



Innovative Salt Marsh Restoration Techniques for the Great Marsh

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On the Cover: The North Pool following runnel activities that reduced chronic flooding in the Great Marsh, Newbury, Massachusetts.

TABLE OF CONTENTS

Cover Page	i
Report Citation Page	ii
Table of Contents	iii
Introduction	1
Innovative <i>Phragmites</i> Control	2
<i>Greenhouse Experiment</i>	2
<i>Field Experiment</i>	8
Tidal Circulation Restoration	15
Ditch Remediation	24
Plant Community Development Following <i>Phragmites</i> Removal	30
Summary	32
Acknowledgements	34
References	35
Appendix I	36
Appendix II	49
Appendix III	51
Appendix IV	85

Introduction

Salt marshes along the East Coast bore the brunt of Hurricane Sandy. By providing such ecosystem services as storm surge protection and protection from shoreline erosion, they helped reduce the impact of this storm. Salt marshes also provide vital habitat to many wildlife species including migratory waterfowl, and obligate species such as saltmarsh sparrows and willets. Salt marshes are also important in sustaining fisheries to support local and offshore food webs. By providing innovative restoration techniques, this project has increased the resilience and habitat value of selected project sites as well as provided additional resiliency tools to coastal managers at other locations along the East Coast. All of the fieldwork for this project was conducted in the Great Marsh, which runs along the north shore of Massachusetts from Cape Ann to Salisbury. Many partners are engaged in conservation and restoration of the Great Marsh and the Parker River NWR manages a large portion of this system. The most relevant partners for this project include Parker River NWR, Northeast Wetland Restoration Inc., Massachusetts Natural Heritage Program, Mass Audubon, and Eight Towns and the Great Marsh.

Several innovative salt marsh restoration techniques were conducted at selected locations in the Great Marsh within the boundaries of the Parker River National Wildlife Refuge (NWR). A monitoring program has been established to implement and gather data from three innovative restoration techniques and also evaluate changes in previously established *Phragmites australis* monitoring plots. The four major efforts are: (1) **Innovative *Phragmites* Control:** Traditionally non-toxic substances (i.e., sugar) were used to control this invasive plant. Trials were conducted in the field as well as a greenhouse experiment. (2) **Restoration of Tidal Circulation:** Selected locations of marsh that were incorrectly impounding surface water were altered through creation of a shallow runnel to allow tidally influenced drainage and re-vegetation from existing and planted culms of *Spartina alterniflora*. (3) **Ditch Remediation:** Selected salt hay ditches were made shallower by placing and holding salt hay with twine to promote ditch closure and reduce excessive drainage and surface subsidence. (4) **Plant Community Development following *Phragmites* removal:** Using study plots established in 2010, areas where *Phragmites* stands had been sprayed with herbicide were surveyed to determine the long-term effects of this management action on native vegetation cover.

Innovative *Phragmites* Control

Greenhouse Experiment

Methods: Fourteen large sediment cores containing invasive *Phragmites* were harvested from a New Hampshire tidal marsh in mid July 2014. While still in the field, cores were fitted into 5 gallon buckets ('pots') with the soil surface several centimeters below the rim to allow for complete inundation when simulating spring tides and transported to the Jackson Estuarine Laboratory in Durham, NH. Shortly after, all shoots were clipped. Once plants had grown new shoots to approximately 30 cm, the healthiest 12 pots were randomly assigned into a 3x4 array in the greenhouse, consistently watered (15 ppt) fortnightly as well as rotated weekly throughout the experiment duration. Treatment began in mid August 2014 and concluded early October 2014, although watering, rotation and measurements persisted for an additional year. To simulate irregular tidal flooding, plants were watered and flooded for 3 hours fortnightly. Between watering, pots were allowed to drain to 10 cm below the rim. Plants were treated with sucrose, table sugar (6 mM and none) and salt (1.8 ppt added to ambient bay water and ambient bay water) in a two way factorial experiment with three replicates (Fig. 1a). Salt and sugar additions were based off a 16.5 L soil volume, with an estimate of 75% soil moisture. Salt additions comprised of 1.5 L of 15 ppt water with an additional 22.5 g of salt, which increased this watering solution to 30 ppt and intended to increase salinity of treated experimental units by 1.8 ppt. Sugar additions were 75 g sugar dissolved in 1.5 L bay water, which created a concentration of 0.6% in the treated pots. And finally, the sugar+salt treatment was a combination of the salt and sugar additions.

Plant responses (shoot survival, density and height) and soil characteristics (salinity, Eh, pH and sulfide concentration) were measured prior to watering every two weeks through October (10 weeks total). Shoot heights were measured to the tip of the tallest green leaf. Shoots less than 2 cm were not measured for height nor counted. Pore water was collected in the center of the pots at 15 cm depth using a 1 mm I.D. stainless steel tubing with a 60cc syringe (i.e., 'sipper' method). Salinity was measured by using a temperature-corrected refractometer. Redox potential and pH were measured using an Orion 3 Star Portable multimeter equipped with an ORP probe or Ross Sureflow pH electrode, respectively. Redox values were corrected for the combination electrode (+244 mV) and pH (59 mV per unit from 7.0) to arrive at Eh. Pore water (0.05 mL) was injected into a 20 mL scintillation vial containing zinc acetate for later laboratory analysis of sulfides, which were determined colorimetrically using the method of Cline (1969). All sample vials were stored for 2 weeks at 4°C prior to analysis.

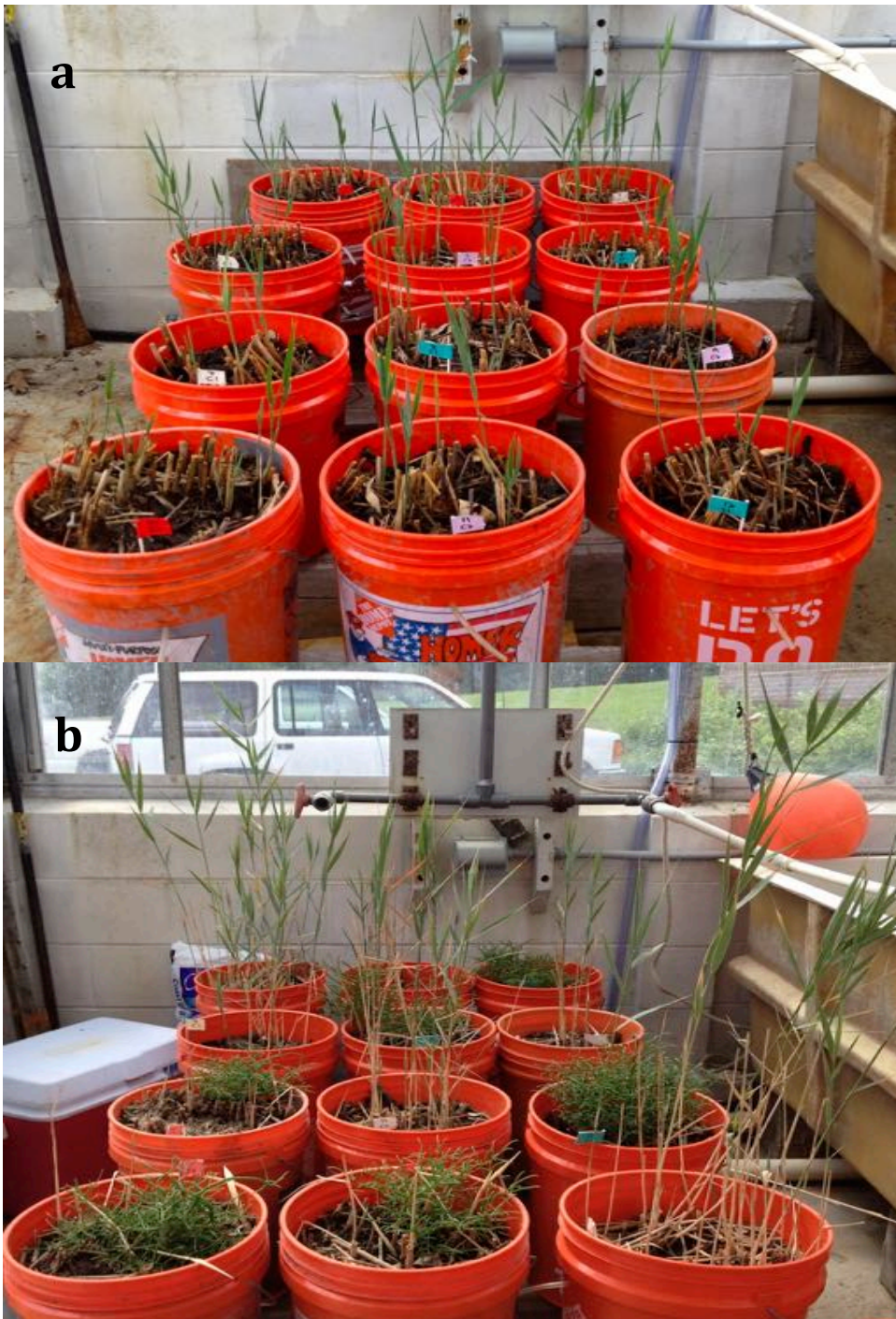


Figure 1. *Phragmites* sediment cores at JEL greenhouse a) several weeks after excavation; and b) after one year, with only live plants in treatments without sugar (salt and control treatments). Treatments (sugar, sugar+ salt, salt and control) were randomly assigned and applied four times in the fall. *Salicornia depressa* grew as volunteers in all pots where *Phragmites* had died and one pot with live *Phragmites*.

Plants were watered regularly and allowed to overwinter in the greenhouse. In spring, plants were rotated and watered regularly, but no treatments were applied in 2015. The experiment was concluded in September 2015.

Results and Discussion: Within weeks, plants treated with sugar or sugar and salt (but not salt only and controls) showed signs of drought stress (leaf curling, yellowing) and shoot death. Plants grown in control and salt only treatments showed no ill effects and these were the only plants that survived (Fig.1b). A complete set of fortnightly photographs of the experimental plants can be seen in Appendix I.

The percentage of plant shoots surviving each treatment is shown in Figure 2. When the data were examined for each sampling date, there were significant differences among treatments beginning at week four (p values along x-axis). Because there did not seem to be a salinity effect, the control and salt only treatments were grouped and compared with the sugar and sugar + salt treatments for each date using linear contrasts. A significant effect for those pots receiving the sugar treatments began at four weeks and most pots had no living shoots after eight weeks. The total length of live shoots was compared among treatments (Fig. 3). Similarly, a significant effect was found beginning at two weeks for the experiment as a whole (p values along x-axis), with no sugar treatments growing taller and sugar treatments dying back (shown as different letters).

Pore water characteristics are presented in Table 1 showing data from shallow collections (deep pore water results are shown in IIII). Salinity increased in the first ten weeks of the experiment, with ambient bay water climbing from 15 to 25 ppt and the salinity treatments from 17 to 29 ppt. Pore water pH averaged around 6.0 for control and salt treatments, but fell to under 5.0 for sugar treatments (Table 1). Using linear contrasts, comparisons at eight and ten weeks showed sugar treatments had significantly lower pH.

Redox values were corrected for the combination electrode and pH to arrive at Eh. Pore water from 15 cm depth showed fairly low Eh values for all treatments (<-300 mV; Table 1), especially the sugar treatments, but treatment differences were not significant. Sulfide concentrations were fairly high in this experiment. Averaged over the first ten weeks, sulfide values for control and salt only treatments were 1.7 and 1.6 mM, respectively, and with added sugar these averaged 2.4 and 2.2 mM. Although not statistically significant, these differences were anticipated, with added sugar stimulating anaerobic bacterial respiration and sulfide accumulation. It appears some of the sulfide may have re-oxidized and led to significantly lower pH values measured in the sugar treatments. Although the mechanism of death for the *Phragmites* is not known, sulfide accumulation and soil acidification are likely to be associated with the cause (Chambers et al. 2003).

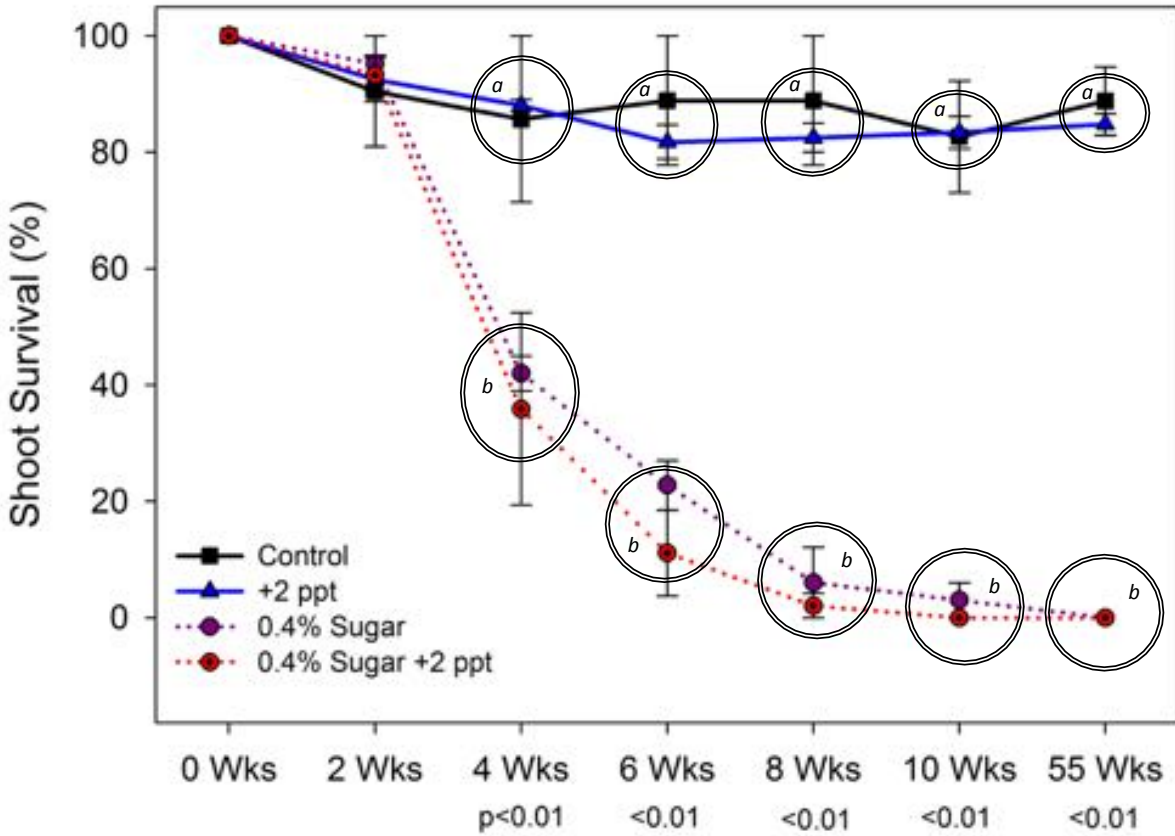


Figure 2. Greenhouse experiment measuring *Phragmites* shoot survival over time, in controls (square) when treated with salt (triangle), sugar (circle) or both (circle with dot). Treatment was tested on weeks separately using ANOVAs when an effect was evident (p -values of no effect are shown on the x-axis). Linear contrast grouping and significant results are indicated by double lined circles and different letters.

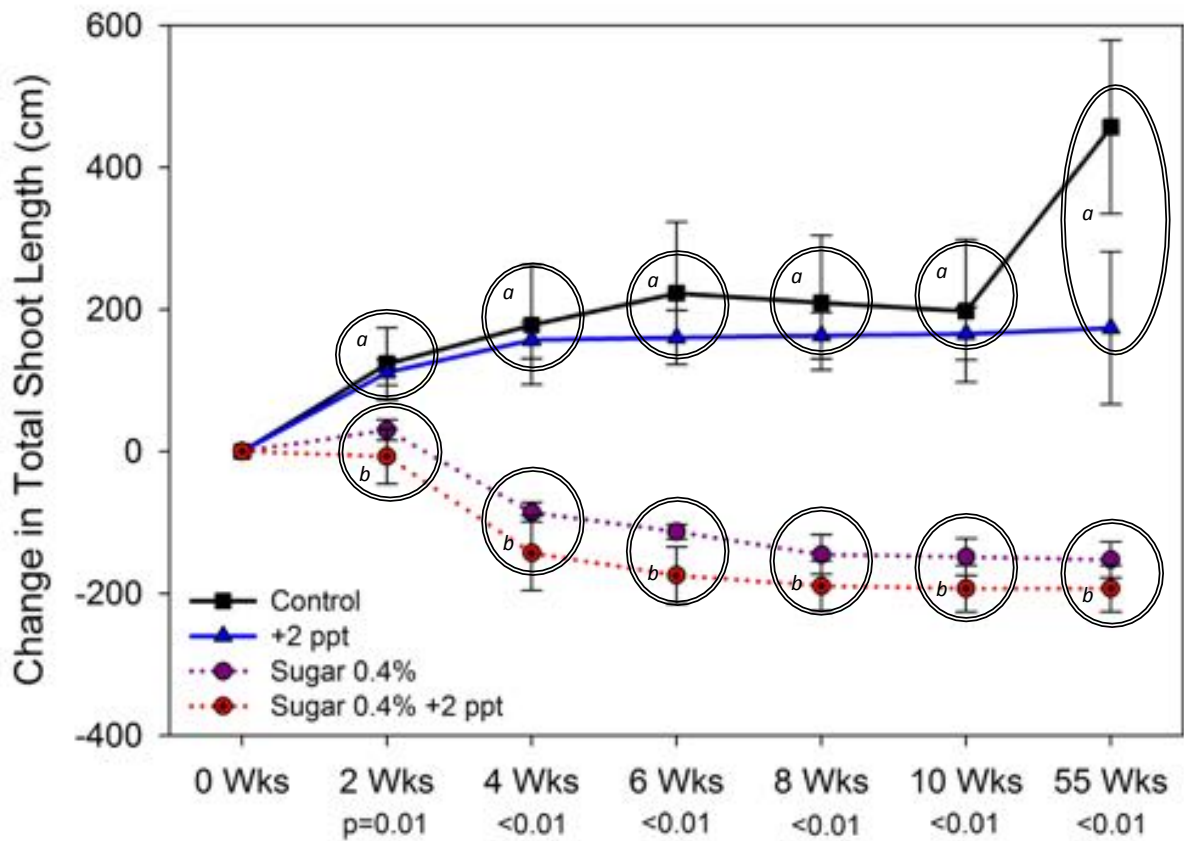


Figure 3. Greenhouse experiment measuring change in total shoot length of *Phragmites* over time, in controls (square) when treated with salt (triangle), sugar (circle) or both (circle with dot). Treatment was tested on weeks separately using ANOVAs when an effect was evident (p -values of no effect are shown on the x-axis). Linear contrast grouping and significant results are indicated by double lined circles and different letters.

Shallow Salinity (ppt)								
Week	Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0								
2	16.0	1.0	17.7		17.7		17.3	0.3
4	15.7	0.7	20.0	0.3	17.7	0.3	18.7	0.3
6	19.7	0.3	23.7	1.0	21.0	0.9	21.3	0.9
8	20.3	0.3	26.0	0.7	21.7	1.5	24.3	1.2
10	24.0	0.0	29.0	1.0	26.7	1.7	29.3	1.5
55	36.7	1.7	39.7	1.0		1.8	27.0	0.6

Shallow Redox Potential (mV)								
Week	Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0								
2	-288.3	25.2	-303.7	11.6	-306.3	18.5	-305.0	31.3
4	-314.7	21.5	-337.3	27.4	-356.3	6.6	-307.7	5.8
6	-322.3	1.7	-317.3	11.1	-352.7	10.2	-339.3	29.7
8	-332.3	17.9	-329.3	13.6	-327.0	24.0	-340.3	11.7
10	-348.7	15.2	-347.7	3.0	-381.7	46.4	-387.7	6.4
55	-341.3	20.3	-348.7	15.1			-282.7	25.9

Shallow pH								
Week	Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0								
2	6.09	0.11	6.35	0.08	6.01	0.31	6.10	0.30
4	6.50	0.35	6.07	0.12	5.59	0.55	5.94	0.12
6	6.17	0.05	6.19	0.17	5.26	0.53	5.25	0.44
8	6.35	0.25	6.03	0.21	4.90	0.48	4.31	0.23
10	5.61	0.37	6.05	0.21	4.62	0.51	4.23	0.14
55	6.12	0.09	5.88	0.34			5.66	0.28

Shallow Sulfides (mM)								
Week	Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0								
2	1.01	0.51	1.43	0.49	1.90	0.49	1.30	0.64
4	2.07	0.69	1.75	0.65	2.74	0.20	2.48	0.45
6	1.81	0.23	1.43	0.61	1.86	0.27	2.00	0.39
8	2.43	0.09	1.73	0.40	2.69	0.26	2.62	0.38
10	0.97	0.42	1.82	0.10	2.60	0.53	2.74	0.47
55	1.49	0.60	1.61	0.64			0.66	0.30

Table 1. Pore water results for the greenhouse experiment on *Phragmites* including means and standard errors for salinity, Eh (corrected redox), pH and sulfide concentration. Data shown here for pore water collected at shallow depth (~15cm); data for deep (~30cm) collections is included in Appendix II. Low water levels prevented sampling at shallow depths for week 0.

Field Experiment

Methods: Invasive *Phragmites* plants were also treated with sugar and salt in a field experiment located in the northern portion of Great Marsh. A series of tubes (5-gallon buckets with the bottom cut out) were installed at several monoculture stands bordering Little Pine Island Creek in July 2015. *Phragmites* shoots within and around these tubes were cut shortly afterward and treatments began a month later, once new shoots re-grew. Plants were treated fortnightly, 5 times in total, until early October 2015. Treatments included: 1) Control (no tube), 2) Control (tube), 3) Salt additions, 4) Sugar additions and 5) Sugar + salt additions. Two replicates of each treatment were established in each of the three stands, making a total of 6 replicates. Salt and sugar additions were nearly identical to the concentrations applied in the greenhouse experiment. The only difference came from watering with adjacent creek water, which varied from 14-23ppt, instead of a consistent 15 ppt used in the greenhouse.

Vegetation and porewater measurements were taken prior to treatment, after 3 treatments (mid September) and after 2 more treatments (mid October). Plants were measured for shoot survival, density and height, and porewater was measured for salinity, redox potential, pH and sulfide concentration, using the same methods described for the greenhouse study.

Results and Discussion: After treatments began, all treatments and controls exhibited declines in survival when measured after six weeks (Fig. 4). After 10 weeks, sugar treatments showed significantly greater mortality, as indicated by the linear contrast results. Total shoot length did not change in controls that were not isolated from the rest of the marsh by the tubes (Fig.5). Groups of *Phragmites* shoots isolated from the marsh with tubes and untreated (control) or treated with salt showed no decline in total shoot length after six weeks and slight, but not significant, declines after ten weeks. The tubes themselves may have resulted in loss of shoots and vigor because isolating the shoots from the rest of the *Phragmites* stand may have increased stress on the isolated plants. Rhizome connections among plants have been shown to relieve stress and improve plant performance (Amsberry et al. 2000, Bart et al. 2006). In contrast to the controls and the salt only treatment, the two sugar treatments showed rapid and significant declines in shoot length (Fig. 5).

Pore water was collected at 20 cm from the centers of the pots and control areas at 0, six and ten weeks of the experiment. Salinity ranged from 20 to 25 ppt, with the higher levels associated with salt additions (+ 2 ppt; Table 2). Overall variability was high in the field, but after ten weeks, linear contrasts showed that pH and Eh fell to significantly lower levels and sulfide concentrations were significantly greater in the sugar treatments (Figs. 6 and 7).

Although treatments were similar in the greenhouse and field experiments, precipitation and tidal flooding could not be controlled in the field. Such differences may have led to slightly different results for added sugar effects on pore water (significantly greater sulfide accumulation and lower pH in the greenhouse and significantly lower Eh and pH and greater sulfides in the field) but both experiments showed sugar treatments have a negative impact on *Phragmites* success. Evidence exists for increased sediment stress (flooding, low Eh, high sulfides) reducing plant vigor in native marsh grass (Mendlesohn et al. 1979, Howes et al. 1984) and even stronger impacts on invasive *Phragmites* grasses (Chambers et al. 2002, 2003).

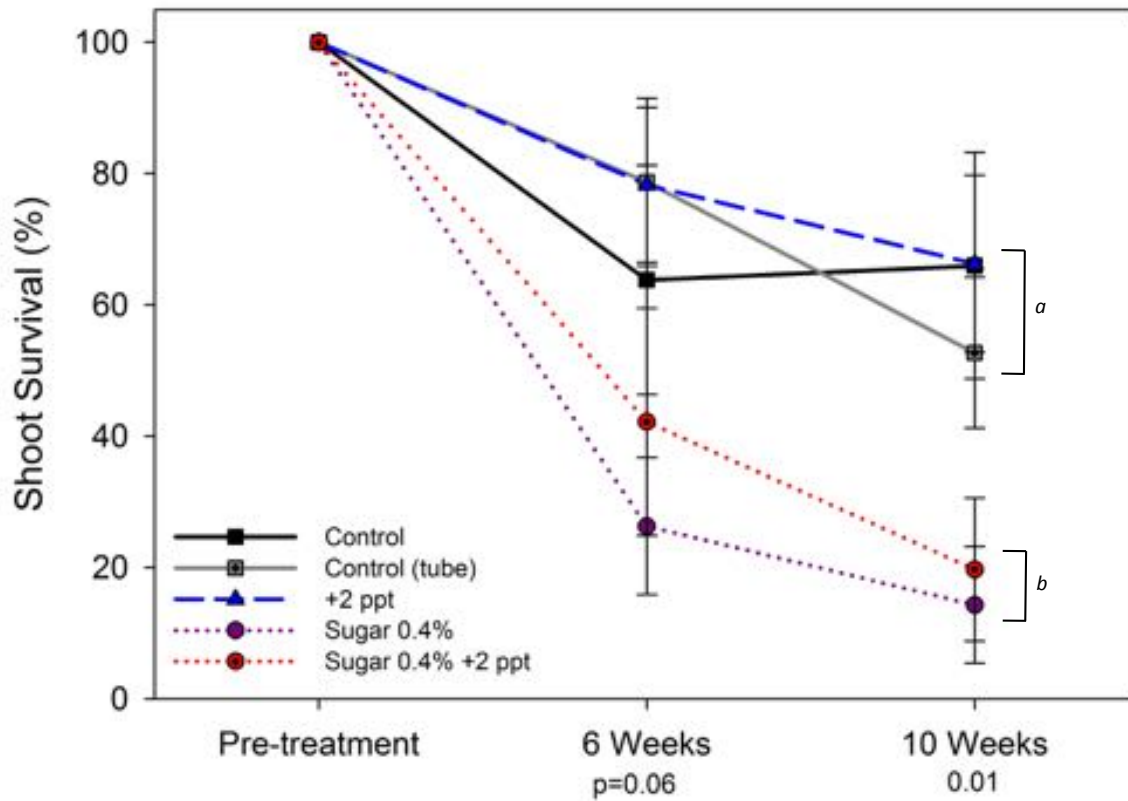


Figure 4. Field experiment measuring *Phragmites* shoot survival over time in controls (square symbols) and when treated with salt (triangle), sugar (circle) or both (circle with dot). Overall treatment effects were tested at week six and ten separately using ANOVAs (p values shown on the x-axis). Linear contrast groups and significant results are indicated by brackets and different letters.

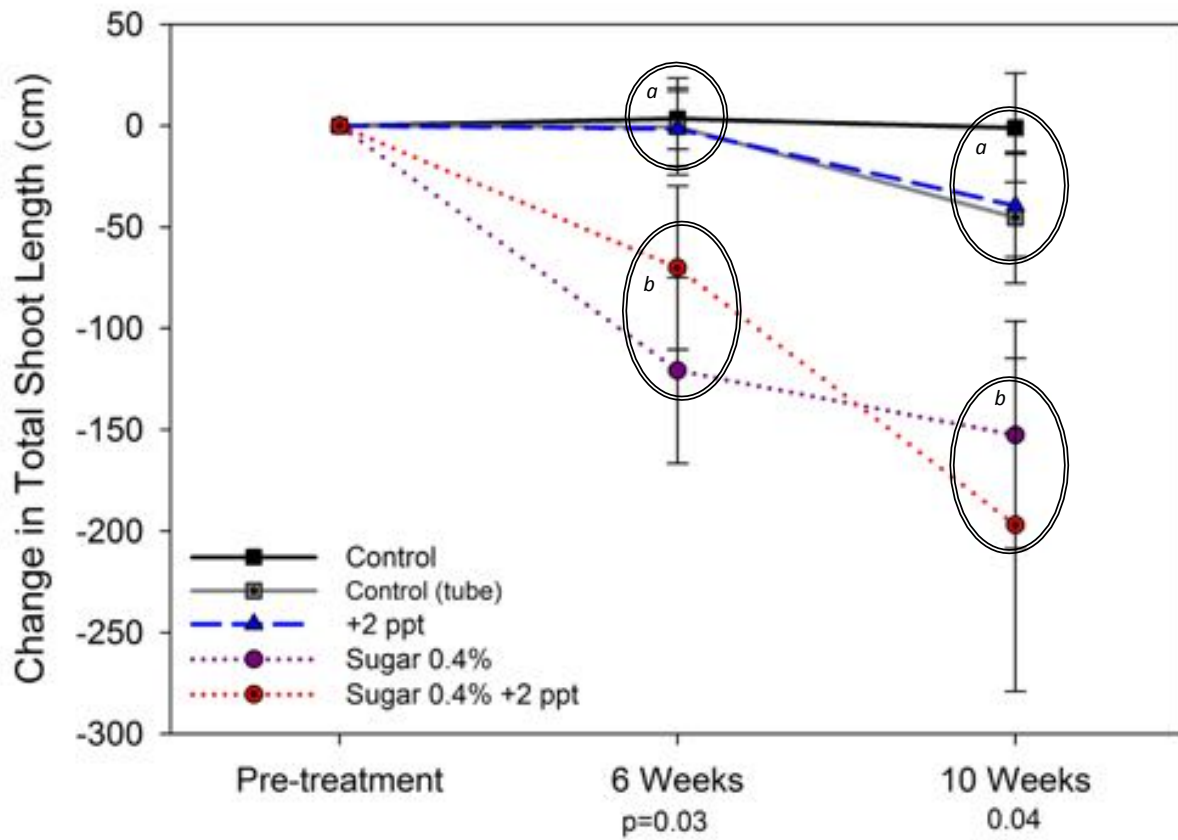


Figure 5. Field experiment measuring change in total shoot length of *Phragmites* over time in controls (square symbols) and when treated with salt (triangle), sugar (circle) or both (circle with dot). Overall treatment effects were tested at weeks six and ten separately using ANOVAs (p values shown on the x-axis). Linear contrast groups and significant results are indicated by brackets and different letters.

Table 2. Pore water results for the sugar and salt field experiment on *Phragmites* including means and standard errors for salinity, redox potential (corrected for pH), pH and sulfide concentration. Pore water was collected at approximately 20 cm depth.

Salinity (ppt)										
Week	Control		Control (tube)		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0	23.5	1.3	23.7	1.5	22.0	1.1	23.5	1.5	23.0	1.4
6	22.8	0.8	22.5	1.4	24.5	0.9	24.0	0.9	25.5	1.0
10	22.0	0.8	19.8	0.9	19.8	0.9	22.4	0.9	21.8	0.9

Redox Potential (mV)										
Week	Control		Control (tube)		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0	-119.5	27.2	-171.3	51.4	-184.8	45.1	-203.2	35.0	-197.3	56.9
6	-195.8	44.5	-225.0	51.8	-247.5	50.7	-273.3	29.3	-232.0	53.3
10	-112.3	35.7	-111.2	35.7	-86.2	36.7	-258.8	21.9	-280.5	24.7

pH										
Week	Control		Control (tube)		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0	6.07	0.08	6.1	0.1	6.11	0.08	6.08	0.08	5.72	0.41
6	7.22	0.09	6.96	0.20	7.01	0.09	7.13	0.05	6.74	0.38
10	6.33	0.15	6.45	0.19	6.56	0.19	6.12	0.30	5.34	0.34

Sulfides (mM)										
Week	Control		Control (tube)		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0	0.25	0.13	0.10	0.05	0.12	0.08	0.35	0.29	0.12	0.08
6	1.09	0.39	0.91	0.53	2.23	0.55	1.73	0.43	1.57	0.58
10	0.65	0.54	0.42	0.12	0.30	0.13	1.67	0.59	1.83	0.53

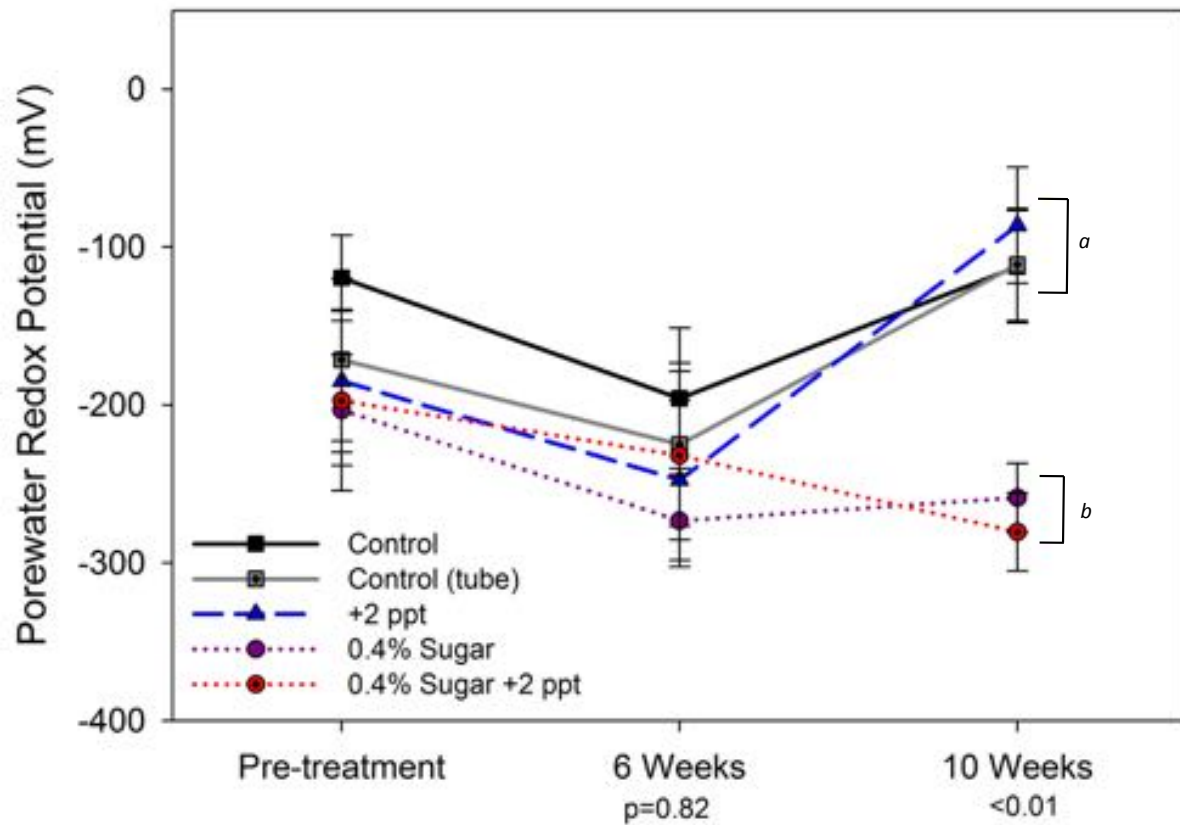


Figure 6. Pore water Eh from field experiment in controls (squares) and when treated with salt (triangle), sugar (circles) or both (circles with dots). Treatment was tested on weeks separately using ANOVA (p values are shown on the x-axis). Linear contrast groups and significant results are indicated by brackets and different black letters. Redox potential was corrected for pH deviating from 7.0 to arrive at Eh.

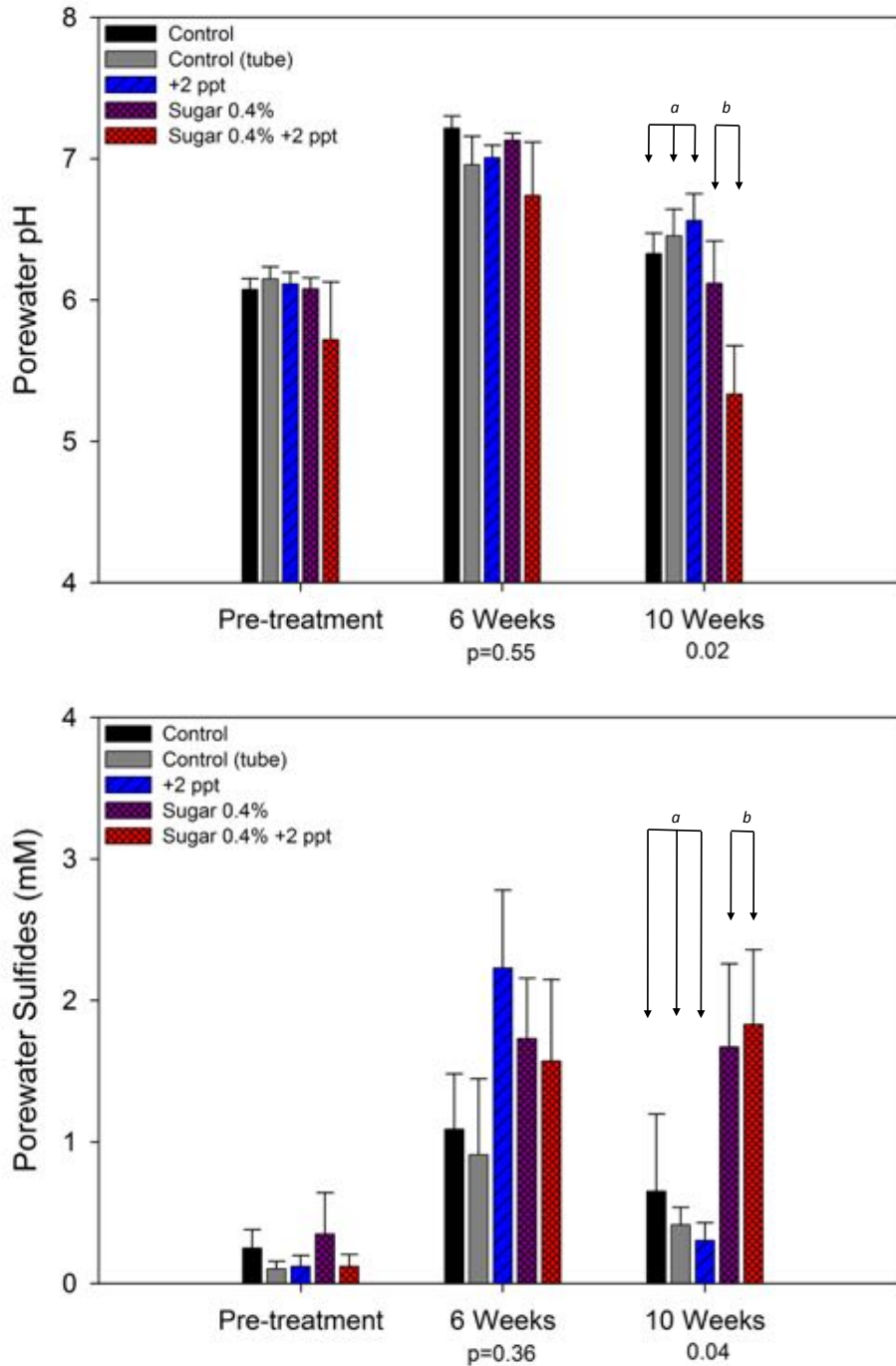


Figure 7. Field experiment pore water measures of: a) pH and b) Sulfide concentration for *Phragmites* exposed to: Control (no tube), Control (tube only), + 2 ppt Salinity, 0.4 % sugar and added salt and sugar treatments. Crosshatch bars represent treatments including sugar. Treatment effects were tested on weeks separately using ANOVA (p values shown on the x-axis). Linear contrast grouping and significant results are indicated by black arrows and letters.

Tidal Circulation Restoration

Methods: Two sites were selected for circulation restoration in the Great Marsh, between Pine Island and the Parker River. Large areas of open water in the high marsh with linear portions of pool shorelines, atypical of natural marsh pools, were examined in the field. Evidence of recent dieback of emergent marsh grasses, rafted mats of algae, and gradual deepening or shallow scarps were used to identify potential restoration sites. Two sites with these characteristics and possessing very close hydrologic pathways (either natural creeks or ditches) were selected for restoration (aerial Fig. 8).



Figure 8. Locus map showing North and South pools for runnel activities.

Using a hand spade, two drainages (30 cm wide and 15 cm in depth) were created in the large southern pool and one in the northern pool (Fig. 9). Drainage lengths varied from 60 to 200 cm in length. Water level recorders (based on capacitance, Odyssey™) were established in each pool, one hydrologic channel and a nearby unaltered pool with natural features to create a six-week record of tidal hydrology for each summer (Fig. 10).

Permanent vegetation monitoring plots were set up at the edges of each treated pool. Plots were 70 cm by 70 cm in size (0.5 m²) and established in pairs at the pool/marsh edge, with one in the pool and one in the high marsh. Visual estimation of plant cover by species was made in late spring and late summer of 2015 and late summer of 2016. Five sets of plots were randomly placed along four sides of each of the two pools (40 plot pairs total). In addition, pilot re-vegetation plots (about 1 by 1 m in size) were planted with 20 plugs of *Spartina alterniflora* at the edge of each side of the two pools (8 plots total). Plugs were collected from nearby healthy low marsh. Plant survival and cover were assessed at the peak of 2015 and 2016 growing seasons. Relative elevations of the water level recorders and each of the plant monitoring and revegetation plots were measured using a laser level and Real Time Kinematic (RTK) GPS system capable of ±2cm accuracy (Leica GSSN Rover model GS14).



Figure 9. David Burdick and Christopher Peter inspecting runnel at South Pool, Great Marsh (2016).

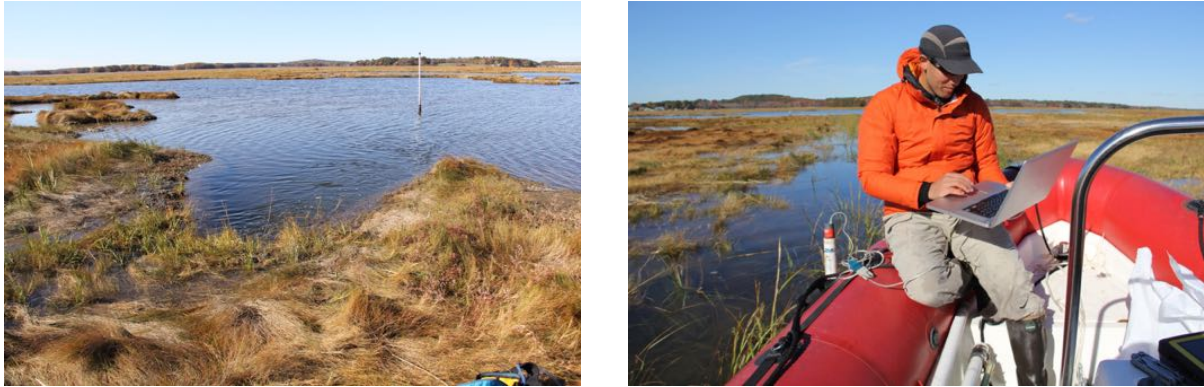


Figure 10. Pool with water level recorder in place (left) and downloading recorder data late in the season during a Spring tide (right).

Results and Discussion: Water level recorders located in or very near natural tidal creeks show both sites experience semi-diurnal tides, but with few tides overtopping the high marsh enough to completely flood the pools (Figs. 11 and 12). The water level recorder near the north runnel was placed higher in the intertidal zone because the tidal creek was less than 1 meter deep relative to the surface of the high marsh. The south runnel drainage was quite deeper, as reflected in the tidal signal. A complete set of graphs for all six water level recorders can be found in Appendix II.

The addition of shallow runnels in the two pools allowed a portion of each pool to drain, especially during neap tides. The edges of the pools were exposed to the air several hours each day on moderate tides and for several consecutive days during neap tides, rather than being submerged continuously (Figs. 11 and 12). As the pool edges drained on a more regular basis, *Spartina alterniflora* began to invade the mud and recapture the pool edges as marsh. This can be seen in the pie charts of the pool edge vegetation that show increases in cover of *S. alterniflora* (Figs. 13 and 14). In the North Pool, *Spartina patens* also appears to be increasing in cover at the pool edges (Fig. 13). Along the high marsh edge outside both pools (where flooding stress and smothering by wind and wave-blown algal mats had been killing the perennial grasses), we observed slight increases in *S. alterniflora*, and larger increases in *S. patens* (Figs. 13 and 14).

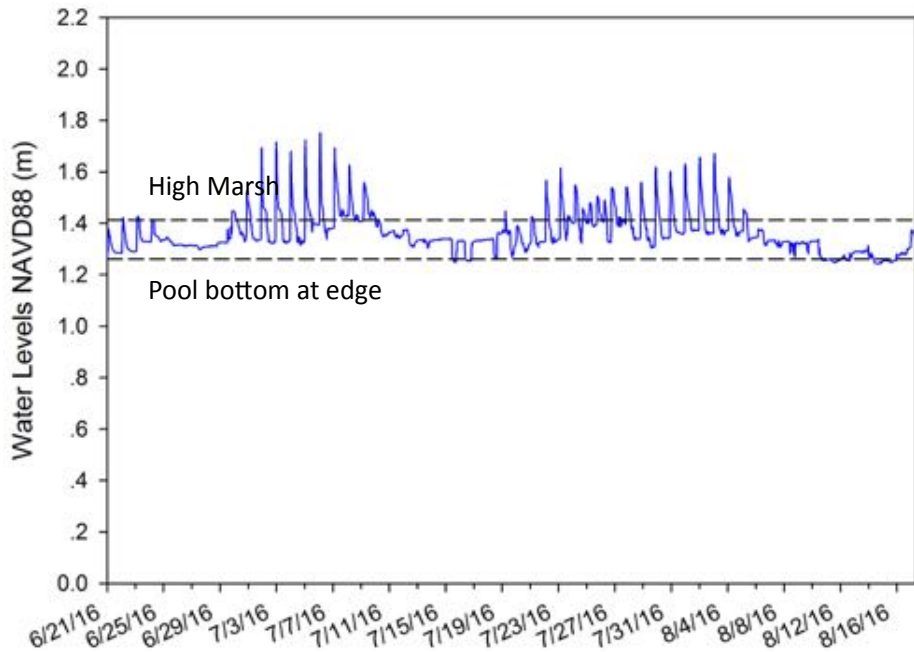
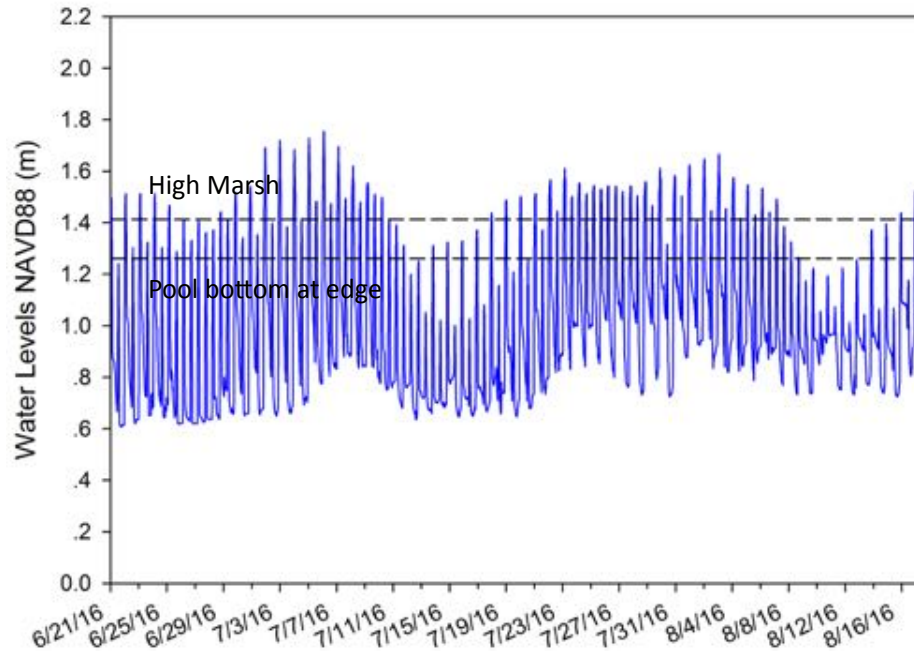


Figure 11. Water level records for Northern Pool showing: a) semi-diurnal tides in the drainage creek relative to the position of the high marsh and the bottom of the pool; and b) water levels in the pool with experimental runnel. Note: pool floods for several days every two weeks and drainage below the high marsh does not exceed 20 cm.

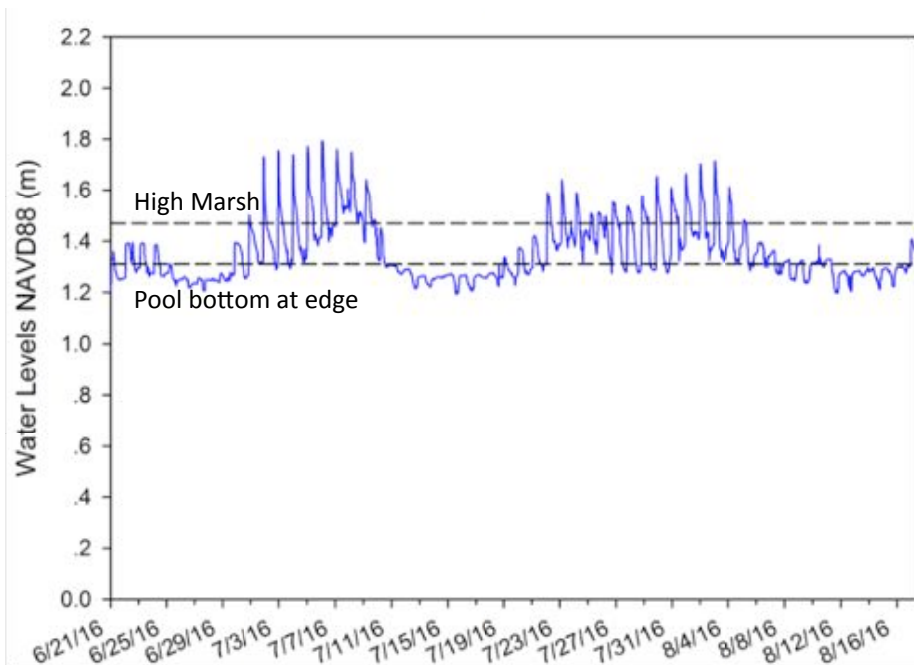
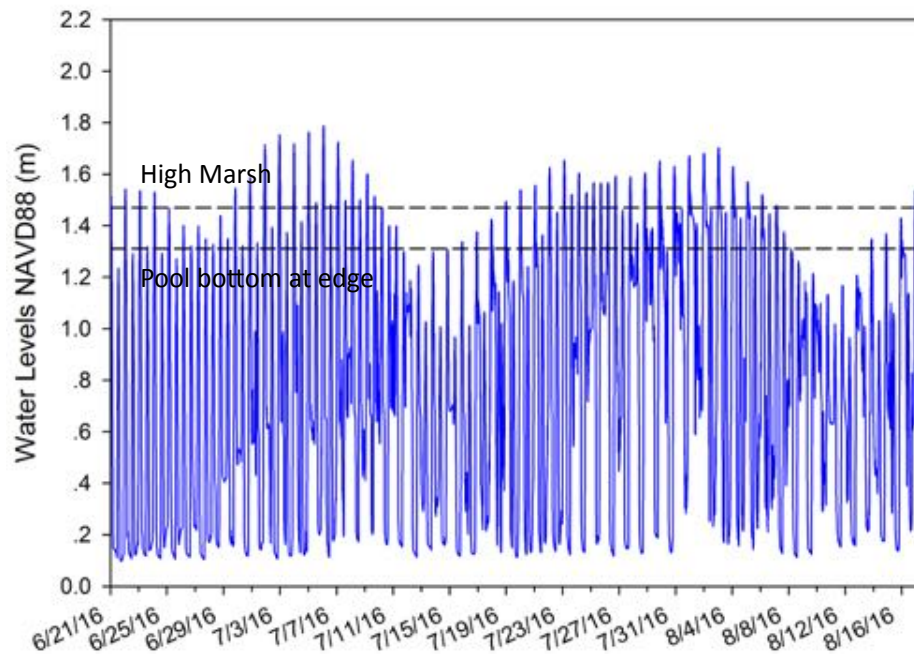


Figure 12. Water level records for Southern Pool showing: a) semi-diurnal tides in the drainage creek relative to the position of the high marsh and the bottom of the pool; and b) water levels in the pool with experimental runnel. Pool floods for several days every two weeks and drainage below the high marsh rarely exceeds 20 cm. (Note: signal for creek does not provide accurate data for many of the low tides.)

In addition to the natural colonization of the edges of the pools by native perennial grasses, we wanted to determine if we could accelerate the revegetation process by planting *Spartina alterniflora* in shallow muddy edges of the pool. We examined survival and percentage cover of plants in four plots around each pool following planting in summer of 2015 (Fig.15). By fall, survival was about twice as great in the North Pool (85%) compared to the South Pool (45%). Our observations suggest some plots in the larger South Pool were smothered by algal mats that killed the plants. The differences in plant survival were reflected in greater cover of *S. alterniflora* in the North Pool (35%) compared to the South Pool (25%) the following summer (Fig. 15).

It has only taken one year to show expansion of plants at the pool edges and success in planting *Spartina alterniflora* in experimental efforts to reverse the expansion of large pools and especially those pools that appear to be relicts of 20th century ditching practices. However, further monitoring will be required to determine whether high marsh will build up the surface elevation of the pool edges where high marsh had previously collapsed and ultimately improve marsh resilience to storms and sea level rise.

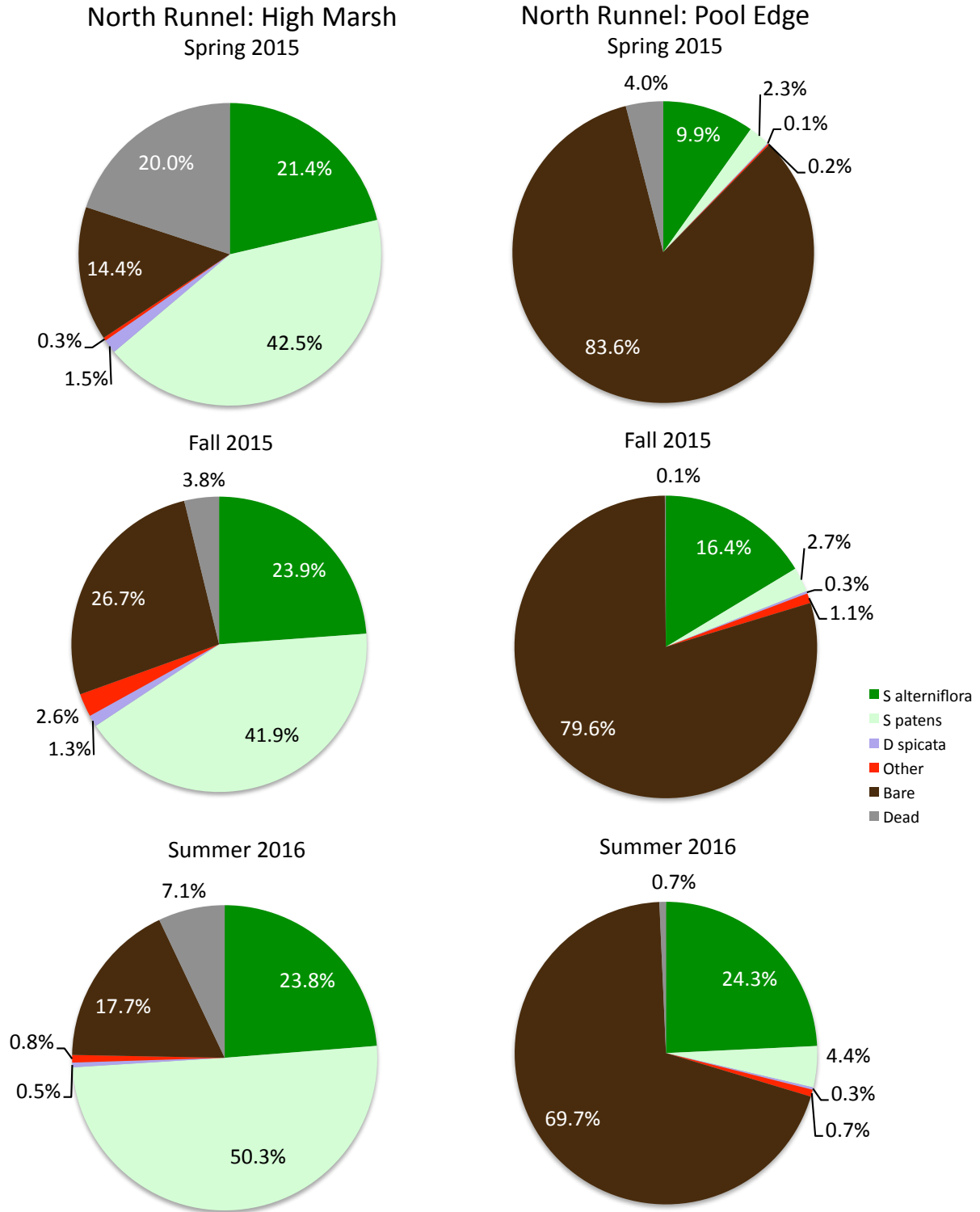


Figure 13. Vegetation of permanent plant plots adjacent (high marsh) and within (pool edge) North runnel treatment pool.

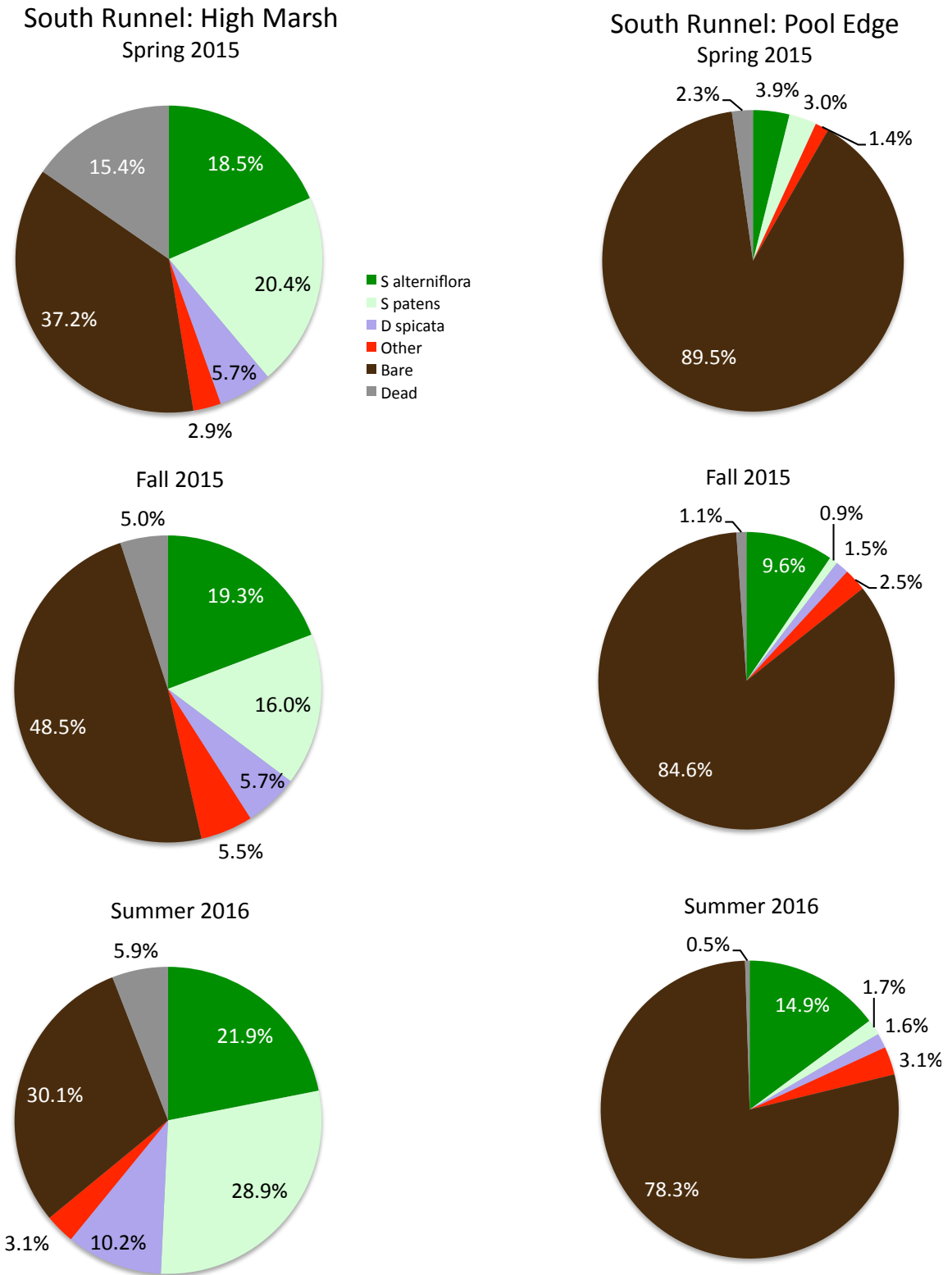


Figure 14. Vegetation of permanent plant plots adjacent (high marsh) and within (pool edge) South runnel treatment pool.

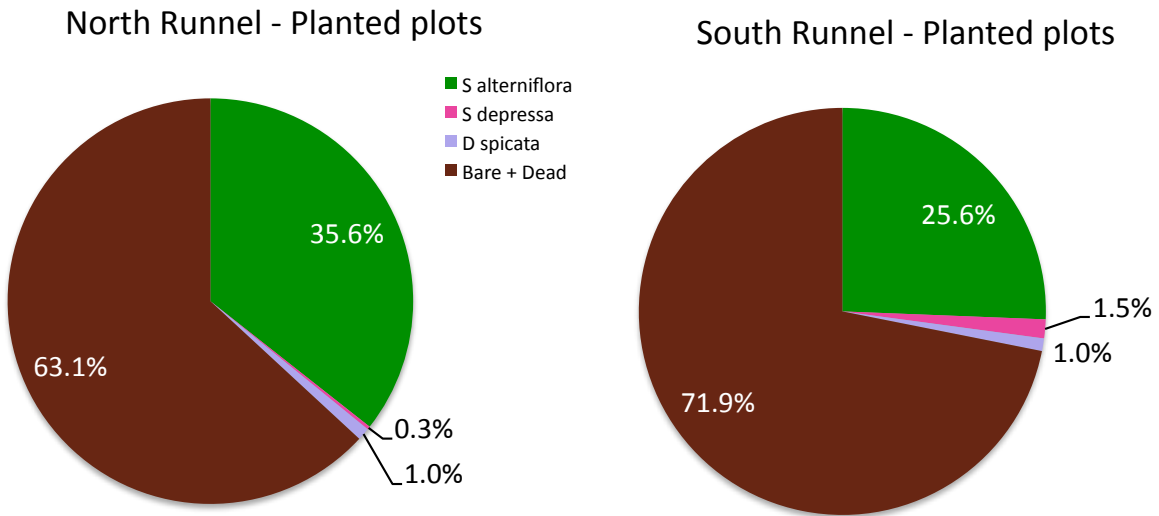
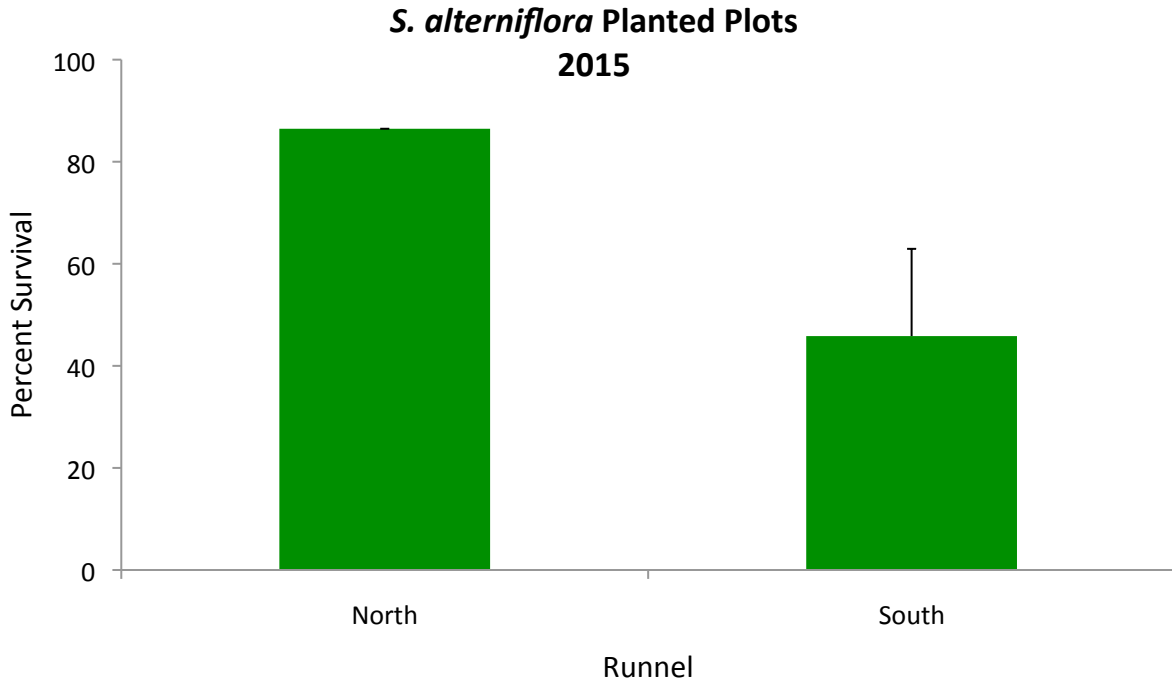


Figure 15. Survival of *Spartina alterniflora* planted within pools in fall 2015 (upper) and plant cover in planted plots the following growing season (2016, lower pie charts).

Ditch Remediation

Methods. Four areas with dense ditching around Nelson’s Island were selected for remediation (Fig. 16). In total, nine ditches were treated in fall 2014 and again one year later in fall 2015 using a technique developed by Geoff Wilson of Northeast Wetland Restoration. Eight ditches were left untreated since our goal was not to eliminate all ditches but to reduce the number of ditches. Salt hay was cut on the marsh surface, raked or blown into the treatment ditch, and secured with twine (Fig. 17) by Northeast Wetland Restoration.



Figure 16. Ditch remediation plots at Nelson’s Island, Rowley, Massachusetts.



Figure 17. Ditch recently filled with salt hay mown from marsh on right. Twine holds cut grasses in place and is biodegradable.

We selected three approaches to monitor the changes we expected to observe in the marsh due to the slow process of these experimental ditches becoming shallower and colonized by low marsh plants (e.g. *Spartina alterniflora*). Approaches included 1) detailed elevation transects using a laser level to measure the elevation along cross-sections of the marsh that included both treatment and control (unfilled) ditches (Fig. 18); 2) establishment of photo stations located at opposing ends of each ditch; and 3) establishment of vegetation monitoring plots on the marsh surface and in the ditches.



Figure 18. Surveying marsh surface, ditch edge and bottom elevations along perpendicular transects in Nelson's Island marsh.

Results and Discussion: The first set of elevation transects were done to establish a baseline so we could measure subsequent changes in ditch depths. However, the transect results also revealed subsidence of the entire high marsh surface where ditches were spaced fairly close together (<20 meters). Transects were run on four occasions from fall 2014 to fall 2016. For the sake of brevity, we show one transect over time to illustrate the subsidence associated with closely spaced ditches and the shallowing of some of the ditches that were partially filled with the cut vegetation (Fig. 19).

Not all, but most treated ditches became significantly shallower, with an average increase in bottom elevation of 15 cm (+/- 2 cm) compared with no change in untreated ditches (0 cm +/- 4 cm) after two years. As ditches became shallower, they began to support more low marsh grass: *Spartina alterniflora*. A BACI design (2015 vs. 2016 and treated vs. untreated) was used to test if there were more shoots or more cover of *S. alterniflora* in ditches following treatment. Both tests were significant at the 0.10 level, suggesting the treated ditches were becoming more vegetated with *S. alterniflora* (Fig. 20). Note that stem counts and percentage cover appeared to have already increased by summer of 2015 relative to the untreated ditches.

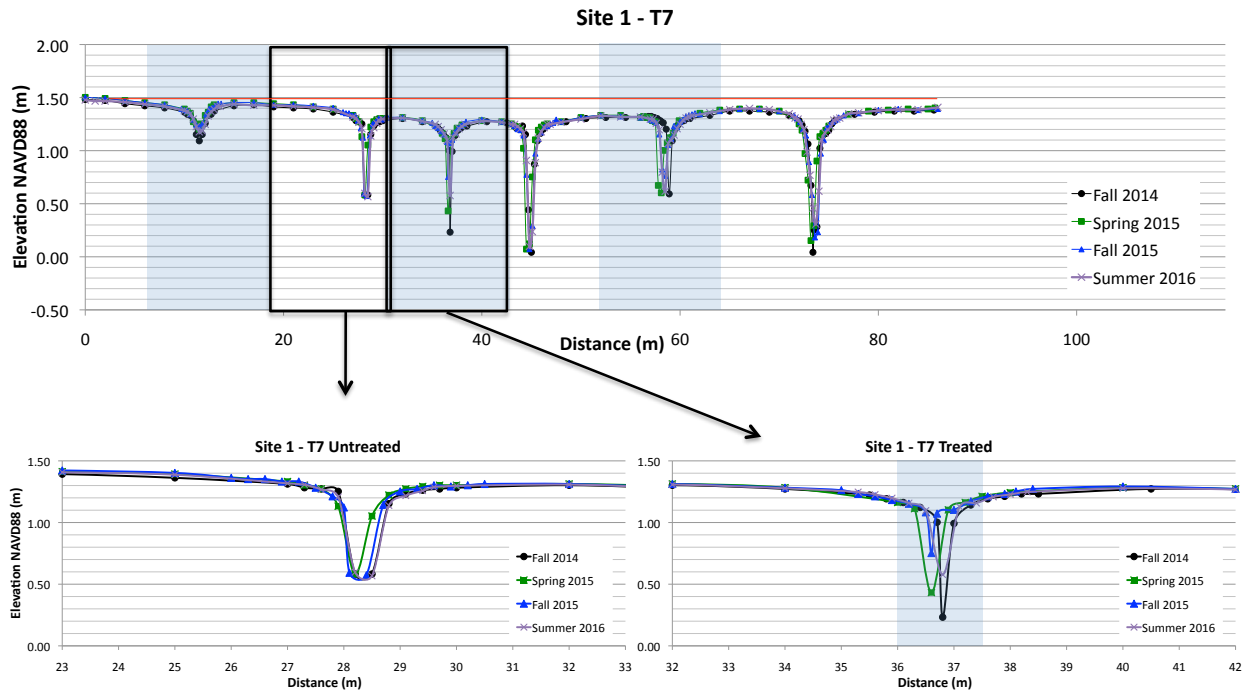


Figure 19. Elevation cross-section of ditch remediation Site #1 showing three treated (shaded in blue) and three untreated ditches over two years (fall 2014 to summer 2016). Insets show details of one treated and untreated ditch. Horizontal line is a guide to show relative amount of high marsh subsidence associated with the dense ditch spacing. Note shallow ditch on left (30 cm deep) does not show local subsidence.

Photo stations were established prior to ditch remediation actions. Wood stakes marked photo stations, however many stakes were dislodged and missing by the following spring. Nonetheless, landscape features and the ditch ends themselves facilitated repeated photos and aided in photo interpretation. While not all ditches treated resulted in visual changes to creek bottom topography, the majority did appear to grow narrower to the naked eye. Bank vegetation was noticeably more dense, perhaps growing more vigorously due to the added nutrient input from marsh cuttings additions (Figure 21).

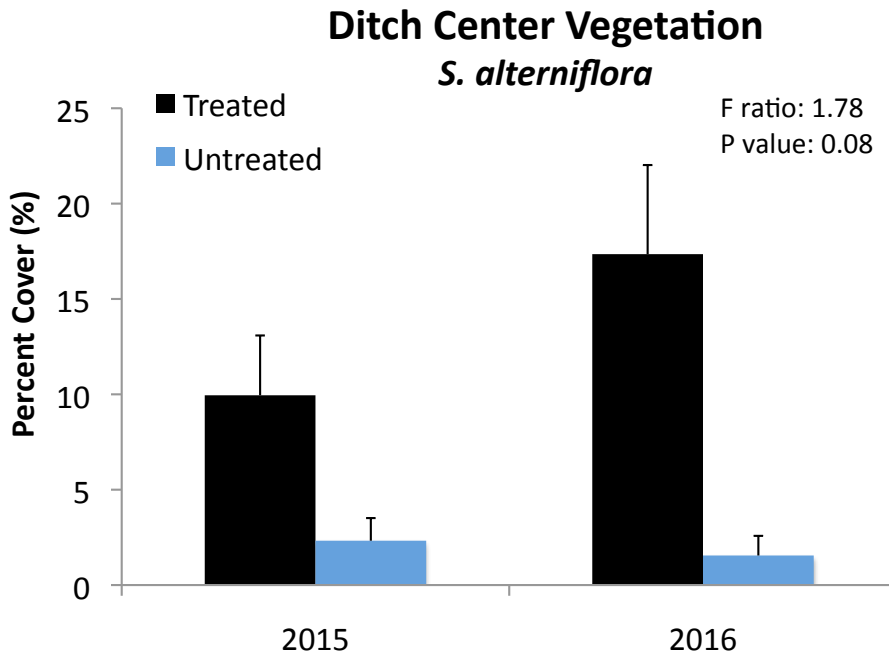
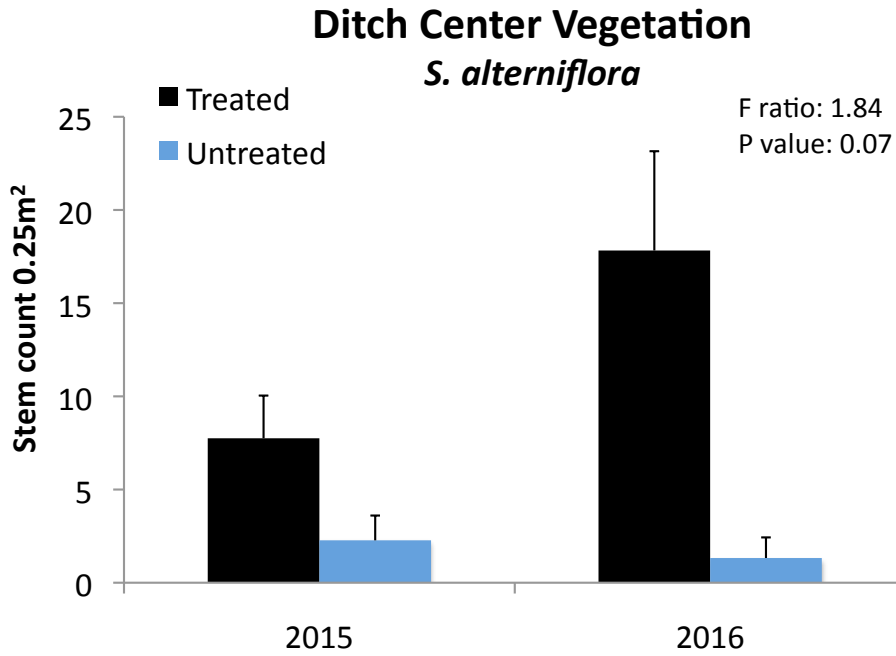


Figure 20. *Spartina* growth in treatment and control ditches showing shoot number and percentage cover and results from a BACI design analysis with F ratios and *p* values shown for the interactive term of treatment by date. Note that ditch treatments began in 2014.



Figure 21. Example of one of the experimental ditch plots with marsh cuttings additions. While difficult to assess changes to creek bottom elevation, the bank vegetation does appear more dense and creek width grows narrower over time. A complete photo series for all sites can be found in Appendix III.

Plant Community Development Following *Phragmites* Removal

Methods: In August 2015 vegetation and soil pore water were assessed at pre-established *Phragmites* plots (1 m² in size) to determine the effects of previously applied herbicide traditionally used to control *Phragmites* in the Great Marsh. The herbicide was applied between 2008 and 2011 to seven *Phragmites* stands. Plots had been established at the centers and edges of the stands as well as at native, untreated high marsh. At several herbicide treated sites, *Phragmites* was all but eliminated from the original stand centers established in 2009. In some cases, however, a remnant/reinvaded stand emerged in close proximity to the original stand center. Vegetation and pore water were also assessed at these stands. Vegetation metrics included percentage cover by species (grouped as native halophytes here), number of species and *Phragmites* cover, shoot density and height (three tallest). Pore water was withdrawn at two depths (15 and 40 cm) at each plot and measured for salinity, pH, redox potential and sulfide concentration. See previous section (Innovative *Phragmites* Control) for detailed pore water methods.

Results and Discussion: Pore water Eh was greater in the shallow pore water and although not statistically significant, native soils showed lower Eh and new *Phragmites* stands the highest Eh (Fig. 22). Conversely, native marsh showed the greatest sulfide accumulation and new *Phragmites* stands the least sulfides. Our results support the idea that *Phragmites* is able to oxidize the soil, increasing Eh and decreasing the reduced sulfides (Amsberry et al. 2000, Burdick and Konisky 2003, Chambers et al. 2003), resulting in less stressful growing conditions. Pore water salinity varied between 18 and 23 ppt while pH varied between 6.1 and 6.7, with neither variable related to plot type or soil depth.

Vegetation characteristics showed native high marsh had the greatest cover of halophytes (native marsh plants) and reinvaded marsh had the lowest halophyte cover and the greatest *Phragmites* cover, as might be expected (Table 3). Treated areas had the greatest richness (greatest number of native marsh species), averaging 6.3 species per plot, while the plots reinvaded by *Phragmites* had the lowest. Treated stands also had low amounts of *Phragmites* persisting, showing herbicide application requires follow up with spot treatment in later years. The data also show that removal of *Phragmites* had a stimulating effect on species richness of the native marsh, presumably due to new resources becoming available (space, light and nutrients) to less common plants that existed in the seed bank (Ailstock et al. 2001).

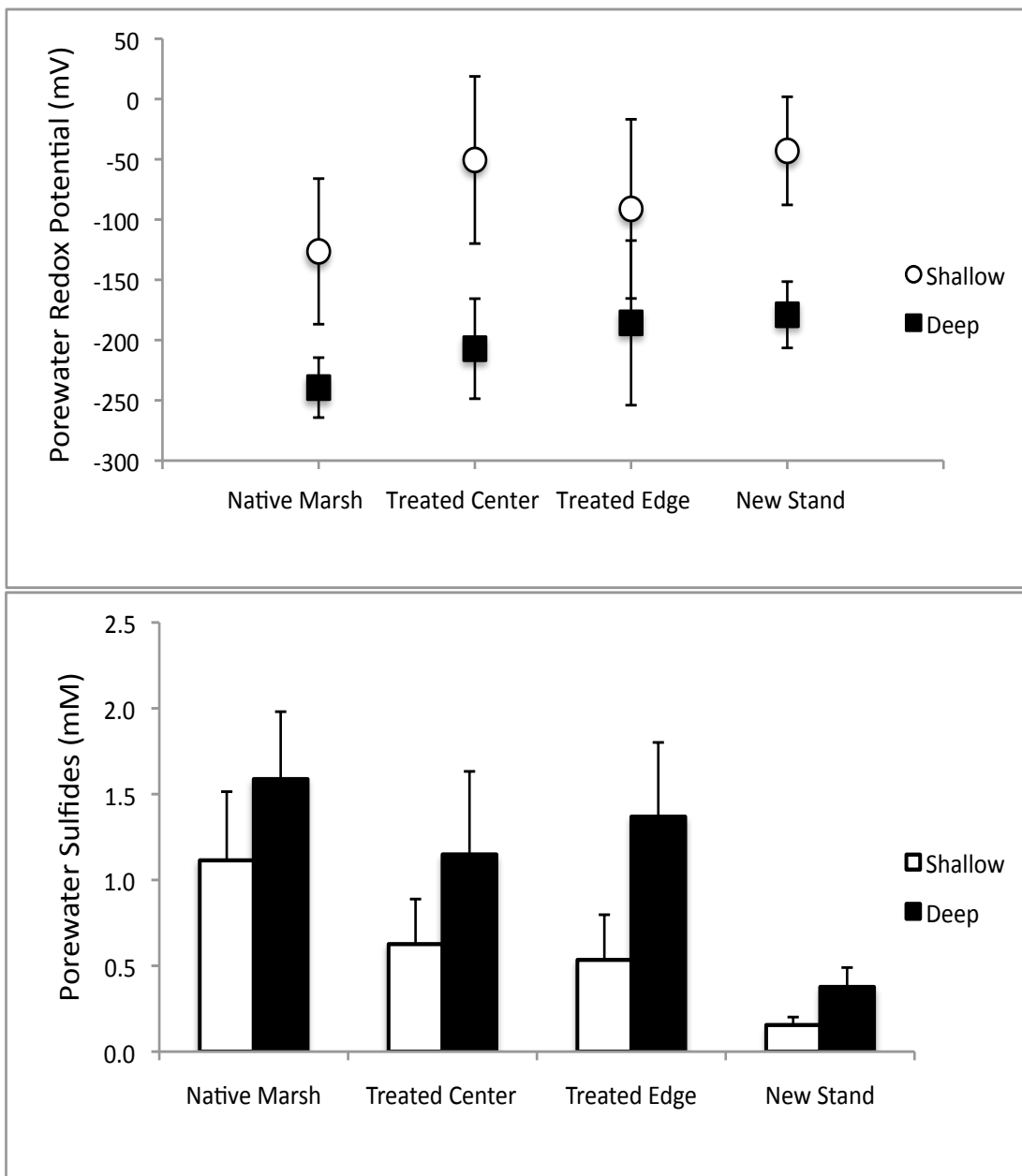


Figure 18. Pore water redox potentials and sulfide concentrations at shallow (15 cm) and deep (40 cm) soils of native high marsh, the center and edges of *Phragmites* stands treated with herbicide in 2008-2011 and new *Phragmites* stands.

Table 3. Characteristics of marsh vegetation in treated *Phragmites* stands (herbicide used in 2008 - 2011), marsh areas reinvaded by *Phragmites*, and native high marsh.

	Treated		Reinvaded		Native	
	X	SE	X	SE	X	SE
% Total Live	88.0	2.1	90.5	3.3	92.6	2.0
% Halophytes	79.3	6.8	39.8	8.7	92.6	2.0
% Bare Ground	7.6	1.1	6.5	1.5	4.0	1.0
% Dead	7.7	1.2	8.3	1.7	8.0	1.2
% Wrack	0.0	0.0	0.0	0.0	0.0	0.0
Richness of Halophytes	6.3	1.1	3.3	0.6	3.7	0.5
<i>Phragmites</i> Morphology						
Percent Cover	7.1	6.3	50.8	8.7	0.0	0.0
Height (cm)	108.3	51.0	163.1	13.0	0.0	0.0
Density (m ⁻²)	16.6	15.0	96.0	31.9	0.0	0.0

The efficacy of herbicide control and the return of a native plant community with high diversity (relative to native marsh) are both signs that the management strategy at Parker River NWR is working; not only is it effective in reducing dominance of invasive, exotic *Phragmites*, and reducing its spread, but also establishing excellent growing conditions for the return of a high diversity native marsh plants. There is however, the possibility for *Phragmites* to these reinvade these areas or adjacent areas if further management is not continued. Currently, *Phragmites* still inhabits half the monitored sites, albeit as highly reduced populations.

Outreach: Sharing our results with the scientific community as well as coastal resource managers and restoration practitioners is an important goal of all of our projects. It is especially important here since this particular research was supported by Sandy funding to aid in managing for healthy resilient marshes that provide critical ecosystem services for our society.

We presented our findings from the runnel and ditch remediation research at three regional and two international meetings: 1) Merrimack Valley Beach Alliance meeting held at Parker River NWR at the request of Senator Bruce Tarr on 30 October 2015; 2) Regional USFWS Marsh Management Meeting Parker River NWR on 15 November 2015; 3) Two abstracts at the Society for Wetlands Scientists Annual Meeting Providence RI, May-June 2015; and 4) Restore America's Estuaries conference in December 2016 (See Appendix IV for abstracts).

Summary

Salt marshes have been recognized as a self-maintaining habitat that supports many fish and wildlife species as well as providing humans with critically important ecosystem services, such as protection from storms and erosion, sea level rise, filtration of pollutants and cycling of key nutrients (Barbier et al. 2011, Chmura et al. 2012). Since many salt marshes have been lost to filling and dredging and others have been degraded by restricted hydrology and invasive species (e.g. *Phragmites australis*), it is especially important for coastal managers to manage salt marshes to ensure their vitality and ability to respond to sea level rise and storms. This point was made clear by the passage of Superstorm Sandy, where healthy marsh systems showed little damage, did not require emergency management funds and protected landward development.

Unfortunately many of our salt marshes are degraded by invasive *Phragmites* and may not be able to provide quality habitat for fish and wildlife (Burdick and Konisky 2003). Our report shows that the current management strategy using herbicide control of specific *Phragmites* stands before they become large appears to remove most of the invader and provides good habitat to support the development of a diverse mix of native marsh plants for several years. Where the use of herbicide conflicts with the mission of the Reserve, such as in Rachel Carson NWR, we have investigated non-herbicide methods of *Phragmites* control using natural products, (e.g. table sugar). Both greenhouse and field experiments showed that repeated treatments of low amounts of sugar (0.4% in the soil pore water) is effective at reducing plant vigor and survival. The addition of sugar stimulates bacterial respiration, which drives down the soil pH and Eh and fosters accumulation of sulfides, toxic to *Phragmites* at lower levels than native plants. Just as *Phragmites* has been shown to ameliorate soil stressors through the oxidizing effect of their roots and rhizomes (Amsberry et al. 2000), the addition of sugar counteracts such benefits and magnifies soil stressors.

Other marshes are exhibiting long-term legacy impacts from the ditching that was prevalent in the 20th century. Intense ditching in some marshes has led to subsidence, shown clearly by the cross-sections across the marsh platform. We found that ditch remediation, where perennial grasses are cut at the end of the growing season and added to the ditch, reduced the depth of ditches. This practice also encouraged the growth of *Spartina alterniflora* in the ditches, which is expected to help the ditches fill even faster over time. Reducing the intensity of ditches that over drain the marsh and oxidize the sediments was shown to be a feasible management action, but it will be important to continue monitoring to determine whether the shallower ditches lead to complete restoration. We hypothesize ditches less than 30 cm deep will allow more rapid accumulation of surface sediments across the surface of the entire high marsh to increase its surface elevation, thus making the marsh more resilient to impacts from sea level rise.

Another legacy impact from ditching appears as large pools on the marsh platform. Pools form because surface flows become impounded between ditches and spoil piles, resulting in large pools, often with straight linear sides. These pools are atypical of natural pools on the high marsh and expand as water is trapped, causing flooding stress to high marsh plants and allowing algal mats to smother vegetation along the edge, leading to marsh collapse and further pool expansion. Based on some pioneering work in Rhode Island (Sue Adamowicz, personal communication), we established runnels, shallow drainage features, 20 cm deep and up to 200 cm long, in two experimental pools. Data from water level recorders and our observations show that these shallow runnels allowed pools to partially drain, especially during neap tide periods. The exposed mud flat allowed for formerly retreating edge vegetation to expand into the pools. Low marsh plants (e.g. *Spartina alterniflora*) and pioneering native species including *Salicornia depressa* were able to survive and flourish in the shallow pool edges, no longer chronically flooded or smothered by algae. The runnel approach piloted here appears to be an efficient way to prevent unchecked expansion of impounded areas where emergent grasses have been declining, leading to peat collapse.

Both the ditch remediation and pool runnel techniques appear to be especially well suited to marsh management where the goal is increasing the resilience of the marsh to climate change and reducing legacy impacts from ditching. Both represent small to moderate scale opportunities for increasing marsh resiliency with relatively little impact or need for engineered or chemical-based solutions. Moreover, since areas suitable for these approaches are easily identified using aerial photo interpretation and GIS, it is relatively simple for resource area managers to map areas and develop a modular approach of implementation over multiple years to bring about resiliency actions gradually and as-needed to meet management goals within limited budget cycles.

Acknowledgements

Our efforts were funded by the U.S. Fish and Wildlife Service (USFWS): Hurricane Sandy DOI #FWS/R5/CGS and FWS Contract No.F14AP00522; Hurricane Sandy; Restore the Great Marsh. We are thankful for the cooperation and support of Parker River National Wildlife Refuge in Newburyport, MA, where all the field projects occurred. The staff at these NWR's, specifically, Susan Adamowicz, Frank Drauszewski, Nancy Pau, Bob Springfield and Katie Bland all made significant contributions to this project. In addition, Hanna Mogensen, Devin Batchelder, Sydney Nick and Charlie Williford participated in field or lab components of the project. We thank the Conservation Commissions, their staff and the towns of Newbury and Rowley for hosting our experimental research in their marshes. Finally, we thank Dave Shay and the staff at Jackson Estuarine Laboratory, University of New Hampshire for help with logistics and in conducting the greenhouse experiment.

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Appendix I. Photographic record of the greenhouse experiment growing *Phragmites* with salt and sugar additions.

0 Weeks



1 Week



2 Weeks



3 Weeks



4 Weeks



5 Weeks



6 Weeks



7 Weeks



8 Weeks



9 Weeks



10 Weeks



39 Weeks



55 Weeks



Appendix II. Additional Data and Results

Pore water results for the *Phragmites* greenhouse experiment.

Week	Shallow Salinity (ppt)								Deep Salinity (ppt)							
	Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt		Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0									13.7	0.3	14.7	0.3	15.7	0.7	15.0	1.5
2	16.0	1.0	17.7		17.7		17.3	0.3	15.0	0.6	16.7	1.3	18.0	0.0	16.3	1.7
4	15.7	0.7	20.0	0.3	17.7	0.3	18.7	0.3	14.3	0.3	17.7	1.3	18.3	0.3	18.3	0.3
6	19.7	0.3	23.7	1.0	21.0	0.9	21.3	0.9	16.7	0.7	21.0	2.6	20.3	0.3	18.7	1.2
8	20.3	0.3	26.0	0.7	21.7	1.5	24.3	1.2	18.7	1.3	21.0	2.3	23.0	3.5	19.3	1.7
10	24.0	0.0	29.0	1.0	26.7	1.7	29.3	1.5	22.3	1.2	27.0	2.1	27.0	2.1	25.3	2.3
55	36.7	1.7	39.7	1.0	1.8		27.0	0.6	36.7	1.7	37.7	1.5			28.7	0.9

Week	Shallow Redox Potential (mV)								Deep Redox Potential (mV)							
	Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt		Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0									-344.0	11.4	-351.3	23.1	-349.3	13.4	-356.7	12.8
2	-288.3	25.2	-303.7	11.6	-306.3	18.5	-305.0	31.3	-346.3	20.3	-356.3	21.2	-336.0	16.8	-360.0	13.3
4	-314.7	21.5	-337.3	27.4	-356.3	6.6	-307.7	5.8	-379.7	2.4	-381.3	7.2	-368.0	14.0	-322.0	13.6
6	-322.3	1.7	-317.3	11.1	-352.7	10.2	-339.3	29.7	-364.0	4.4	-371.3	5.9	-350.0	31.8	-347.7	19.0
8	-332.3	17.9	-329.3	13.6	-327.0	24.0	-340.3	11.7	-351.3	15.9	-340.7	6.8	-338.7	13.3	-356.0	9.1
10	-348.7	15.2	-347.7	3.0	-381.7	46.4	-387.7	6.4	-357.3	3.5	-357.3	9.2	-388.0	18.0	-391.0	6.2
55	-341.3	20.3	-348.7	15.1			-282.7	25.9	-337.0	50.6	-398.7	13.8			-347.0	34.7

Week	Shallow pH								Deep pH							
	Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt		Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0									7.09	0.07	7.18	0.11	7.21	0.09	7.02	0.21
2	6.09	0.11	6.35	0.08	6.01	0.31	6.10	0.30	6.01	0.37	6.80	0.17	5.47	0.33	6.14	0.38
4	6.50	0.35	6.07	0.12	5.59	0.55	5.94	0.12	6.54	0.10	6.39	0.09	4.81	0.18	5.82	0.29
6	6.17	0.05	6.19	0.17	5.26	0.53	5.25	0.44	6.24	0.19	6.40	0.03	5.02	0.70	5.87	0.63
8	6.35	0.25	6.03	0.21	4.90	0.48	4.31	0.23	6.47	0.24	6.52	0.18	5.22	0.74	4.96	0.34
10	5.61	0.37	6.05	0.21	4.62	0.51	4.23	0.14	6.38	0.25	6.54	0.13	4.50	0.41	4.70	0.72
55	6.12	0.09	5.88	0.34			5.66	0.28	6.10	0.13	5.99	0.33			5.30	0.68

Week	Shallow Sulfides (mM)								Deep Sulfides (mM)							
	Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt		Control		+2ppt		Sugar 0.4%		Sugar 0.4% +2ppt	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
0									2.57	1.04	3.37	0.35	2.74	0.29	2.91	0.06
2	1.01	0.51	1.43	0.49	1.90	0.49	1.30	0.64	1.84	0.92	3.34	0.07	3.24	0.23	3.29	0.32
4	2.07	0.69	1.75	0.65	2.74	0.20	2.48	0.45	3.30	0.14	3.05	0.21	2.65	0.22	2.42	0.45
6	1.81	0.23	1.43	0.61	1.86	0.27	2.00	0.39	2.22	0.11	2.70	0.26	2.43	0.03	2.76	0.42
8	2.43	0.09	1.73	0.40	2.69	0.26	2.62	0.38	2.62	0.08	3.20	0.20	3.02	0.24	2.93	0.29
10	0.97	0.42	1.82	0.10	2.60	0.53	2.74	0.47	2.89	0.19	3.00	0.64	2.79	0.49	3.00	0.19
55	1.49	0.60	1.61	0.64			0.66	0.30	1.69	0.84	2.78	0.07	2.87		1.26	0.76

Permanent vegetation plot results at South and North pools with experimental runnels.

South Pool	Fall 2014		Spring 2015		Fall 2015		Summer 2016	
	High Marsh	Pool Edge	High Marsh	Pool Edge	High Marsh	Pool Edge	High Marsh	Pool Edge
<i>Agalinas maritima</i>	0	0	0	0	0.1	0	0	0
<i>Atriplex patula</i>	0	0	0.1	0	0.4	0.1	0.1	0
<i>Distichlis spicata</i>	12.5	3.0	5.7	0.0	5.7	1.5	10.2	1.6
<i>Glaux maritima</i>	0	0	0	0	0	0.1	0	0
<i>Juncus gerardii</i>	0	0	1.0	0.3	0	0	0	0
<i>Limonium nashii</i>	0	0	0.0	0	0.0	0	0.0	0.0
<i>Plantago maritima</i>	0	0	0	0	0	0	0.1	0.0
<i>Puccinellia maritima</i>	0	0	0.0	0	1.0	0	0.5	0
<i>Ruppia maritima</i>	0.1	3.1	0.0	1.6	0	1.9	0.4	1.5
<i>Salicornia depressa</i>	0	0	0.8	0.2	0.8	0.4	0.1	1.5
<i>Solidago sempervirens</i>	0	0	0	0	0	0	0.0	0
<i>Spartina alterniflora</i>	18.5	5.6	18.5	3.9	19.3	9.6	21.9	14.9
<i>Spartina patens</i>	23.8	5.2	20.4	3.0	16.0	0.9	28.9	1.7
Total	54.9	16.8	46.4	8.9	43.3	14.3	62.1	21.2

North Pool	Fall 2014		Spring 2015		Fall 2015		Summer 2016	
	High Marsh	Pool Edge	High Marsh	Pool Edge	High Marsh	Pool Edge	High Marsh	Pool Edge
<i>Agalinas maritima</i>			0	0	0.0	0	0	0
<i>Atriplex patula</i>			0.0	0	0.0	0.0	0.2	0
<i>Distichlis spicata</i>			1.5	0.1	1.3	0.3	0.5	0.3
<i>Glaux maritima</i>			0	0	0	0.0	0	0
<i>Juncus gerardii</i>			0.0	0.0	0	0	0	0
<i>Limonium nashii</i>			0.1	0	0.2	0	0.5	0.1
<i>Plantago maritima</i>			0	0	0	0	0.2	0.3
<i>Puccinellia maritima</i>			0.3	0	0.0	0	0.0	0
<i>Ruppia maritima</i>			0.0	0.2	0	0.8	0.0	0.0
<i>Salicornia depressa</i>			0.0	0.0	2.1	0.3	0.2	0.2
<i>Solidago sempervirens</i>			0	0	0	0	0.4	0
<i>Spartina alterniflora</i>			21.4	9.9	23.9	16.4	23.8	24.3
<i>Spartina patens</i>			42.5	2.3	41.9	2.7	50.3	4.4
Total			65.7	12.4	69.3	20.3	75.9	29.4

Appendix III
1-1 East



Appendix III
1-1 West



Appendix III
1-2 East



Appendix III
1-2 West



**Appendix III
1-3 East**



Appendix III
1-3 West



Appendix III
1-4 East



Appendix III
1-4 West



Appendix III
1-5 East



Appendix III
1-5 West



Appendix III
1-6 East



Appendix III
1-6 West



Appendix III
2-1 North



Appendix III
2-1 South



Appendix III
2-2 North



Appendix III
2-2 South



Appendix III
2-3 North



Appendix III
2-3 South



Appendix III
2-4 North



Appendix III
2-4 South



Appendix III
3-1 East



Appendix III
3-1 West



Appendix III
3-2 East



Appendix III
3-2 West



Appendix III
3-3 East



Appendix III
3-3 West



Appendix III
4-1 North



Appendix III
4-1 South



Appendix III
4-2 North



Appendix III
4-2 South



Appendix III
4-3 North



Appendix III
4-3 South



Appendix III
4-4 East



Appendix III
4-4 West



Appendix IV.

New England Estuarine Research Society, Semi-annual meeting in York Maine, April 2016

D. M Burdick*(1) C. R. Peter (1), G. E. Moore (1), S. Adamowicz (2), N. Pau (3)

(1) Jackson Estuarine Laboratory, University of New Hampshire, Durham, NH

(2) Rachel Carson National Wildlife Refuge, Wells, ME

(3) Parker River National Wildlife Refuge, Newburyport, MA

CAN ADDING SUGAR TO SOIL REDUCE GROWTH AND SUCCESS OF PHRAGMITES AUSTRALIS IN SALT MARSHES?

A non-native form of *Phragmites australis* has been invading tidal marshes in New England. Recent evidence suggests it is most successful in mesohaline marshes, but can also survive and expand in salt marshes. Phragmites has been successfully controlled using chemical herbicides, followed by rapid colonization by a diverse plant community, (at Parker River National Wildlife Refuge). At the Rachel Carson NWR, herbicide is not an option and we are exploring alternatives to stress or eliminate this invader. We studied the effects of sugar on Phragmites in greenhouse and field experiments. For the greenhouse experiment, soil cores from Phragmites stands were exhumed and re-grown to 30 cm in height before treating with sugar (to produce 0.4% sugar solution in soils) and salt (+15 ppt) every two weeks for two months. Between treatments, plants cores were watered as needed with ambient seawater (about 20 ppt). The survival of Phragmites treated with sugar in the greenhouse was less than 50% by 4 weeks and 5% by 8 weeks. Rapid plant death followed leaf curling, indicating severe osmotic stress to the plants. In 2015, in-situ treatment units were countersunk into four stands of Phragmites at Parker River NWR and watered with sugar and/or salt every two weeks for six weeks (four treatments in a factorial design). In the soil porewater, redox potential and pH became lower in sugar than only salt or water (control) treatments, whereas sulfide concentrations increased to 1.7 mM, high enough to stress Phragmites. Although differences were not as dramatic as found for the greenhouse experiment, sugar treatments led to decreased growth and survival in the field, suggesting promise for control using non synthetic chemicals.

Society for Wetlands Scientists Annual Meeting Providence RI, May-June 2015

Evaluation of Salt Marsh Vegetation Response to Herbicide Treatment in Great Marsh, Parker River National Wildlife Refuge, Massachusetts, USA

Gregg Moore, David Burdick, Chris Peter, Robert Buchsbaum

The effectiveness of selective herbicide application to treat invasive common reed (*Phragmites australis*) was evaluated in a portion of Great Marsh within the Parker River National Wildlife Refuge in Newbury Massachusetts. *Phragmites* stands had been treated 1-2 times over two growing seasons using glyphosate (Roundup™). Twelve treated stands were selected for study, initiated in the third and fourth year since herbicide treatment began. Effectiveness was defined as reduction in common reed percent cover, stem density and height, as well as increased presence and percent cover of native halophytes. Following treatment, and apparent eradication of *Phragmites*, a total of 27 plant species from 15 families were noted in monitoring plots. The dominant family, Poaceae, accounted for 22% of the species, followed next by Asteraceae (15%), and Chenopodiaceae (11%). The majority (73%) of the total live plant cover following treatment was native salt marsh perennial grasses, and to a lesser extent forbs, and one shrub species. Despite a dramatic reduction, some 15% of percent cover in treated stands was still attributed to *Phragmites*. However, this contribution was linked to one plot in which management was not as successful as the others. In contrast, untreated control plots maintained 77% *Phragmites* cover and only 3% native halophytes, with the remaining area either bare or covered in a dense layer of wrack. Overall, treated plots experienced subtle shifts in species composition and percent cover in monitoring plots during the summer, with decreases in the early emergent species and also *S. patens*, which were largely replaced by *D. spicata* and *Glaux maritima* later in the year. Management significantly reduced *Phragmites* but also established a diverse, native population of halophytes in a period of 2-4 years. This study underscores the importance of monitoring vegetation change beyond initial results of chemical treatment as the return of native plants may help exclude the return of invasives and insure management success into the future at salt marsh sites impacted by invasive species.

Society for Wetlands Scientists Annual Meeting Providence RI, May-June 2015

Promoting Resilience by Removing Vestiges of Hydrologic Manipulations in the Great Marsh, MA

David Burdick¹, Gregg Moore¹, Chris Peter¹, Geoff Wilson² and Susan Adamowicz³

¹Jackson Estuarine Laboratory, University of New Hampshire; ²Northeast Wetland Restoration; ³Rachel Carson NWR, USFWS.

Through a partnership, we have begun to pilot new approaches to reducing the presence and effects of past ditching. The practice of ditching began in the 17th century to enhance salt hay production and harvest, but was expanded and intensified in the 20th century to reduce mosquito populations. Ditches drain the marsh, resulting in substantial subsidence and carbon loss, and spoil piles alter hydrology and contribute to large inter-ditch impoundments that impact marsh productivity and resilience. In New England, most marshes are ditched and some have intense ditching with ditches every 10 m of marsh. Complete restoration to pre-settlement times is unlikely to be achieved – locating and re-excavating the original tidal creeks would be difficult. Early attempts at plugging ditches to reduce draining led to excessive impounding and generation of hydrogen sulfide behind the plugs. In the Great Marsh, several intensely ditched areas have been chosen for ditch remediation, a relatively new process. Following the growing season, inter-ditch vegetation is cut, placed in the ditches, and secured by biodegradable twine. The treatment was applied to every other ditch for two successive years at two sites and is in the first year at another four sites. Monitoring has shown steady declines in ditch depth, leading to recolonization by *Spartina alterniflora* after two years. Long-term monitoring will be required to determine if sediment accumulations allow succession to high marsh along these artificial drainage paths. Some other areas of the Great Marsh exhibit a pattern of pool formation between ditches, perhaps due to spoils impounding water. Based on work in southern New England, we are also piloting a reconnection of these pools to existing hydrologic paths using shallow runnels to expose soils along the edges (but not deeper centers) of the pools. Monitoring of the pools will examine natural recruitment and experimental trials will test the potential for enhanced recruitment through seeds, bare root culms or plugs. These two pilot projects seek to provide new tools to improve management of intensely ditched marshes that are abundant throughout New England.