC tube (95 cm) through which a longer metal rod (135 cm) was dropped into the sediment from a height of 85 cm. The length of rod protruding above the top of the PVC tube after the drop was then measured. This was repeated three times in three random locations within each plot and the average value calculated. The longer the section of rod protruding above the top of the PVC tube the harder the substrate (i.e., penetration is lower), and vice versa.

Data analysis

All non-parametric analyses of species cover data were done using Primer ver. 6 software (Plymouth Marine Laboratory, UK). Analysis of Similarities (ANOSIM), using Bray-Curtis similarity indices, provided a statistical test of species composition changes between survey years. Similarities Percentages (SIMPER) revealed which species contributed most to dissimilarities among years. Changes in the cover of individual species (e.g., time1 vs. time2) were assessed using Wilcoxon signed-rank tests. Cluster analysis was used to indicate resemblances among marshes with respect to individual environmental variables. Principle components analysis was used to illustrate how multiple variables contributed to disparities in the overall character of marshes. To determine relationships between plant height/biomass components and environmental variables multivariate forward stepwise regression was used. An $\alpha=0.05$ was used to assess the statistical significance of all analyses. It should be mentioned here that there are a number of drawbacks with this statistical technique, however. For example, collinearity and inflated R^2-values are two potential outcomes. In addition, the use of an automated routine in selecting the best model may produce results that are somewhat artificial. Another potential problem is that stepwise regression tends to capitalize on chance features of the data, with the result being that the model may not be applicable to new datasets. That said, we selected the initial monitoring variables based on the best professional judgment of CACO staff as well as ecological theory.

Results

Environmental variables

Soil organic matter

Soil organic matter (OM) differed substantially among marshes, ranging between mean values of 2.0% (HH) and 16.5% (NI) (ANOVA F=7.44, p<0.001) (Figure 2). In general, mean OM was low in HH, JM, MM, and NM and high in NI and PB. The GUT and WE had intermediate levels of OM (both were 9.6%). The absolute amounts of OM and patterns among the different marshes were very similar in 2003 and 2013 (no OM data were collected in 2008). Only MM exhibited a relatively large difference between years, with much lower values in 2013 compared with 2003.

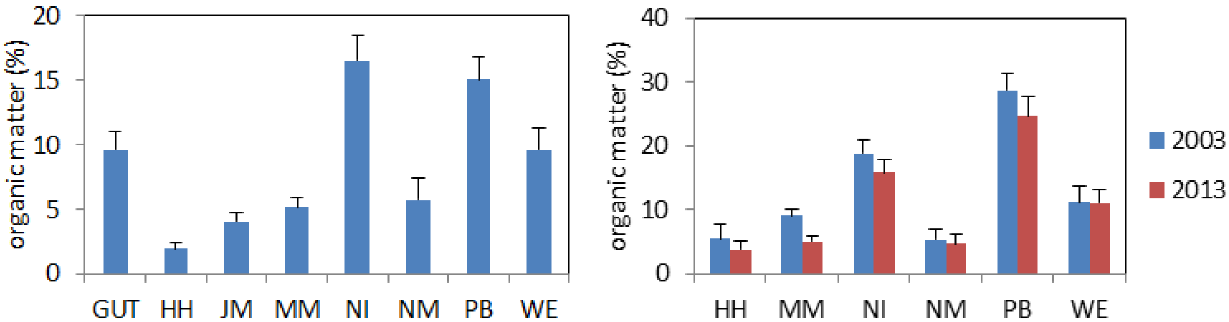

Figure 2. Organic matter content of soils collected in 2013 (left) and in 2003 vs. 2013 (right) (soil samples were not collected in GU in 2004 for determination of soil organic matter content; JM was not part of the monitoring network in 2003; error bars indicate magnitude of the standard errors of the means).

Soil hardness

Soil hardness, as indicated by length of rod protruding from the drop cylinder varied little among marshes with the exception of NM, which had higher soil hardness (Figure 3). Values ranged between 24.4 cm (JM) and 28.7 cm (NM). The value from JM was not statistically different from any marsh except NM (no hardness data were collected in 2003 or 2008). It is not known why NM has such hard soils compared to the other marshes, but it may be that these soils were more compacted for some reason. It is also noteworthy that NM soils had the highest percentages of 0.25-0.5 mm particles (intermediate sand), which also may have contributed to its hardness.

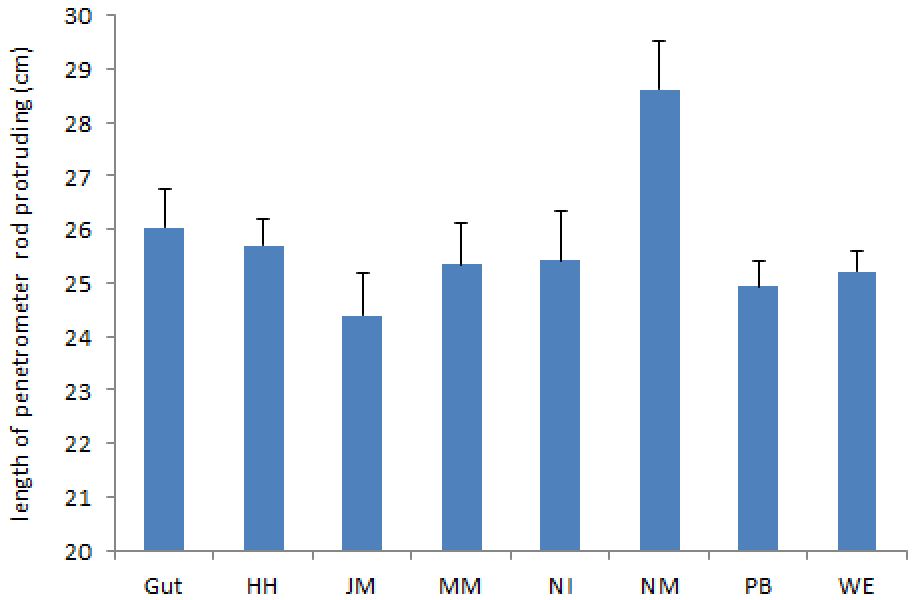

Figure 3. Soil hardness in 2013 as measured by rod penetrometer (higher values indicate harder soils; error bars indicate magnitude of the standard errors of the means).

Particle Size Analysis (PSA)

Particle sizes varied substantially among marshes with distinct similarities among certain groups (Figure 4). The 0.25-0.5 mm and 0.5-1 mm size fractions (corresponding to medium-grained sand) constituted the largest proportion of particles in all marshes except HH, WE, and NI. In HH and WE, the 1-2 mm and 0.5-1 mm fractions dominated (coarse sand), while particle size classes were more evenly distributed in NI. The largest fractions of 0.25-5 mm sand were found in MM. The smallest particle sizes (< 0.1 mm) constituted the least amount of sediment in all marshes. The largest fractions of < 0.05 mm silt were found in NI.

Cluster analysis illustrated similarities in PSA fractionation among marshes (Figure 5). HH and WE were closely related as were GUT, JM, and MM, which is perhaps logical given the geographic proximity of these sites to each other. NI, NM, and PB also clustered together and all are in the same general area of CACO along the Atlantic coast.

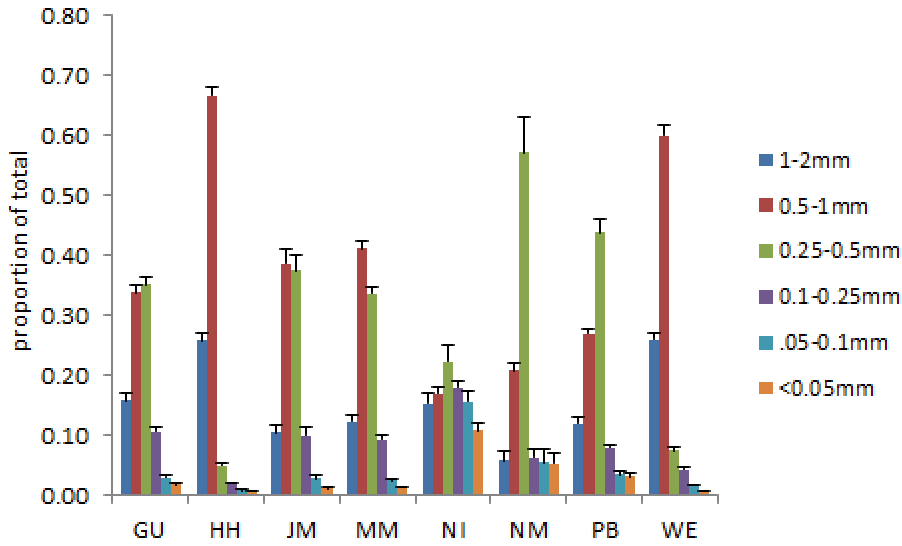

Figure 4. Proportions of the various soil particle size fractions by marsh (error bars = standard error of the mean; error bars indicate magnitude of the standard errors of the means).

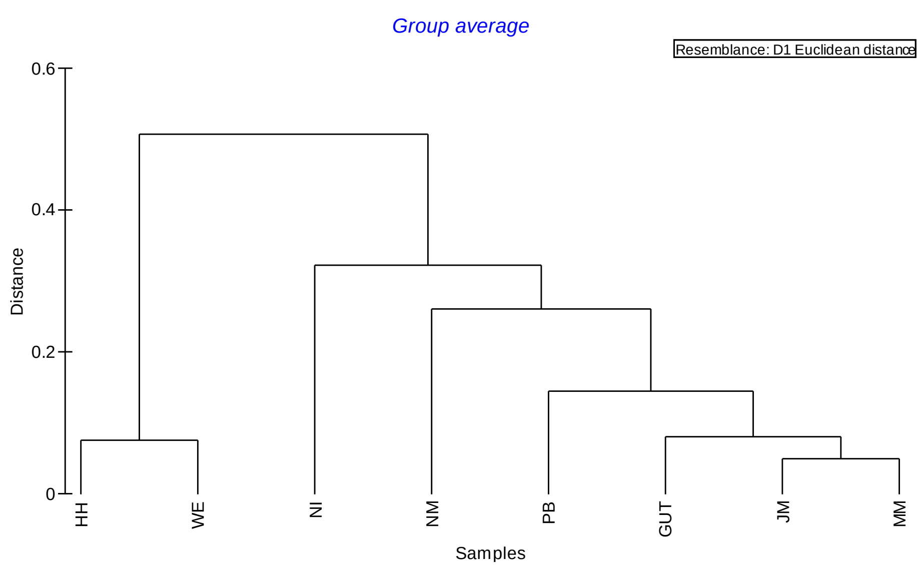

Figure 5. Cluster analysis of 2013 particle size fractionation.

When PSA fractions were lumped into the categories of 0.25-2-mm (coarse) and <0.05-0.25-mm (fine), there were clear differences among marshes (Figure 6). Of particular note were HH and WE, that had very low percentages of fine sediments, whereas NI had a high percentage of fines.

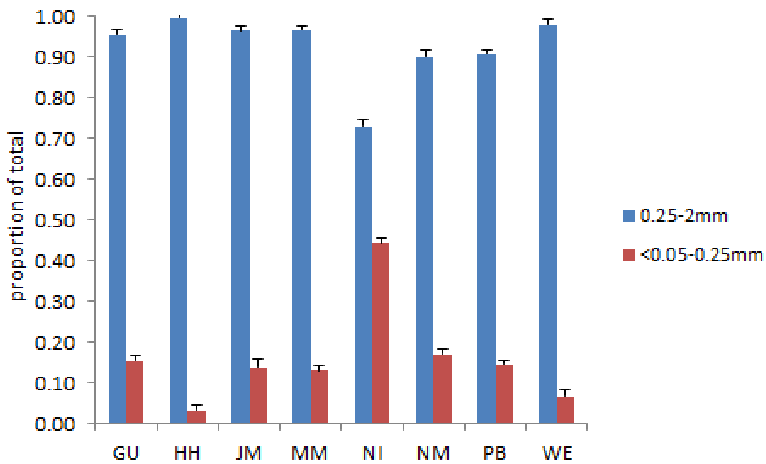

Figure 6. Proportions of coarse (0.25-2mm) vs. fine (<0.05-0.25 mm) particle size fractions by marsh (error bars = standard error of the mean; error bars indicate magnitude of the standard errors of the means).

In terms of PSA changes through time, sediment size fractions differed only slightly within individual marshes between 2003 and 2013 (no PSA data was collected in 2008) and the relative proportions remained very similar. Among all marshes, the relative proportions of the different PSA fractions differed to a minor extent between 2003 and 2013 (Figure 7).

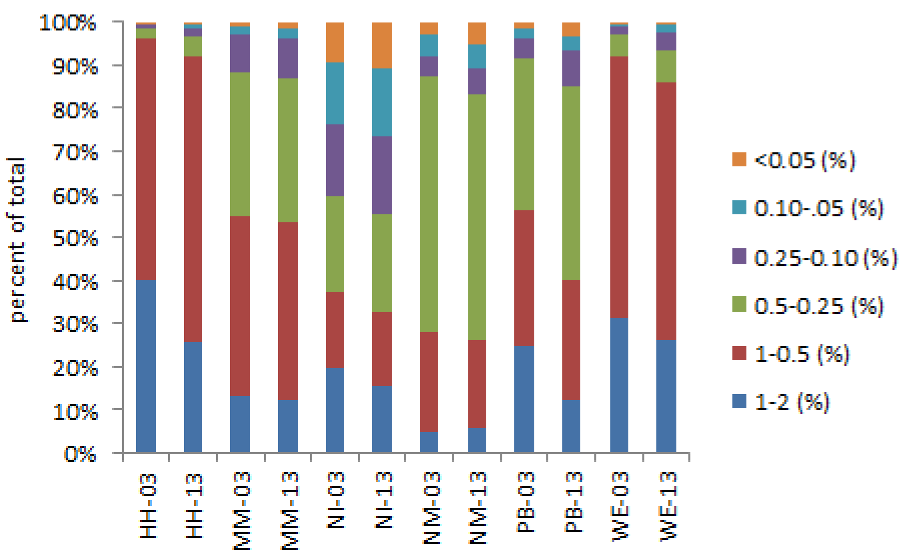

Figure 7. Relative amounts of different particle sizes by marsh and year (soil samples were not collected in GU in 2004 for determination of PSA fractions; JM was not part of the monitoring network in 2003).

When put into the broader categories of coarse (0.25-2 mm) vs. fine (<0.05-0.25 mm) sediments described above, the patterns are much the same in that NI has much more fines than other marshes (Figure 8). This pattern was evident in both 2003 and 2013.

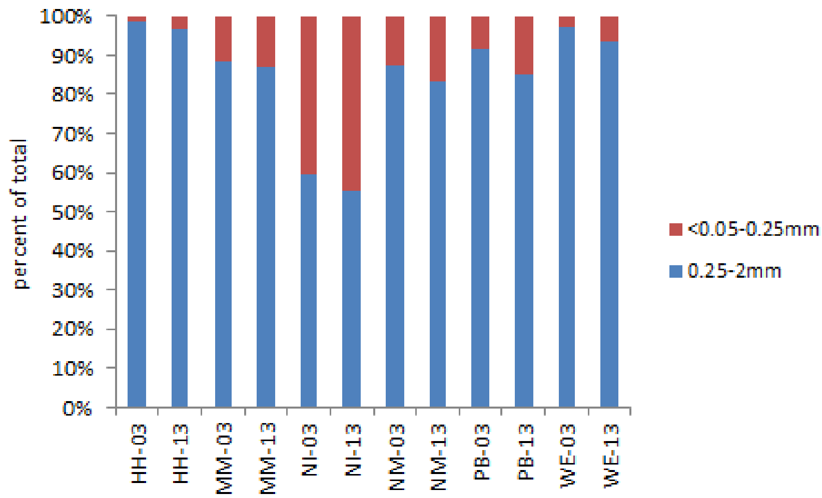

Figure 8. Relative amounts of coarse (0.25-2 mm) vs. fine (<0.05-0.25 mm) particle sizes by marsh and year (soil samples were not collected in GU in 2004 for determination of PSA fractions; JM was not part of the monitoring network in 2003).

When the values for 2003 and 2013 are averaged and cluster analysis performed, the similarities and differences among marshes become apparent (Figure 9). HH and WE are very similar to each other, as are MM and PB. NI and NM also group together although the linkage is not direct.

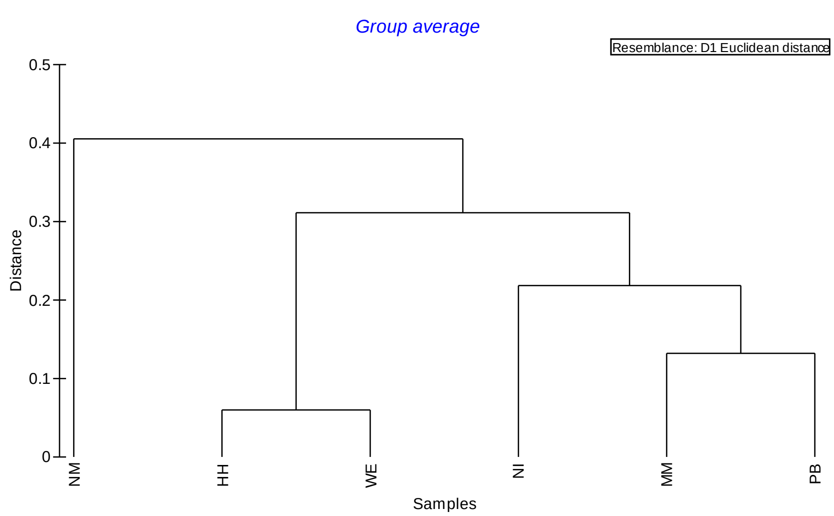

Figure 9. Cluster analysis of PSA fractionation (mean of 2003 and 2013) (soil samples were not collected in GU in 2004 for determination of PSA fractions; JM was not part of the monitoring network in 2003).

Porewater salinity
Porewater salinities exhibited a relatively narrow range, although some subtle patterns were evident (Figure 10). In general, porewater salinities were lower in GU and PB than they were in other marshes while NI and NM were generally higher. Porewater salinity patterns among marshes were quite similar in each year of survey, but there were some year to year variations within individual marshes, especially at GU and NM. At GU, salinity was much lower in 2003 than in 2008 or 2013. At NM, salinity in 2003 was much higher than in 2008 or 2013. All other marshes showed only minor variation among years.

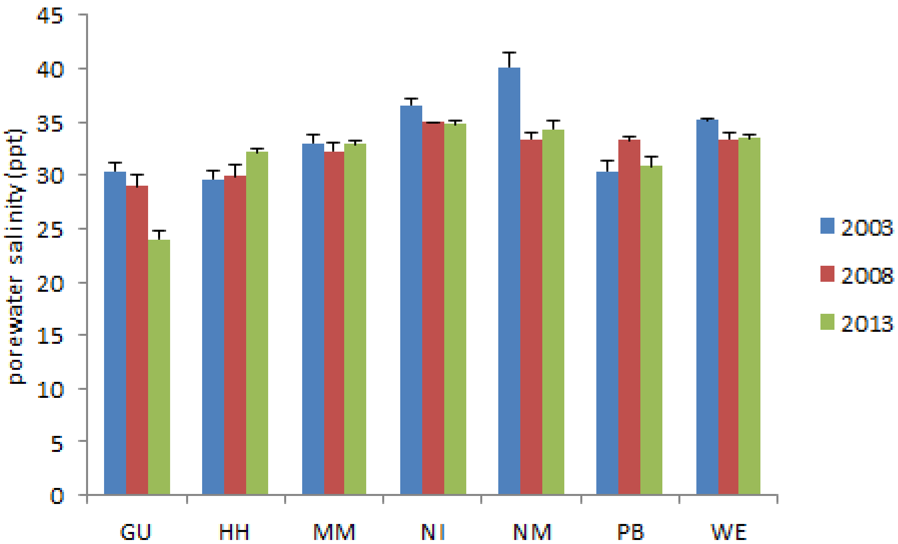

Figure 10. Porewater salinity by marsh and year (error bars are standard errors of the means; GU was sampled in 2004; error bars indicate magnitude of the standard errors of the means).

When only the mean salinity values for all three years were plotted, differences among marshes emerge more clearly (ANOVA $F=37.8$, $p<0.001$) (Figure 11). GU had the lowest salinity value of 27.8 ppt, while NM had the highest with 35.9 ppt for a total range of 8.1 ppt. All other marshes were intermediate between these values.

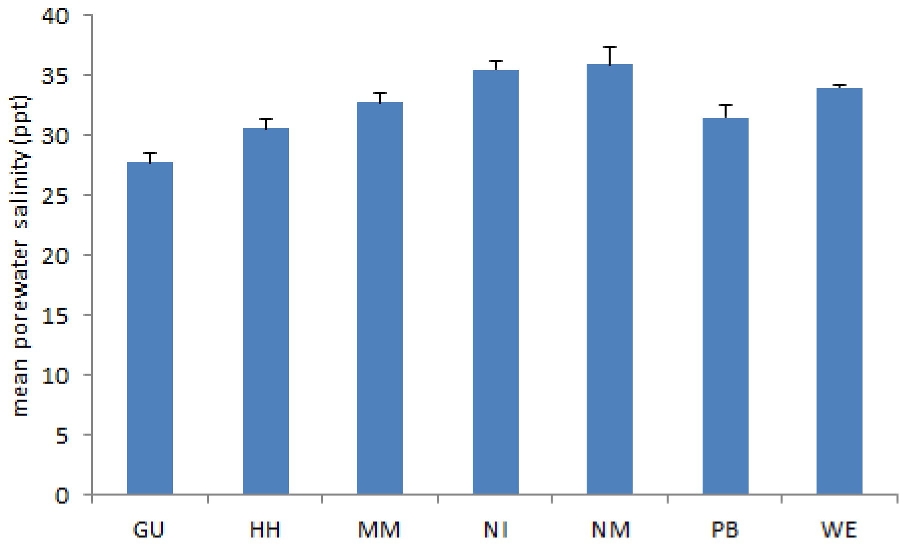

Figure 11. Mean porewater salinity (all years) in 2013 by marsh.

Principle components analysis of all environmental variables (normalized) shows that in 2013 PSA fractions accounted for most of the variability among marshes (Figure 12). This is followed by soil organic matter, salinity, and hardness – all of which were roughly similar in their contribution to variability. The first two axes accounted for ~90% of the variation. The PC1-axis explains 81% of the variability while the PC2-axis explains only 8.7% (error bars indicate magnitude of the standard errors of the means).

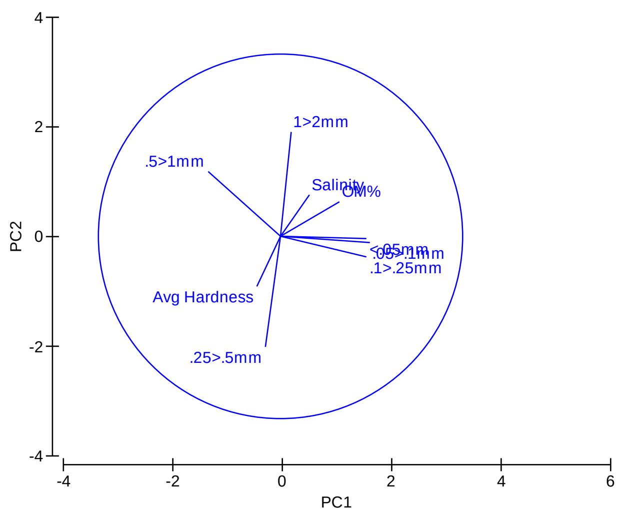

Figure 12. PCA of environmental variables in 2013. The length of the lines indicates the relative contributions of each parameter.

Vegetation

In some marshes (WE, PB, HH, and GU) additional plots were established in 2008. Thus, the comparison of plant communities between 2008 and 2013 included more plots than between 2003 and 2013 for these marshes. In addition, JM was not sampled in 2003 as this marsh was added to the monitoring network in 2008.

S. alterniflora heights

Table 1 indicates when each marsh was sampled by year. Plant heights recorded in June-August (in plots common to all three years of sampling) (in plots common to all three survey years) were highly variable among marshes and within marshes from year to year (Figure 13). Heights ranged in total between 52 cm (NM, 2003) and 134 cm (WE, 2003). In 2003, WE plants were tallest and NM were the shortest. In 2008, WE plants were tallest and JM were the shortest. In 2013, GU plants were tallest and NI were the shortest. Furthermore, in some marshes plant heights increased between 2003 and 2013, whereas in others they decreased. The only discernible, albeit subtle, trend was that at NI and NM plants were generally short compared with the other marshes in all three years. That said, differences in plant height are to be expected from year to year even if measured on the same date due to differences in growing season conditions (e.g., precipitation, temperature, etc.).

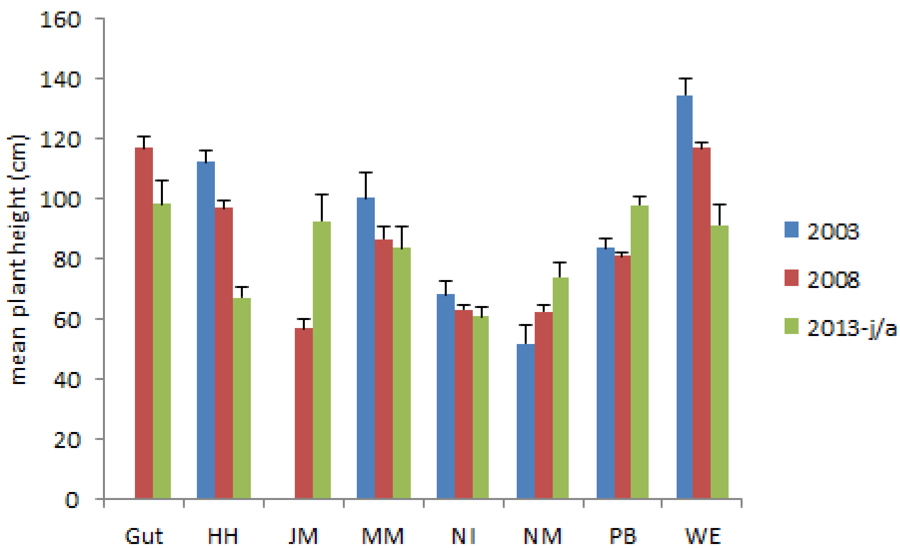

Figure 13. Mean plant heights by marsh measured in June-July (j/a indicates June-August and differentiates these measurements from those taken in Aug-Sept; plants heights at GU were not sampled until 2008; error bars indicate magnitude of the standard errors of the means).

Table 1. Sampling dates for *S. alterniflora* heights by year (2013a=early sampling, 2013b=late sampling).

	2003	2008	2013a	2013b
Gut	not sampled	7/1/08	7/11/13	9/3/13
HH	7/26/03, 8/11/03	6/30/08	6/28/13	8/23/13
JM	not sampled	7/2/08	7/29/13	9/5/13
MM	8/6/03, 8/19/03	7/2/08	7/12/13	9/5/13
NI	8/5/03, 8/12/03	7/8/08	7/16/13	8/30/13
NM	7/31/03	7/9/08	7/17/13	8/29/13
PB	8/4/03	7/8/08, 7/17/08	7/23/13, 8/9/13	9/26/13
WE	8/7/03, 8/14/03, 8/18/03	6/25/08, 6/26/08	7/9/13	8/26/13

When the mean values for all three surveys are plotted, clearer differences among marshes emerge ($F=18.71$, $p<0.001$) (Figure 14). Values ranged between 114 cm (WE) and 63 cm (NM). In general, plants were tallest in GU and WE, shortest in NM and NI, and intermediate in HH, JM, MM, and PB.

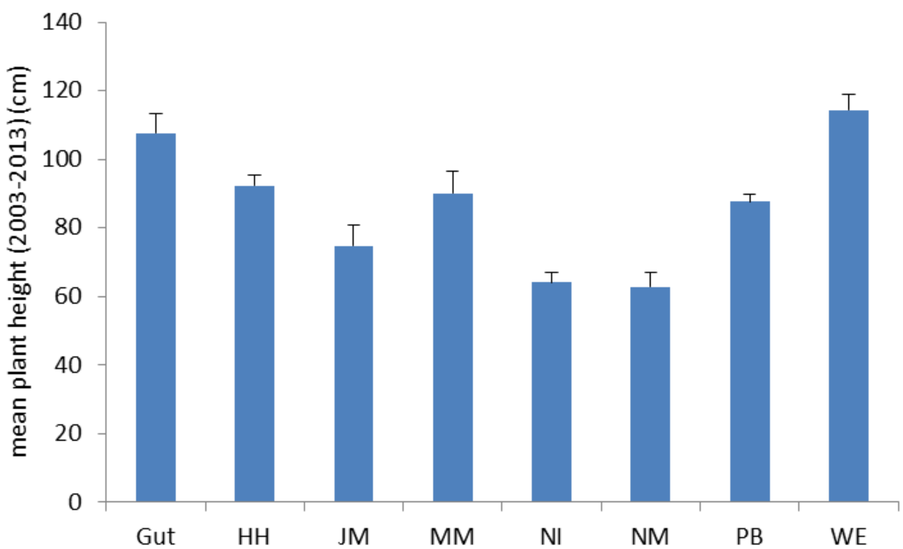

Figure 14. Mean plant height (all years) by marsh (error bars indicate magnitude of the standard errors of the means).

Mean plant heights also differed based on time of measurement in 2013 (ANOVA, $F=2.47$, $p=0.02$) (Figure 15). Plants measured in July-August were often shorter by a compared to those measured in late August-September. The exceptions were PB and JM, which were very similar at both times.

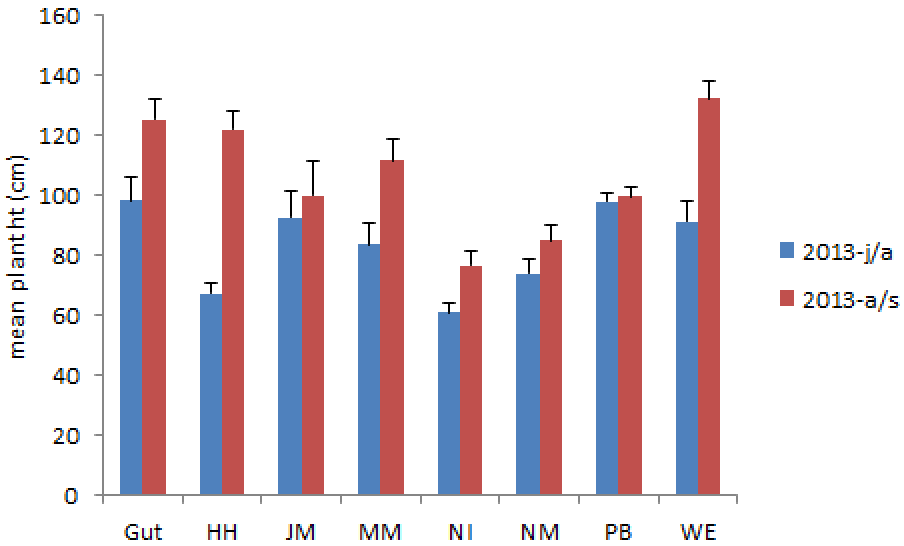

Figure 15. Mean plant heights by marsh measured in June-August (j/a) vs. late August-September (a/s) (2013) (error bars indicate magnitude of the standard errors of the means).

Plant height in 2013 (data from late August-September) was regressed (forward stepwise) against percent organic matter OM, soil hardness, PSA fractions, and porewater salinity. Plant height was negatively correlated with percent organic matter and salinity but positively correlated with the 0.5-1-mm and 1-2-mm PSA fractions in a weak, but significant, relationship (R^2=0.24, p<0.001) (Figure 16).

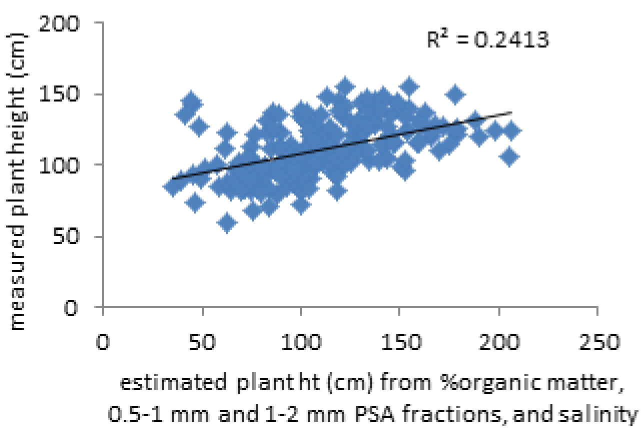

Figure 16. Relationship between measured plant height vs. height estimated from % organic matter, 0.5-1 mm and 1-2 mm PSA fractions, and salinity.

Biomass

Aboveground biomass (AG) ranged between 6.6 g core^{-1} (GU) and 10.6 g core^{-1} (WE) but did not vary significantly among marshes (ANOVA F=1.37, p=0.22) (Figure 17a). Like height, AG biomass values were very high at WE and low at NI and NM. However, AG exhibited a slightly different pattern than plant heights in that values for GU were low compared to other marshes. Belowground biomass (BG) exhibited a different pattern, with the highest values occurring at JM (5.9 g core^{-1} the lowest at HH (2.2 g core^{-1}) (ANOVA F=2.54, p=0.02) (Figure 17a). Total biomass (Total) was highest at JM, PB, and WE (≥13.8 g core^{-1}) and slightly lower at GU, HH, MM, NI, and NM (≤11.7 g core^{-1}) (ANOVA F=1.17, p=0.32) (Figure 17a). AG:BG biomass was much higher at HH and WE (≥3.4) than any of the other marshes (ANOVA F=4.75, p<0.001) (Figure 17b). Comparatively low values occurred at JM, NI, and NM (≤1.7). Grouping the particle size fractions into coarse (0.25-2-mm) vs. fine (<0.05-0.25-mm) sediments, produced no improvement in the regression R^2 values for any biomass variable.

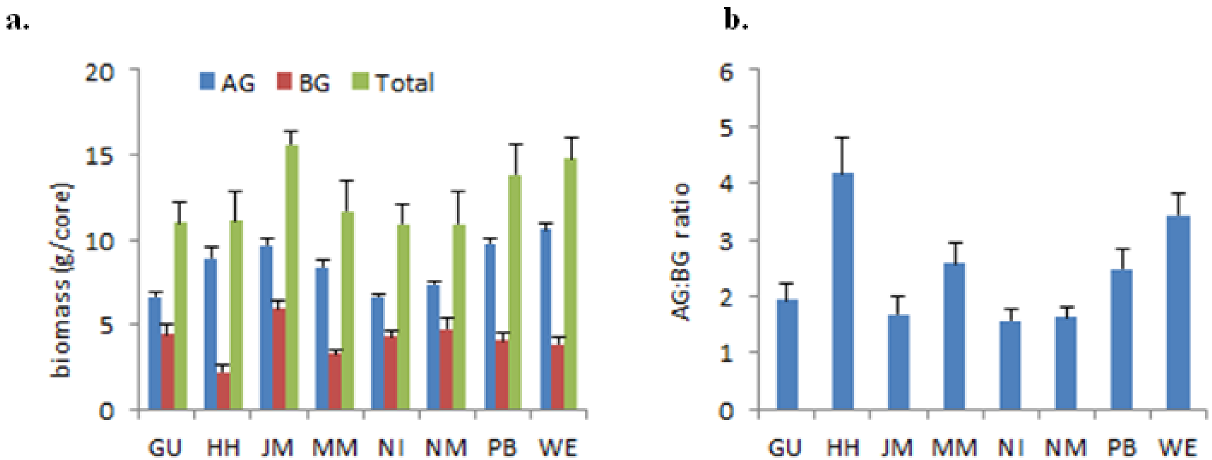

Figure 17. Aboveground, belowground, and total biomass (a) and aboveground to belowground ratios (b) by marsh in 2013 (error bars indicate magnitude of the standard errors of the means).

Aboveground biomass (AG), belowground biomass (BG), total biomass, and AG:BG biomass were regressed (forward stepwise) against percent organic matter, soil hardness, all PSA fractions, and porewater salinity. A number of significant but weak relationships were evident. AG was negatively correlated with organic matter and positively with the 1-2-mm PSA fraction (R^2=0.09, p=0.02). BG was negatively correlated with the 0.5-1-mm PSA fraction (R^2=0.11, p=0.003). Total biomass did not have a was not significantly correlated while AG:BG was positively correlated with the 0.5-1 mm PSA fraction) (Figure 18).

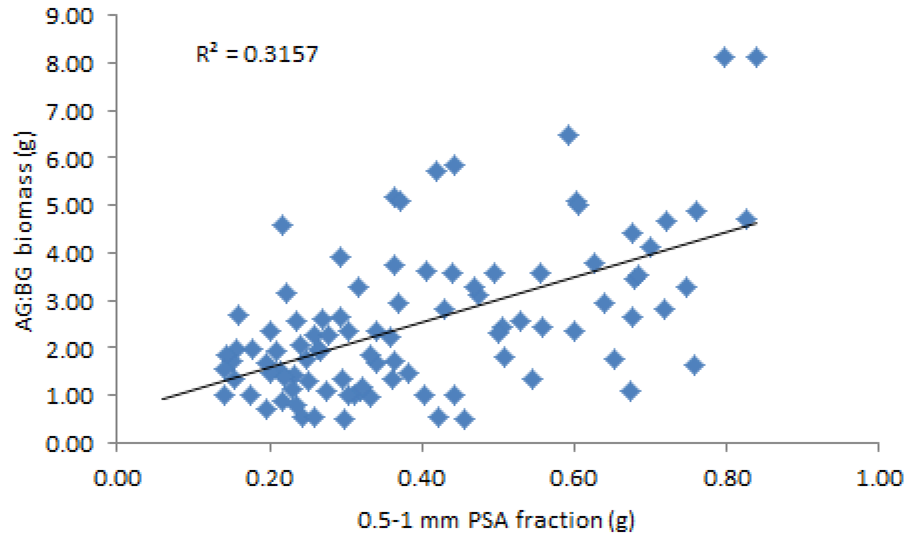

Figure 18. Regression of AG:BG biomass vs. 0.5-1 mm PSA fraction.

When simple linear regression analysis was performed on the mean site values for biomass fractions vs. environmental variables, some very strong relationships were observed. For example, AG:BG ratios were positively correlated with the amount of larger (>0.5-mm) (R^2=0.88) particle size fractions and were negatively correlated with smaller (<0.5 mm) (R_2=0.89) particle size fractions (Figure 19).

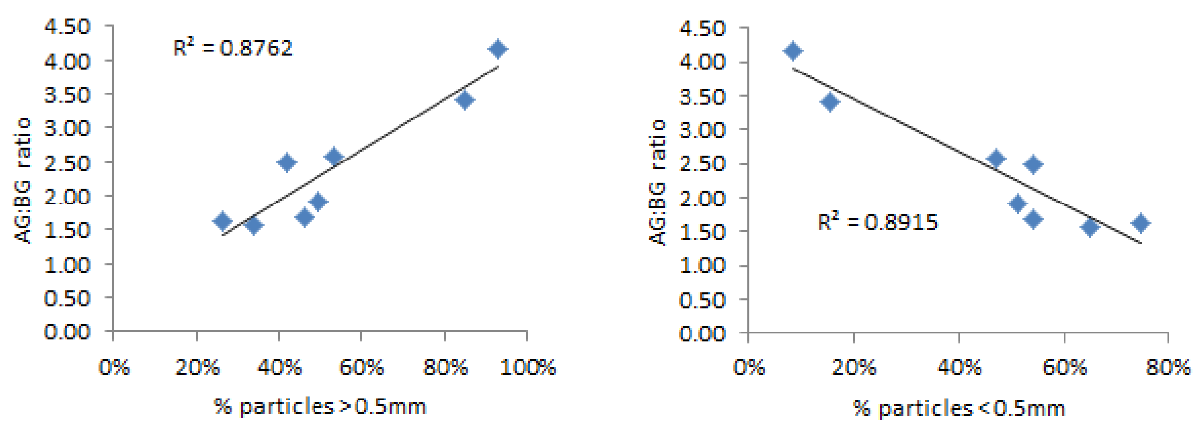

Figure 19. Simple linear regression of mean AG:BG ratios for all marshes vs. large and small particle size percentages.

Plant Species richness

Plant species richness ranged from six 6 (HH, NM) to ten (PB) among all sites and years for plots common to all three years of the survey. Over time there were relatively minor changes in species richness (by one or two taxa)and there were no consistent positive or negative trends in species richness (Figure 20a). In 2013, which included the additional plots that were established in 2008, the range was six (NM) to 12 (PB) species (Figure 20b). WE also had an elevated number of species at 10.

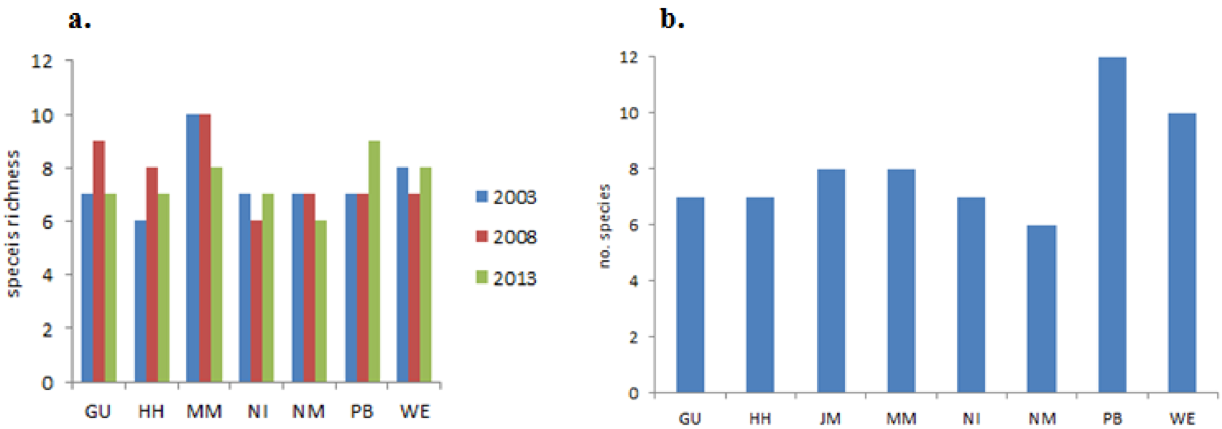

Figure 20. Species richness by year and marsh (a) (only plots common to all three years; GU was sampled in 2004) and in 2013 (b) (includes additional plots established in 2008).

Plant communities of individual marshes

West End marsh

ANOSIM indicated a significant change in plant community composition between 2003 and 2013 in WE (ANOSIM Global R=0.105, p=0.001). SIMPER suggested that dissimilarities were mainly due to *S. alterniflora* and *S. patens*. Between 2003 and 2013, changes in the cover of *S. maritima* (decrease), *S. alterniflora* (decrease), and *Suaeda* spp. (decrease) were significant based on the Wilcoxon sign-rank test (Table 2). Species frequencies changed very little with the exception of *Suaeda* spp. and *Salicornia maritima*, both of which decreased substantially. The rest exhibited very little change (≤0.05). The total number of species for both years was 8 although *D. spicata* appeared while *Plantago maritima* was not detected in 2013.

Table 2. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in WE in 2003 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value (Note: summed cover class scores are shown as a way of more concisely presenting the data and were not used in statistical testing; the actual cover scores for each plot were).

Species	sumCC-03	sumCC-13	Diff	W(p)	freq03	freq13	Diff
Distichlis spicata (p)	0	1	1	0.99	0.00	0.02	0.02
Limonium carolinianum (p)	19	8	-11	0.17	0.14	0.12	-0.02
Plantago maritima (p)	1	0	-1	0.99	0.02	0.00	-0.02
Salicornia maritima (a)	36	1	-35	0.01	0.21	0.02	-0.19
Salicornia virginica (p)	43	19	-24	0.06	0.21	0.19	-0.02
Spartina alterniflora (p)	267	198	-69	< 0.01	0.93	0.88	-0.05
Spartina patens (p)	28	18	-10	0.50	0.10	0.07	-0.02
Spergularia salina (p)	6	1	-5	0.50	0.05	0.02	-0.02
Suaeda spp. (a)	38	7	-31	0.01	0.26	0.12	-0.14
spp. richness	8	8	0				

Like the previous time period, there was a significant difference in the plant community composition between 2008 and 2013 (ANOSIM, Global R R=0.034, p=0.018). SIMPER suggested that *S. alterniflora* (decrease), *S. maritima* (decrease), and *S. patens* (decrease) were most responsible for dissimilarities between years. Cover changes during this time were only significant for *Suaeda* spp. and *S. maritima*, both of which declined (Table 3). Likewise, the frequencies of *Suaeda* spp. and *S. maritima* were much reduced (-0.19 and -0.23, respectively) in 2013. Other frequency changes were relatively minor (≤0.08). Species richness increased by two (appearance of *Plantago maritima* and *Puccinellia maritima*, both perennials) between 2008 and 2013.

Table 3. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in WE in 2008 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value; N/A indicates where statistics could not be conducted because the species was present in only one plot.

Species	sumCC-08	sumCC-13	Diff	W (p)	freq-08	freq-13	Diff
Distichlis spicata (p)	1	5	4	0.34	0.02	0.06	0.04
Limonium carolinianum (p)	18	16	-2	1.00	0.18	0.19	0.01
Plantago maritima (p)	0	3	3	0.50	0.00	0.04	0.04
Puccinellia maritima (p)	0	2	2	0.35	0.00	0.04	0.04
Salicornia maritima (a)	54	1	-53	<0.01	0.25	0.02	-0.23
Salicornia virginica (p)	18	19	1	0.54	0.07	0.15	0.08
Spartina alterniflora (p)	251	226	-25	0.09	0.80	0.83	0.03
Spartina patens (p)	98	86	-12	0.55	0.29	0.26	-0.03
Spergularia salina (p)	2	1	-1	N/A	0.02	0.02	0.00
Suaeda spp. (a)	39	8	-31	<0.01	0.30	0.11	-0.19
spp. richness	8	10	2				

A significant shift in species composition between 2003 and 2013 (Global R=0.12, p=0.001) was detected by ANOSIM, caused primarily by *S. alterniflora* and *Salicornia virginica* as indicated by

SIMPER. However, cover change was only significant for *S. alterniflora* (decreased) (Table 4). For species frequencies, *S. maritima* exhibited the most change (decrease of 0.37), followed by *S. alterniflora* (decrease of 0.17) and *S. virginica* (increase of 0.13). The rest had minor changes in frequency (≤0.10). Species richness increased by one due to the appearance of *D. spicata* in 2013.

Table 4. Summed cover class scores (sumCC), species frequencies (freq), and species richness in HH in 2003 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-03	sumCC-13	Diff	W (p)	freq-03	freq-13	Diff
Distichlis spicata (p)	0	2	2	0.50	0.00	0.03	0.03
Limonium carolinianum (p)	32	15	-17	0.04	0.30	0.27	-0.03
Salicornia maritima (a)	59	6	-53	< 0.01	0.47	0.10	-0.37
Salicornia virginica (p)	74	77	3	0.79	0.37	0.50	0.13
Spartina alterniflora (p)	162	90	-72	< 0.01	0.90	0.73	-0.17
Spartina patens (p)	11	5	-6	0.58	0.07	0.03	-0.03
Suaeda spp. (a)	22	6	-16	0.29	0.23	0.13	-0.10
spp. richness	6	7	1				

Between 2008 and 2013, there was no significant change in species composition although the statistical probability was very near the threshold of 0.05 for statistical significance (ANOSIM, Global R=0.028, p=0.059). *Limonium carolinianum*, *S. maritima*, and *Suaeda* spp. all decreased significantly in cover between 2008 and 2013 (Table 5). Other species showed no significant change. The frequency of *Suaeda* spp. changed the most (decrease of 0.37), followed by *S. maritima* (decrease of 0.21). *Salicornia virginica* was the only species to exhibit an increase in frequency (increase of 0.13). For all other species, changes were negative and relatively minor (≤0.07).

Table 5. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in HH in 2008 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-08	sumCC-13	Diff	W (p)	freq-08	freq-13	Diff
Distichlis spicata (p)	7	4	-3	0.50	0.08	0.06	-0.02
Limonium carolinianum (p)	25	15	-10	0.02	0.27	0.20	-0.07
Plantago maritima (p)	1	0	-1	N/A	0.03	0.00	-0.03
Salicornia maritima (a)	44	6	-38	0.04	0.30	0.09	-0.21
Salicornia virginica (p)	51	79	28	0.14	0.30	0.43	0.13
Spartina alterniflora (p)	116	118	2	0.66	0.78	0.77	-0.01
Spartina patens (p)	17	18	1	1.00	0.08	0.09	0.00
Suaeda spp. (a)	44	6	-38	< 0.01	0.49	0.11	-0.37
spp. richness	8	7	-1				

Nauset Island

Between 2003 and 2013, there was no significant change in species composition (ANOSIM Global R=0.034, p=0.12). Only *S. alterniflora* exhibited a significant change in cover (decrease) (Table 6). In terms of frequencies, *S. virginica* underwent a large reduction (decrease of 0.18). All other species fluctuated to a minor extent (≤0.08) between the two years and species richness remained the same although *S. biglovii* disappeared, while *S. salina* appeared in 2013.

Table 6. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in NI in 2003 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-03	sumCC-13	Diff	W (p)	freq-03	freq-13	Diff
Limonium carolinianum (p)	11	8	-3	0.59	0.33	0.32	-0.02
Salicornia biglovii (p)	5	0	-5	N/A	0.06	0.00	-0.06
Salicornia maritima (a)	7	4	-3	0.61	0.22	0.16	-0.06
Salicornia virginica (p)	29	15	-14	0.11	0.50	0.32	-0.18
Spartina alterniflora (p)	125	100	-25	< 0.01	1.00	0.95	-0.05
Spartina patens (p)	41	36	-5	0.73	0.44	0.37	-0.08
Spergularia salina (p)	0	2	2	N/A	0.00	0.05	0.05
Suaeda spp. (a)	9	8	-1	0.85	0.22	0.26	0.04
spp. richness	7	7	0				

Plant community composition was statistically similar in 2008 and 2013 (ANOSIM Global R=-0.025, p=0.88). Only *S. salina* changed significantly (increased from zero) in cover during this time period (Table 7). *S. maritima* exhibited the largest decrease in frequency (-0.18), although all species that were present in at least 25% of the plots in 2003 showed reductions. In contrast, *S. virginica* increased by 0.18. All other species increased or decreased by a relatively minor amount (≤0.09). The number of species recorded in the monitoring plots increased by 1 between 2008 and 2013 (appearance of *S. salina*).

Table 7. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in NI in 2008 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-08	sumCC-13	Diff	W (p)	freq-08	freq-13	Diff
Limonium carolinianum (p)	10	12	2	0.66	0.36	0.32	-0.05
Salicornia maritima (a)	11	4	-7	0.19	0.32	0.14	-0.18
Salicornia virginica (p)	11	17	6	0.35	0.18	0.36	0.18
Spartina alterniflora (p)	103	103	0	1.00	0.95	0.86	-0.09
Spartina patens (p)	56	50	-6	0.54	0.50	0.41	-0.09
Spergularia salina (p)	0	3	3	0.01	0.00	0.09	0.09
Suaeda spp. (a)	8	10	2	0.69	0.23	0.32	0.09
spp. richness	6	7	-1				

Nauset mainland

There was a significant difference in plant communities between 2003 and 2013 (ANOSIM Global R=0.062, p=0.045). Changes in the abundance of *S. alterniflora* and *S. patens* explained most of the variability between years according to SIMPER. When analyzed on an individual species basis, neither *S. alterniflora* nor *S. patens* exhibited a significant difference in cover between 2003 and 2013 (Table 8). Only *L. carolinianum* and *S. biglovii* experienced significant declines. In terms of frequencies, *S. biglovii* exhibited the largest change (disappeared in 2013). *Suaeda* spp. also decreased in frequency (-0.44) while all other species increased with *L. carolinianum* increasing the most (0.22). Species richness declined by 1 between 2003 and 2013 (loss of *S. biglovii*).

Table 8. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in NM in 2003 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-03	sumCC-13	Diff	W (p)	freq-03	freq-13	Diff
Limonium carolinianum (p)	1	10	9	0.05	0.06	0.28	0.22
Salicornia biglovii (a)	13	0	-13	0.01	0.44	0.00	-0.44
Salicornia maritima (a)	14	8	-6	0.62	0.28	0.33	0.06
Salicornia virginica (p)	24	25	1	0.79	0.44	0.56	0.11
Spartina alterniflora (p)	77	85	8	1.00	0.83	0.94	0.11
Spartina patens (p)	13	24	11	0.36	0.22	0.33	0.11
Suaeda spp. (a)	17	4	-13	0.10	0.28	0.11	-0.17
spp. richness	7	6	-1				

Between 2008 and 2013 no significant changes occurred in overall community composition, although the probability value was very close to the threshold of 0.05 for statistical significance (ANOSIM Global R=0.053, p=0.06). Changes in cover were only significant for *S. bigelovii*, which disappeared (Table 9). Similar to the previous frequency summary, *S. biglovii* accounted for the largest change (disappeared, decrease of 0.44) among species between 2008 and 2013. *S. virginica* increased by the largest amount during this time (0.44). *S. maritima* also increased but by a smaller amount (0.28), while *Suaeda* spp. were reduced (-0.17). Other changes for the remaining species were relatively minor (≤0.11). Species richness decreased from 7 in 2008 to 6 in 2013 (loss of *S. bigelovii*).

Table 9. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in NM in 2008 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-08	sumCC-13	Diff	W (p)	freq-08	freq-13	Diff
Limonium carolinianum (p)	7	10	3	1.00	0.22	0.28	0.06
Salicornia bigelovii (a)	18	0	-18	0.01	0.44	0.00	-0.44
Salicornia maritima (a)	1	8	7	0.06	0.06	0.33	0.28
Salicornia virginica (p)	4	25	21	0.07	0.11	0.56	0.44
Spartina alterniflora (p)	93	85	-8	0.09	0.89	0.94	0.06
Spartina patens (p)	24	24	0	0.38	0.33	0.33	0.00
Spergularia salina (p)	0	4	4	0.50	0.00	0.11	0.11
Suaeda spp. (a)	8	2	-6	0.45	0.28	0.11	-0.17
spp. richness	7	6	1				

Middle Meadow vegetation

ANOSIM indicated no significant shifts in plant community composition occurred between 2003 and 2013 in Middle Meadow (ANOSIM Global R=0.02, p=0.13). *S. alterniflora* and *S. patens* cover did, however, decrease significantly while no other species exhibited a significant change (Table 10). The frequency of *S. patens* also decreased (-0.16), as did *Suaeda* spp. (-0.12). In contrast *S. maritima* increased by almost the same amount (0.15). All other species showed relatively minor positive or negative frequency changes of ≤0.09. Species richness decreased from 11 to 8 (loss of *Elymus repens*, *S. marina*, and *Suaeda* spp.), although these species were not major components of the community in 2003.

Table 10. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in MM in 2003 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-03	sumCC-13	Diff	W (p)	freq-03	freq-13	Diff
Aster subulatus (p)	0	1	1	N/A	0.00	0.03	0.03
Distichlis spicata (p)	38	28	-10	0.17	0.18	0.21	0.02
Elymus repens (p)	9	0	-9	0.50	0.06	0.00	-0.06
Juncus gerardii (p)	6	5	-1	0.50	0.06	0.03	-0.03
Limonium carolinianum (p)	9	2	-7	0.10	0.12	0.03	-0.09
Salicornia maritima (a)	3	9	6	0.23	0.03	0.18	0.15
Salicornia virginica (p)	21	9	-12	0.17	0.15	0.09	-0.06
Spartina alterniflora (p)	112	88	-24	0.04	0.67	0.68	0.01
Spartina patens (p)	98	52	-46	0.01	0.48	0.32	-0.16
Spergularia marina (p)	1	0	-1	N/A	0.03	0.00	-0.03
Suaeda spp. (a)	14	0	-14	0.10	0.12	0.00	-0.12
spp richness	10	8	-2				

ANOSIM suggested that there were no significant shifts in plant community composition between 2008 and 2013 in MM. Cover changes also were not significant for any species and relatively few changes in frequency occurred (Table 11). The largest was an increase of 0.12 in *S. maritima*. All other species frequencies changed very little (≤0.09).

Table 11. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in MM in 2008 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-08	sumCC-13	Diff	W (p)	freq-08	freq-13	Diff
Aster subulatus (p)	0	1	1	N/A	0.00	0.03	0.03
Distichlis spicata (p)	31	28	-3	0.75	0.18	0.21	0.03
Elymus repens (p)	7	0	-7	0.50	0.06	0.00	-0.06
Juncus gerardii (p)	6	5	-1	N/A	0.03	0.03	0.00
Limonium carolinianum (p)	7	2	-5	0.17	0.12	0.03	-0.09
Salicornia maritima (a)	8	9	1	0.93	0.06	0.18	0.12
Salicornia virginica (p)	11	9	-2	1.00	0.09	0.09	0.00
Spartina alterniflora (p)	96	88	-8	0.21	0.73	0.70	-0.03
Spartina patens (p)	53	52	-1	1.00	0.36	0.33	-0.03
Spergularia salina (p)	1	0	-1	N/A	0.03	0.00	-0.03
Suaeda sp. (a)	5	0	-5	0.5	0.06	0.00	-0.06
spp. richness	10	8	-2				

The Gut

There were no significant differences in plant communities between 2003 and 2013 (ANOSIM Global R=0.019, p=0.13). There were also no significant changes in cover for any individual species 9Table 12). The largest changes in frequency occurred in *S. patens*, which decreased by 0.16 (Table 11), and *S. alterniflora*, which increased by 0.16. All other species exhibited little change (≤0.08).

Table 12. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in GU in 2003 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-03	sumCC-13	Diff	W (p)	freq-03	freq-13	Diff
Chenopodium alba (p)	2	0	-2	N/A	0.04	0.00	-0.04
Distichlis spicata (p)	7	6	-1	1.00	0.08	0.12	0.04
Elymus repens (p)	0	2	2	N/A	0.00	0.04	0.04
Limonium carolinianum (p)	0	3	3	N/A	0.00	0.04	0.04
Salicornia maritima (a)	6	0	-6	0.50	0.08	0.00	-0.08
Salicornia virginica (p)	8	4	-4	0.50	0.08	0.04	-0.04
Spartina alterniflora (p)	84	88	4	0.63	0.68	0.84	0.16
Spartina patens (p)	34	18	-16	0.13	0.32	0.16	-0.16
Suaeda spp. (a)	11	9	-2	0.71	0.16	0.12	-0.04
spp. richness	7	7	0				

There were no significant differences in plant communities between 2008 and 2013 (ANOSIM Global R=-0.19, p=0.92). Between 2008 and 2013, no significant changes in cover were observed and frequency changes were very minor (≤0.07) (Table 13). *S. alterniflora* changed the most, declining by 0.07.

Table 13. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in GU in 2003 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-08	sumCC-13	Diff	W (p)	freq-08	freq-13	Diff
Atriplex hastata (p)	2	0	-2	N/A	0.05	0.00	-0.05
Distichlis spicata (p)	19	9	-10	0.28	0.10	0.10	0.00
Elymus repens (p)	2	6	4	0.50	0.02	0.05	0.02
Limonium carolinianum (p)	7	5	-2	1.00	0.07	0.05	-0.02
Salicornia maritima (a)	3	0	-3	0.50	0.05	0.00	-0.05
Salicornia virginica (p)	4	4	0	N/A	0.02	0.02	0.00
Spartina alterniflora (p)	153	147	-6	1.00	0.71	0.78	0.07
Spartina patens (p)	64	52	-12	0.79	0.29	0.24	-0.05
Suaeda spp. (a)	17	13	-4	0.75	0.12	0.12	0.00
spp. richness	9	7	-2				

Jeremy marsh

ANOSIM indicated that the overall plant community of JM did not change significantly between 2008 and 2013 (ANOSIM Global R=0.003, p=0.33) (vegetation plots had not yet been established here in 2003). However, *S. alterniflora* (increased) and *S. patens* (decreased) did exhibit significant changes in cover during this time (Table 14). *S. alterniflora* exhibited the largest change in species frequency, increasing by 0.14. Other species both increased and decreased in frequencies by much smaller and variable amounts (≤0.09), while *Distichlis spicata*, *S. maritima*, and *Elymus repens* remained the same. Species richness decreased by 1 (loss of *S. maritima*) between 2008 and 2013.

Table 14. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in JM in 2008 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-08	sumCC-13	Diff	W (p)	freq-08	freq-13	Diff
Distichlis spicata (p)	5	7	2	1.00	0.14	0.14	0.00
Elymus viginicus (p)	2	0	-2	N/A	0.05	0.00	-0.05
Elymus repens (p)	16	7	-9	0.34	0.14	0.14	0.00
Juncus gerardii (p)	7	0	-7	N/A	0.05	0.00	-0.05
Limonium carolinianum (p)	2	0	-2	0.50	0.09	0.00	-0.09
Salicornia maritima (a)	1	1	0	0.50	0.05	0.05	0.00
Spartina alterniflora (p)	21	49	28	0.01	0.32	0.45	0.14
Spartina patens (p)	91	76	-15	0.04	0.64	0.59	-0.05
Suaeda spp. (a)	4	5	1	0.85	0.09	0.18	0.09
spp. richness	9	8	-1				

Pleasant Bay

Plant community composition in PB changed significantly between 2003 and 2013 (ANOSIM Global R=0.217, p=0.001). SIMPER showed that it was primarily *S. patens* and *S. alterniflora* that contributed to this change (Table 15). *Salicornia maritima* (increase), *S. alterniflora* (decrease), and *S. patens* (decrease) exhibited significant changes in cover between 2003 and 2013. There were very few large changes in frequency. The exceptions were *S. maritima*, which increased by 0.38 and *S. patens*, which decreased by 0.12. All other taxa exhibited minor or no changes in frequency (≤0.09). Species richness increased from 6 to 9 between surveys (appearance of *Aster tenuifolius*, *Limonium carolinianum*, *Phragmites australis*, *Suaeda* spp.; disappearance of *Baccharis halimifolia*).

Table 15. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in PB in 2003 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-03	sumCC-13	Diff	W (p)	freq-03	freq-13	Diff
Aster tenuifolius (p)	0	3	3	N/A	0.00	0.09	0.09
Baccharis halimifolia (p)	2	0	-2	N/A	0.03	0.00	-0.03
Distichlis spicata (p)	6	2	-4	1.00	0.03	0.03	0.00
Juncus gerardii (p)	8	13	5	0.75	0.06	0.06	0.00
Limonium carolinianum (p)	0	2	2	0.50	0.00	0.06	0.06
Phragmites australis (p)	0	3	3	N/A	0.00	0.03	0.03
Salicornia maritima (a)	8	22	14	0.05	0.09	0.47	0.38
Spartina alterniflora (p)	202	167	-35	< 0.01	0.85	0.88	0.03
Spartina patens (p)	56	25	-31	0.05	0.26	0.15	-0.12
Suaeda sp. (a)	0	5	5	0.50	0.00	0.06	0.06
spp. richness	6	9	3				

Plant community composition in PB changed significantly between 2008 and 2013 (ANOSIM Global R=0.011, p=0.031). In terms of cover values, only two species exhibited statistically significant change (Table 16). They were *Distichlis spicata* and *Elymus virginicus*, both of which decreased. Most species exhibited relatively minor changes in frequency (≤0.08). *S. maritima* stands out as the one species that changed by the most (increased by 0.16). Species richness decreased by 4 (*Atriplex hastata*, *Elymus virginicus*, *Iva frutescens*, *S. salina* were not recorded in any plots).

Table 16. Summed cover class scores (sumCC), relative species frequencies (freq), and species richness in PB in 2008 and 2013. Letter designation beside species names indicates annual (a) or perennial (p). W (p) is the Wilcoxon signed-rank test probability value.

Species	sumCC-08	sumCC-13	Diff	W (p)	freq-08	freq-13	Diff
Aster tenuifolius (p)	6	8	2	0.93	0.02	0.09	0.07
Atriplex hastata (p)	8	0	-8	0.17	0.03	0.00	-0.03
Distichlis spicata (p)	27	3	-24	0.05	0.07	0.02	-0.04
Elymus virginicus (p)	19	0	-19	<0.01	0.05	0.00	-0.05
Elymus repens (p)	9	37	28	0.03	0.03	0.11	0.08
Iva frutescens (p)	9	0	-9	0.50	0.02	0.00	-0.02
Juncus gerardii (p)	33	34	1	0.95	0.09	0.08	-0.01
Limonium carolinianum (p)	13	12	-1	0.76	0.09	0.09	0.00
Phragmites australis (p)	9	9	0	1.00	0.03	0.03	0.00
Plantago maritima (p)	1	4	3	0.50	0.01	0.02	0.01
Salicornia maritima (a)	44	52	8	0.49	0.22	0.38	0.16
Salicornia virginica (p)	8	17	9	0.13	0.02	0.09	0.07
Spartina alterniflora (p)	375	339	-36	0.00	0.70	0.68	-0.02
Spartina patens (p)	154	111	-43	0.14	0.34	0.29	-0.05
Spergularia salina (p)	4	0	-4	N/A	0.01	0.00	-0.01
Suaeda sp. (a)	17	15	-2	0.65	0.09	0.08	-0.01
spp. richness	16	12	-4				

To summarize all vegetation abundance changes over time, more statistically significant changes in plant community composition were detected between 2003 and 2013 than between 2008 and 2013 (Table 17). Shifts in the patterns of *S. alterniflora* cover (mostly declines) were responsible for the majority of statistically significant changes in vegetation abundance. *Spartina alterniflora* and *S. patens* cover changes were statistically significant more often between 2003 and 2013, but the majority of changes in these two species within a marsh were non-significant.

In terms of individual marshes, PB had the highest number of significant species changes (four) in cover (2008-2013). This was followed by HH (2003-2013 and 2008-2013), PB (2003-2013), and WE (2003-2013) with three species exhibiting significant change. MM (2003-2013), NM (2003-2013), JM (2008-2013), and WE (2008-2013) had two species that changed significantly and NI (2003-2013), MM (2008), NI (2008-2013), NM (2008-2013) only had one. GU did not have any species that changed significantly during either 2003-2013 or 2008-2013.

Table 17. Summary of community composition change (comm-level change), and *S. alterniflora* and *S. patens* cover changes from 2003-2013 and 2008-2013 (N=no significant change, Y=significant change; arrows indicate trend).

		comm-level change (ANOSIM)	**No. spp. with sig. change**	***S. alterniflora* cover change (Wilcoxon test)**	***S. patens* cover change (Wilcoxon test)**	**Species contributing most to comm-level change if sig (SIMPER)**
2003-2013	GU	N	0	N	N	-
	HH	Y	3	Y (↓)	N	*S. alterniflora*
	JM	-	-	-	-	-
	MM	N	2	Y (↓)	Y (↓)	-
	NI	N	1	Y (↓)	N	-
	NM	Y	2	N	N	*S. alterniflora*
	PB	Y	3	Y (↓)	Y (↓)	*S. patens*
	WE	Y	3	Y (↓)	N	*S. alterniflora*
2008-2013	GU	N	0	N	N	-
	HH	N	3	N	N	-
	JM	N	2	Y (↑)	Y (↓)	-
	MM	N	1	N	N	-
	NI	N	1	N	N	-
	NM	N	1	N	N	-
	PB	Y	4	N	N	*S. alterniflora*
	WE	Y	2	N	N	-

Discussion

CACO marshes differ substantially with respect to soil organic matter content and particle size fractionation (particularly the 0.5-1 mm and 1-2 mm size fractions), which were the most important environmental variables influencing plant heights and biomass. NI and PB, which are both older marshes and near each other, had higher organic matter content than the other marshes while MM and NM soils had the most sand within the 0.25-0.5 mm and 0.5-1 mm PSA fractions. For salinity and soil hardness there were few large differences among marshes. Moreover, while there was year to year variability in all environmental variables, there were no striking changes that would indicate a significant temporal shift in conditions (soil harness might increase with increasing soil compaction and the accumulation of peat; Bertness 1988).

The mean heights of *S. alterniflora* were quite different among marshes, with NI and NM having the shortest plants, WE the tallest. Furthermore, it was confirmed that plants measured in July-August are significantly shorter than those measured in late August -September. Thus, although *S. alterniflora* may begin to flower in July, the plants are obviously not finished growing vegetatively and it important to collect the data as late in the field season as possible to best estimate maximum plant height. Plant heights within each marsh system varied among years, presumably due to differences in climatic conditions (e.g., precipitation, temperature). Some marshes appeared to exhibit an upward trajectory in plant heights through time while others exhibited a downward trajectory. Collectively, however, there was no consistent temporal trend among sites.

In 2013, *S. alterniflora* height was negatively correlated with organic matter and salinity, and positively with the 1-2 mm particle size fraction. The various fractions of *S. alterniflora* biomass exhibited a high level of variability among marshes. Aboveground biomass essentially mirrored plant height patterns, but belowground biomass did not. As a result, variability in the ratio between the two was even higher. Marshes with higher proportions of particle sizes in the 0.5-1 mm range (HH, WE) had the highest AG:BG ratios, while Nauset marsh, which has a very low amounts, had the lowest. Aboveground biomass was best related (positively) to the 1-2 mm sand fraction, belowground biomass (negatively) to the 0.5-1 mm fraction. Because biomass was only collected in 2013, no temporal changes could be analyzed. When mean AG:BG ratios for each marsh were plotted against mean values for the >0.5 mm and 0.25-0.5 mm particle size fractions, the correlation was significant and the R_2 values were high. In this regard, AG:BG was positively correlated with the >0.5 mm fractions and negatively correlated with the <0.5 mm fractions. It is not known exactly why particle size was best correlated with *S. alterniflora* heights and biomass (compared to the other variables). However, it may be that the percentage of larger sand particles is correlated with the amount of drainage and therefore oxygen levels in the soil. In this regard, very sandy soils are generally better drained and are more oxidized during low tide than soils with smaller particle sizes (due to less pore space in the latter). There were very minor changes in species richness between years when all marshes were considered simultaneously. Moreover, the changes were always a consequence of variability in the populations of annual and/or the rarest species.

In terms of plant cover, four out of eight and two out of eight marshes exhibited statistically significant community-level vegetation changes between 2003 and 2013 and 2008 and 2013, respectively. SIMPER analyses indicated that patterns of *S. alterniflora* (4 marshes) and *S. patens* (one marsh) cover contributed most to the community dissimilarities between years. *S. alterniflora* cover significantly declined in five marshes (Hatches Harbor, Middle Meadow, Nauset Island, Pleasant Bay, West Eend) between 2003 and 2013 and increased in one between 2008 and 2013 (Jeremy Marsh). *S. patens* declined in two marshes (Middle Meadow and Pleasant Bay) between 2003 and 2013 and in one marsh (Jeremy Marsh) between 2008 and 2013. The *S. patens* declines in Middle Meadow and Jeremy Marsh may be partially explained by salt marsh dieback that is occurring in these marshes – something that has reduced the extent of high marsh vegetation (Smith and Tyrrell 2012). In Pleasant Bay, *S. patens* decline is likely the result of increased tidal amplitude in the larger embayment - a consequence of a new inlet that was created in 2007 from a break in the barrier beach during a storm.

The decline in *S. alterniflora* is more difficult to explain. Some of it may be related to the different methodologies used to estimate cover. For example, it appears that point counts (done in 2003) may overestimate percent cover when the species abundance is high. In this regard, point counts in plots dominated by *S. alterniflora* generally gave a score of 7 (75%+) in 2003 while visual estimates in 2013 were scored as cover class 5 (25-50%) and 6 (50-75%) in 2013. There was also the issue of time of assessment. Marshes that were surveyed early in the field season one year and later in the other can introduce error because plant cover is likely to be slightly less in the former, as shown in the 2013 data. Notwithstanding, the possibility that these trends are real should not be discounted. Mean high water elevation between May 1 and September 30 was substantially higher in 2013 (1.48 m NAVD88) than in 2003 (1.36 m NAVD88) (Boston tide gauge; tidesandcurrents.noaa.gov). In fact, mean high water elevations have been rising since 2003 (Figure 21) and this difference of 12 cm might have contributed to a reduction in the abundance of *S. alterniflora* and *S. patens* in 2013, although elevated water levels would presumably increase the frequency of *S. alterniflora* as it replaces high marsh species (Bertness and Donnelly 2001). Moreover, the growth of *S. alterniflora* at supra-optimal elevations is enhanced by higher water levels up to a certain point (Morris et al. 2013). The increase in high water elevation is due presumably to the metonic cycle plus sea level rise. Both positive and negative changes in other, less common species occurred but collectively there were no consistent trends. For annual species such as *S. maritima*, and *Suaeda* spp., large increases or decreases in cover and frequency may be partially explained by yearly variations in seed germination, dispersal, and establishment.

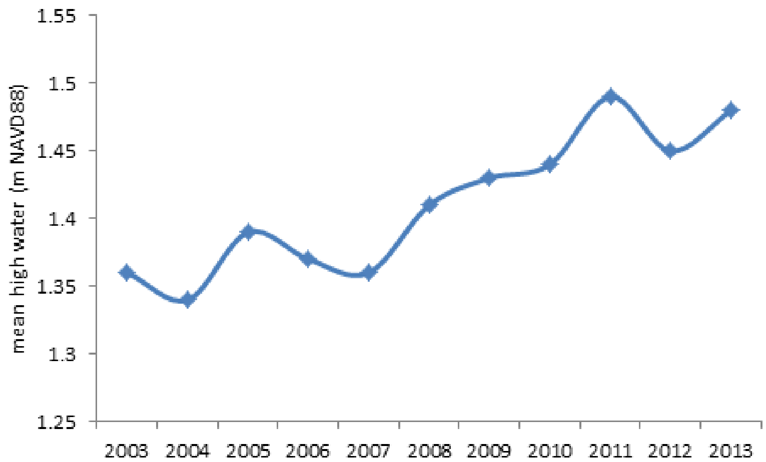

Figure 21. Mean high water elevation in Boston from 2003 to 2013 (points are averages of May 1-Sept 30 values; data from tidesandcurrents.noaa.gov).

In general, the vegetation monitoring indicated that CACO's unrestricted salt marshes have exhibited changes in plant community composition and the cover and frequency of their foundation species, *S. alterniflora* and *S. patens*, over the last decade. It is presently not understood whether these changes represent year to year fluctuations that were within the scope of normal functioning or whether they were a response to the metonic cycle + sea level rise (the metonic cycle is the length of recurrence of the lunar phases, which influences daily, monthly, annual, and decadal amplitudes of the tides). Furthermore, with only three data points (2003, 2008, and 2013) determining any trajectory of change would be somewhat premature. Another decade of monitoring should provide sufficient data for making this assessment.

Recommendations

- *S. alterniflora* heights have been measured during July-August based on previous methods for sampling, which were based on data collected in in Hatches Harbor during 1997-2002. However, it is clear that heights should be measured as late in the field season as possible (~late August-September) in order to reduce temporal-based variability in values among marshes.

- Although LIDAR coverage of the salt marsh study areas is available, it can overestimate elevations by as much as 30 cm due to interference from the vegetation. Accordingly, more accurate estimates of each plot elevation should be acquired using Real Time Kinematic GPS (RTK-GPS), which has an error range of approximately 2-5 cm.

- Collect soil hardness data again using a store-bought soil penetrometer that will work in marsh soils.

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Appendix I

West End marsh

West End marsh is a ~172 acre marsh located at the tip of the Cape Cod peninsula in Provincetown within Cape Cod Bay (Figure 21). A permeable stone dike runs NW-SE along its eastern margin. While the dike has virtually no impact on high and low tide heights it produces a lag in their timing (based on tidal data collected in 2005 by CACO). Currently, there are 7 transects and 58 plots in this marsh.

Figure 22. West End marsh depicting current extent of monitoring plot locations.

Hatches Harbor

Similar to West End marsh, Hatches Harbor lies at the tip of Cape Cod in Provincetown where the Atlantic Ocean meets Cape Cod Bay (Figure 22). It is approximately 3.3 km northwest of West End. Hatches Harbor is bisected by an earthen dike built in the 1930s but the 90 acre part of the marsh discussed here is seaward of the dike and hydrologically unrestricted. There are 3 transects and 41 plots within this area.

Figure 23. Hatches Harbor marsh depicting current extent of monitoring plot locations.

Nauset Island

Nauset marsh is a ~700 acre marsh located on the Atlantic side of CACO in the town of Eastham and Orleans (Figure 23). There are a number of different sections of the marsh that are themselves defined by broad tidal channels. The largest section is ~270 acres and is termed Nauset Island (NI) in this report. There are 3 transects and 22 plots within this area.

Figure 24. Nauset Island marsh depicting current extent of monitoring plot locations.

Nauset mainland

A much smaller section (~48 acres) of Nauset marsh extends out westward from the barrier spit that is connected with the mainland (Figure 24). This section has been termed Nauset mainland (NM) in this report. It has 3 transects and 18 plots.

Figure 25. Nauset mainland marsh depicting current extent of monitoring plot locations.

Middle Meadow vegetation

Middle Meadow is a small (~54 acre) marsh that lies midway between the Gut and Jeremy marshes on the Great Island peninsula along the western edge of Wellfleet in Cape Cod Bay (Figure 25). It is well protected from wave action behind a relatively narrow tidal inlet. There are 34 plots along 6 transects within MM.

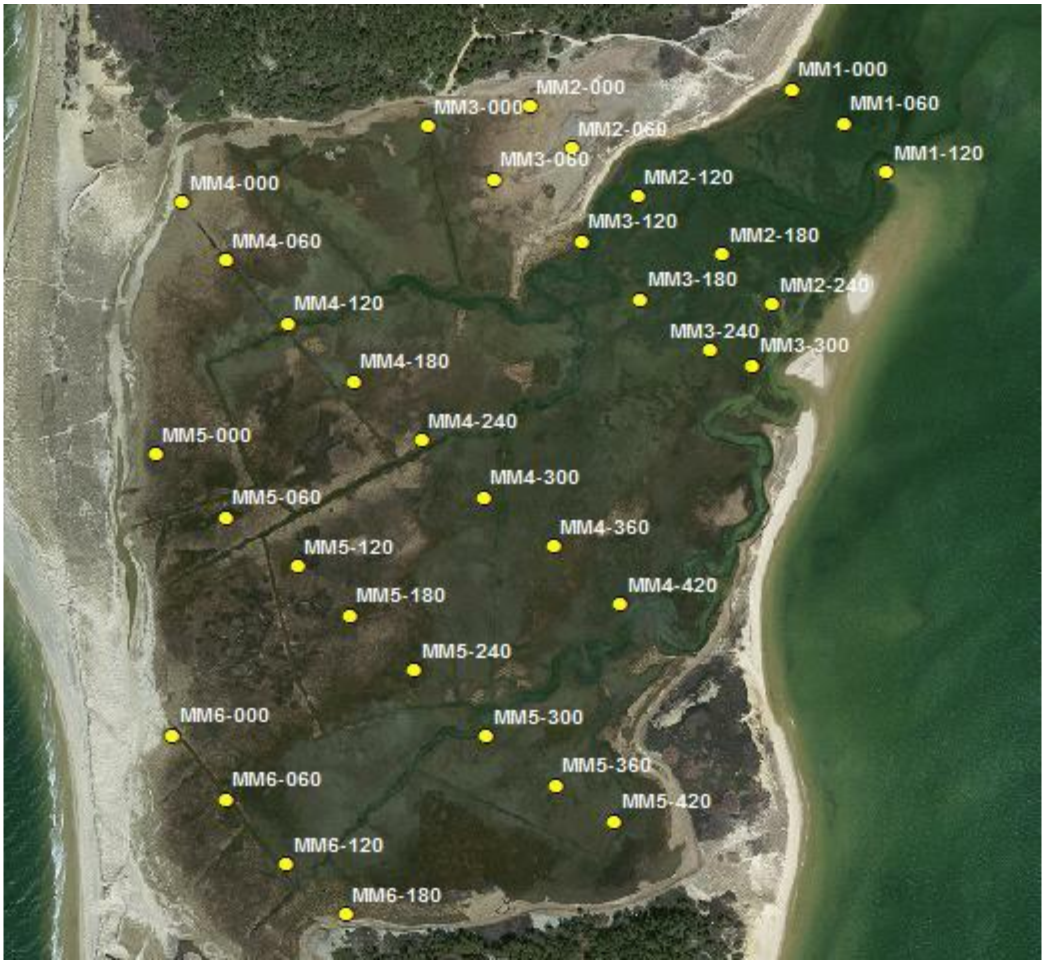

Figure 26. Middle Meadow marsh depicting current extent of monitoring plot locations.

The Gut

The Gut (GU) is a 55 acre marsh also located on the Great Island peninsula but is more of a fringing marsh that is fully exposed to the open waters of Wellfleet Bay (i.e., it does not lay behind a tidal inlet or barrier beach) (Figure 26). There are 7 transects and 47 plots in this marsh.

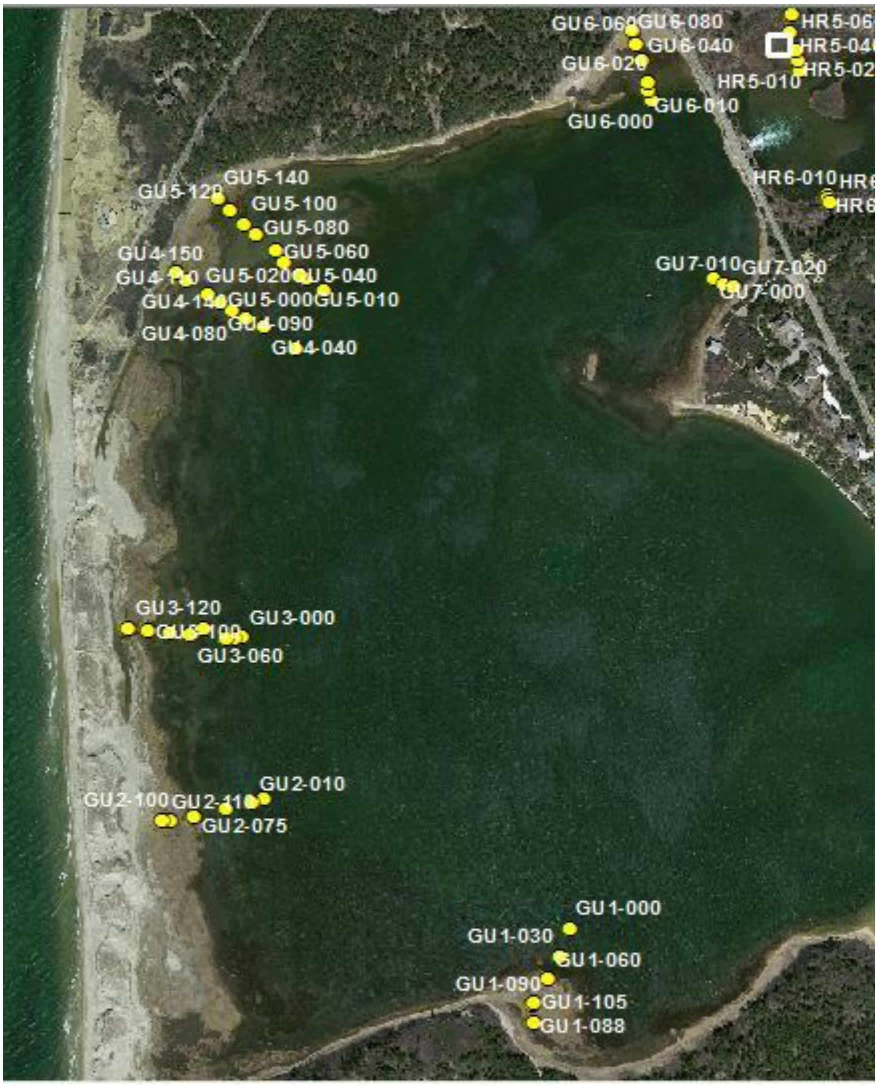

Figure 27. Gut marsh depicting current extent of monitoring plot locations.

Jeremy marsh

Jeremy marsh is the southernmost marsh on Great Island (Figure 27). At ~11 acres, it is the smallest of all areas monitored. There are 24 plots along 3 transects here.

Figure 28. Jeremy marsh depicting current extent of monitoring plot locations.

Pleasant Bay

Pleasant Bay is the largest marsh within CACO's monitoring network. It is located on the Atlantic side, south of Nauset marsh in the towns of Orleans and Chatham, extending westward from the Nauset spit which encloses Pleasant Bay proper (Figure 28). The marsh is roughly 425 acres and there are 92 plots along 14 transects there.

Figure 29. Pleasant Bay marsh depicting current extent of monitoring plot locations.

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