Monitoring and Analysis of Eight Salt Marsh Tidal Restoration Projects on Cape Cod, Massachusetts

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Prepared by: Association to Preserve Cape Cod

Prepared for: Massachusetts Division of Ecological Restoration

Report and associated data collected, analyzed, and compiled by Jordan Mora, April Wobst, Bryan Horsley, Carl DePuy, Melissa Langley, Tara Lewis-Nye, and Jo Ann Muramoto, Ph.D. with support from the Division of Ecological Restoration and anonymous review from regional experts.

APCC Association to Preserve Cape Cod

Massachusetts Department of Fish and Game Division of Ecological Restoration

Invested in Nature and Community

PROJECT PURPOSE

The purpose of this project was to review and analyze pre- and post- salt marsh vegetation monitoring data and compile a comprehensive report on results from eight completed salt marsh restoration projects located on Cape Cod, Massachusetts. The eight sites and the towns in which they are located include: Bass Creek, Yarmouth; Bridge Creek, Barnstable; Namskaket Creek, Brewster; Quivett Creek, Dennis; Sesuit Creek, Dennis; State Game Farm, Sandwich; Stony Brook, Brewster; and Wings Neck, Bourne. All projects addressed a tidal restriction at a road crossing by replacing the existing structures with larger culverts or bridges that allowed increased tidal flow into the upstream salt marsh area. The Association to Preserve Cape Cod (APCC) completed pre- and post-restoration monitoring at these eight salt marsh restoration sites collecting vegetation percent cover, surface and pore water salinity, nekton and avian species abundance, and the presence and height of the invasive species *Phragmites australis*, or common reed. This monitoring was conducted between 2003 and 2020. The goal of this assessment project was to compile existing raw and analyzed vegetation monitoring data, conduct quality control of the data, and complete a comprehensive analysis to examine overall trends by site and across the Cape to evaluate the effects of these restoration projects on plant communities and to provide recommendations for future salt marsh restoration projects, monitoring, and other actions. The focus of this report is on vegetation monitoring data, however results from the salinity monitoring are also provided and discussed.

Contents

INTRODUCTION

Salt marshes are extremely productive coastal ecosystems which provide numerous ecosystem services to humans. These services include, but are not limited to, mitigating the impacts of climate change through carbon storage, improving water quality through filtration and uptake of pollutants, supporting commercial and recreational fish species by providing nursery habitat, and buffering impacts from storms through flood absorption and wave attenuation. Additionally, salt marshes are invaluable in supporting ecological diversity, maintaining coastal aesthetics, and inspiring recreation.

Although the value of salt marshes has been well-documented and regulations to protect these wetlands have been in effect for over fifty years through Section 404 of the Clean Water Act and the Massachusetts Wetlands Protection Act, salt marshes still face numerous threats and continue to be impaired by human activities. One of the most prevalent threats to salt marsh integrity and function is the presence of tidal restrictions due to development in coastal areas. Tidal restrictions (e.g., undersized or collapsed culverts under roads, berms, and railroads) impede the natural saltwater flooding regime by reducing or limiting the range (or amplitude) and flooding extent (i.e., spatial coverage) of the tides upstream of the restriction (Figure 1). In this report, we refer to the upstream portion of the restoration site as the study marsh. Study marshes are characterized by a history of reduced tidal range due to restrictions, but they received restored tidal flows when the tidal restriction was removed. We refer to the downstream part of the marsh, which was not impacted by the tidal restriction, as the reference marsh. The reference marsh is used to compare and track changes in the study marsh (Figure 1).

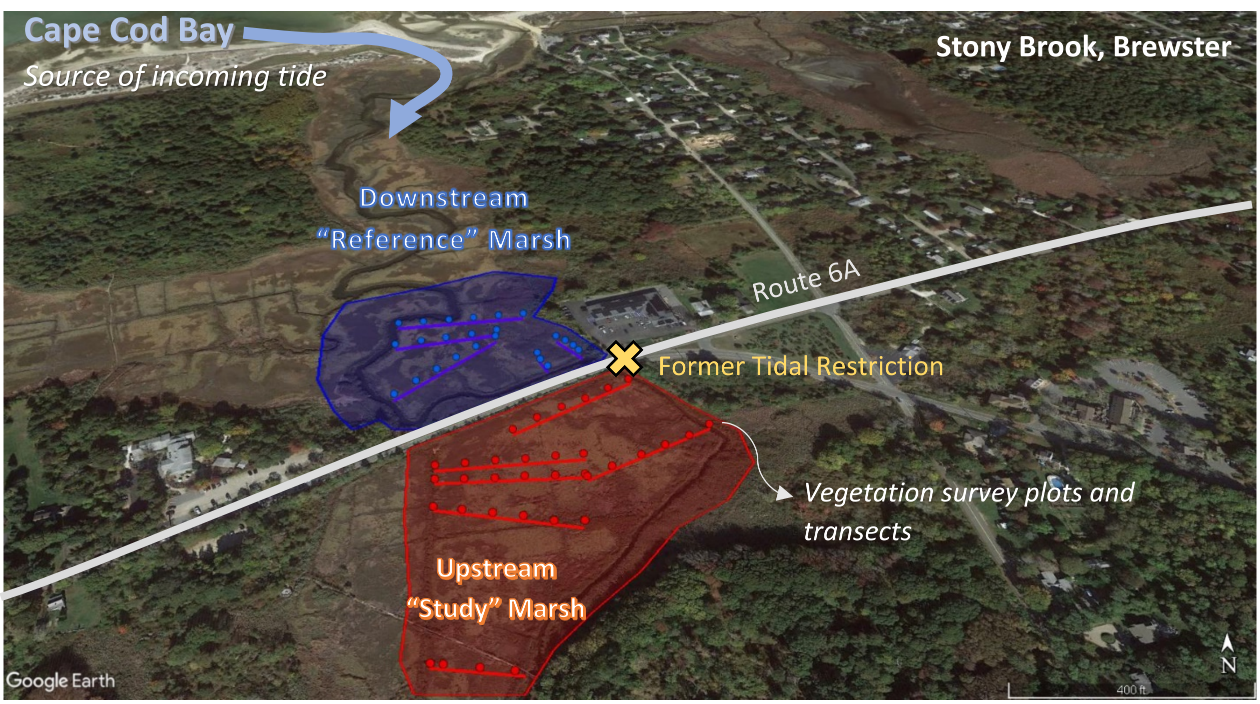

Figure 1: Aerial view of Stony Brook in Brewster, MA, showing the layout of downstream ("reference") and upstream ("study") marsh sections relative to the tidal restriction under Route 6A that was removed in 2010.

Because the biological processes of salt marshes are dependent on adequate tidal hydrology, manipulating the duration, depth and frequency of flooding can alter the salt marsh habitat (i.e., the plant, animal, and microbial community) which can lead to degraded functions and services in the restricted part of the marsh. For example, altered hydrology can lead to the spread of invasive *Phragmites australis* (hereafter referred to as *Phragmites*), or common reed*,* a species which is not as salt tolerant as native salt marsh grasses but can thrive in brackish areas with reduced saltwater flooding. In these less stressful upstream environments, *Phragmites* can dominate the marsh habitat and produce dense monocultures. These monocultures do not provide the same food source or shelter as native plants and can lead to diminished bird and fish species abundance and diversity. Also, the large root network associated with *Phragmites* can disrupt the soil chemistry and modify the bacterial communities altering the rates of decomposition and carbon storage.

Tidal restrictions can also reduce a marsh's capacity to adjust to sea level rise. Salt marshes can adapt to rising seas through two primary means, accretion (i.e., gaining elevation through buildup of sediments and plants) and landward migration. Accretion requires the accumulation of organic material, from slowly decaying plant growth, and deposition of suspended particles, such as fine sediments that flow into the marsh during high tides. Landward migration is upslope movement of salt marsh vegetation as mean sea level rises. Landward migration is limited to areas with relatively shallow sloping upland borders where migration is not blocked by roads, tidal restrictions, and other barriers. Tidal restrictions inhibit these two processes by changing the decomposition rate in the upstream area, reducing sediment supply, and blocking migration.

Thus, salt marshes with long histories of altered tidal hydrology resulting from tidal restrictions are more likely to have subsided (or reduced) elevation from increased plant decomposition and reduced accretion rates (resulting from a decreased sediment supply) as well as increased brackish or freshwater plant species (such as *Phragmites*). These detrimental conditions, singularly or combined, can reduce the ability of the salt marsh to provide the ecosystem services on which humans rely. In order to reset the trajectory of tidally restricted marshes from degradation and help protect coastal homes and businesses, coastal managers and ecologists work to remove these tidal restrictions and restore the natural tidal regime to the full extent of the salt marsh. Redirecting this trajectory is particularly important for protecting our coasts from sea level rise into the future.

To evaluate the impact of tidal restoration on Cape Cod, DER and APCC have collaborated on this effort to review and examine vegetation monitoring data from eight salt marsh restoration sites. All data were collected by APCC as part of routine salt marsh monitoring associated with each project. Table 1 provides the locations and dates of restoration projects as well as the marsh area upstream of the former tidal restriction. A map of the restored salt marsh sites is provided in Figure 2. Because plants are indicators of environmental conditions (i.e., plants have evolved to acclimate to particular habitats so we can use their presence as indicators of the conditions where they live), we chose to focus our analysis and interpretation on the plant community metrics. In 2019, APCC conducted additional field visits of each site to obtain observational notes and photo-documentation of more current conditions.

Table 1. Description of the eight salt marsh restoration sites on Cape Cod.

Site	Town	Waterbody	Latitude	Longitude	Estimated Upstream Affected Wetland Area (acres)	Date of restoratio n	Pre-Restoration Culvert	Post-Restoration Culvert
Bass Creek	Yarmouth	Cape Cod Bay	41.71606°N	70.23712°W	35.3*	2008	4 foot diameter corrugated metal pipe (CMP)	35 foot bridge with a 12 foot channel
Bridge Creek**	Barnstable	Cape Cod Bay	41.70263°N	70.36311°W	42.0*	May 2005	Route 6A: 3x5 foot culvert	Route 6A: 10x10 foot concrete box culvert
Namskaket Creek	Brewster	Cape Cod Bay	41.78101°N	70.01125°W	6.9*	January 2007	2 foot diameter CMP	Twin 5 foot diameter pipes
Quivett Creek	Dennis	Cape Cod Bay	41.74688°N	70.14357°W	11.6*	March 2005	Stack twin 30 inch diameter CMPs	8x8 foot concrete box culvert
Sesuit Creek	Dennis	Cape Cod Bay	41.74526°N	70.16271°W	53.3*	2008	2 foot diameter CMP	Two 12x10 foot concrete box culverts
State Game Farm	Sandwich	Cape Cod Bay	41.73109°N	70.42722°W	2.4*	June 2006	3 foot diameter CMP and earthen dike	36 foot long bridge
Stony Brook	Brewster	Cape Cod Bay	41.75460°N	70.11288°W	31.6*	Fall 2010	3 foot diameter CMP	Two 9 foot concrete box culverts
Wings Neck	Bourne	Buzzards Bay	41.69375°N	70.63554°W	8.0^{+}	2002	2 foot diameter CMP	Two 3x5 foot concrete box culverts

* Source: Cape Cod Commission. 2001. Cape Cod Atlas of Tidally Restricted Salt Marshes.

$^{+}$ Source: Buzzards Bay Project National Estuary Program. 2002. Atlas of Tidally Restricted Salt Marshes in the Buzzards Bay Watershed of Massachusetts (Final). Massachusetts Office of Coastal Zone Management.

** The Bridge Creek restoration project occurred in two phases. In 2003 an under-sized culvert beneath an active railroad line was replaced. In 2005 an under-sized culvert beneath Route 6A was replaced. The restoration monitoring data presented in this report were collected for the second phase of the project.

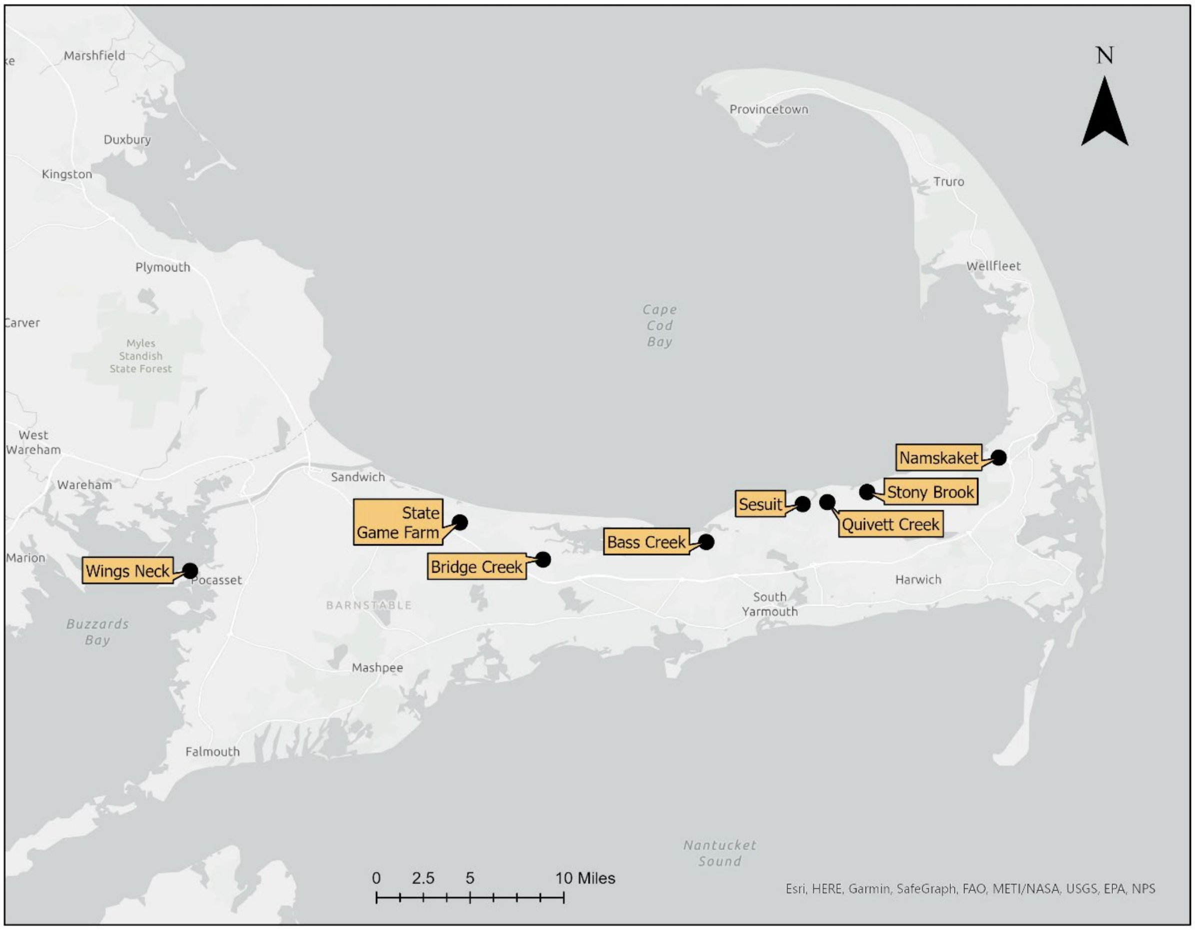

Figure 2: Map of the eight restored salt marsh sites.

METHODS

Pre- and Post-Restoration Monitoring Data Collection and Analysis

From 2003 through 2020, APCC conducted monitoring of select salt marsh restoration sites on Cape Cod. Monitoring was completed as shown in Table 2. Salt marsh monitoring was conducted using methods developed in partnership with DER and based on CZM's *A Volunteer's Handbook for Monitoring New England Salt Marshes*[1] and APCC's state-approved Quality Assurance Project Plan (QAPP) for salt marsh monitoring.
Several sites were monitored for avian and nekton species (Table 2). While results of avian and nekton monitoring are available separately for individual sites, these data were not analyzed or included in this report.

[1] Carlisle, B., A.M. Donovan, A.L. Hicks, V.S. Kooken, J.P. Smith, and A.R. Wilbur. 2002. "A Volunteer's Handbook for Monitoring New England Salt Marshes." Massachusetts Office of Coastal Zone Management, Executive Office of Environmental Affairs.

Table 2: Summary of salt marsh restoration monitoring at eight sites on Cape Cod, 2003 – 2020. All data were collected by Association to Preserve Cape Cod except where data collected by a team from the University of New Hampshire (UNH) are noted.

Name of salt marsh	Years of pre-restoration monitoring	Years of post-restoration monitoring	Years of Monitoring by Parameter				
			Plants	Salinity (Surface and Porewater)	Nekton	Avian species	Phragmites
Bass Creek	2003 - 2007	2008 -2010, 2012	2003-2010, 2012	2003-2010, 2012	2004-2009, 2012	2004-2010, 2012	2005-2008, 2012
Bridge Creek*	2003 - 2005	2005 - 2010	2003-2010	2003-2008	none	2004-2005, 2007-2009	2003-2010
Namskaket Creek	2006 (Study Marsh only)	2007 - 2009, 2011-2012, 2014	2006-2009, 2011	2006-2009, 2011-2012 and 2014	none	2007-2009	2006-2009, 2011
Quivett Creek	2003 - 2004	2005-2009, 2011	2003-2009, 2011	2003-2009, 2011	2006-2009, 2011	2004-2007, 2011	2003-2009, 2011
Sesuit Creek	2007 (UNH)	2007-2008 (UNH), 2009 - 2011, 2016 (UNH), 2018, 2020	2007-2008, 2016 (UNH), 2009-2011, 2018,2020	2007-2008 (UNH), 2009-2011, 2020	2008 (UNH)	none	2007-2008, 2016 (UNH), 2009-2011, 2020
State Game Farm	2003 - 2005	2006 - 2009, 2013	2003-2009, 2013	2003-2008, 2013	2004-2009, 2013	2003-2009	2003-2009, 2013
Stony Brook	2007 - 2010	2011 - 2013	2007-2013	2007-2013	2013-2013	none	2007-2013
Wings Neck	none	2003 - 2007, 2013	2003-2005, 2007, 2013	2003-2007, 2013	none	2004-2006	2003-2005, 2007, 2013

*The Bridge Creek restoration project occurred in two phases. In 2003 an under-sized culvert beneath an active railroad line was replaced. In 2005 an under-sized culvert beneath Route 6A was replaced. The restoration monitoring data presented in this report were collected for the second phase of the project.

Vegetation Monitoring

Vegetation was monitored according to the protocols described in CZM's *A Volunteer's Handbook for Monitoring New England Salt Marshes* whereby permanent one-meter squared plots are established along a series of randomly selected linear transects which start at the tidal creek edge and run into the upland transition border. Where feasible, a minimum of six transects were established at each site: three in the salt marsh downstream of the tidal crossing (i.e., reference marsh) and three in the marsh upstream of the former tidal restriction (i.e., study marsh). Plots for monitoring vegetation were established every 60 feet[2] starting at the creek edge and moving to the upland transition for a transect length of up to 300 feet with two exceptions: 1) transects at Sesuit Creek were located at 0, 10, and 50 feet followed by 50 feet intervals up to 300 feet; and 2) plots were located at more frequent intervals for transects of shorter lengths. Site-specific maps showing the various plot and transect locations are available in Appendix A. Vegetation was monitored within each plot during the peak growing season between July and September. All plants present in the plot were identified to genus and species and percent cover was estimated for each species using standardized cover class midpoints (1%, 3%, 7%, 15%, 25%, 38%, 55%, 76%, 94%). Where standardized cover classes were not applied in the field (e.g., data collected at Sesuit Creek by a research team from the University of New Hampshire), the raw values were converted to the standard cover class midpoints for consistency.

The vegetation datasets were carefully reviewed to check for errors in plot or transect labels, spelling of species name, and cover class midpoints, as well as suspicious or inconsistent species identification and species cover. Any suspect data was either corrected or removed from the dataset and any steps taken were noted in metadata. No changes were made to the raw datasheets or data files.

Major vegetation types and species richness (number of different species within a plot) were calculated for each plot for each year monitored. Species richness was not pursued further as a metric of restoration impact in this report, but results from a previous effort to investigate changes in species richness within the reference and restored marshes are available in Appendix B[3]. Individual species percent cover data were summarized based on the following major vegetation types: *Spartina alterniflora* (the dominant species found in the low marsh), high marsh species (*Spartina patens*, *Distichlis spicata*, and *Juncus gerardii*), other halophytes (all other salt tolerant species excluding *S. alterniflora*, *S. patens*, *D. spicata*, and *J. gerardii*), *P. australis* (invasive species of concern), other abiotic covers (bare ground, dead vegetation, wrack, or open water), or other non-halophytes (salt intolerant species excluding *Phragmites*). Species designations (halophyte vs. non-halophyte) were determined by best professional judgment and review of well-established plant habitat resources to ascertain flooding and salt tolerance[4,5,6]. The master species list and designations as well as presence/absence for eight sites are available in Appendix C.

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[2] Feet (rather than meters) were used as the measure of length when establishing transects and recording plot locations in accordance with the 2002 CZM Volunteer's Handbook.

[3] The results available in Appendix B did not follow the same analytical methods as described below (i.e., plot selection or zone designations). In other words, the previous species richness analysis presented in Appendix B included all the plots monitored in all years, but the results presented here focus on plots that were consistently monitored through time.

[4] Neckles, H. A., G. R. Guntenspergen, W. G. Shriver, N. P. Danz, W. A. Wiest, J. L. Nagel, and J. H. Olker. 2013. Identification of Metrics to Monitor Salt Marsh Integrity on National Wildlife Refuges In Relation to Conservation and Management Objectives. Final Report to U.S. Fish and Wildlife Service, Northeast Region. USGS Patuxent Wildlife Research Center, Laurel, MD. 226 pp.

[5] Tiner, R.W. 2009. *Field Guide to Tidal Wetland Plants of the Northeastern United States and Neighboring Canada: Vegetation of Beaches, Tidal Flats, Rocky Shores, Marshes, Swamps, and Coastal Ponds.* Amherst, MA, University of Massachusetts Press.

[6] GoBotany. Native Plant Trust. National Science Foundation. <gobotany.nativeplanttrust.org>

The percent cover of these six plant community categories were normalized to 100% to standardize the total plot cover and remove inconsistencies related to the cover class combinations. To reduce variability in the data and be able to better visualize how different zones of the marsh were responding to restoration we grouped the plots by major marsh zones following recommendations from Burdick et al. (2020)[7]. Figure 3 illustrates the typical marsh zones seen in New England and the forces that determine the limits of these zones. *Spartina alterniflora* dominates the low marsh because it has evolved to handle the higher stress from daily flooding and soil anoxia (low oxygen). The high marsh species (such as *S. patens*, *D. spicata*, and/or *J. gerardii*) are better competitors (i.e., they use resources more efficiently) but are not well-adapted to the physical stress of the low marsh zone. Finally, upland transition zone species are generally non-halophytes meaning that they have very limited to no flooding and salt tolerance.

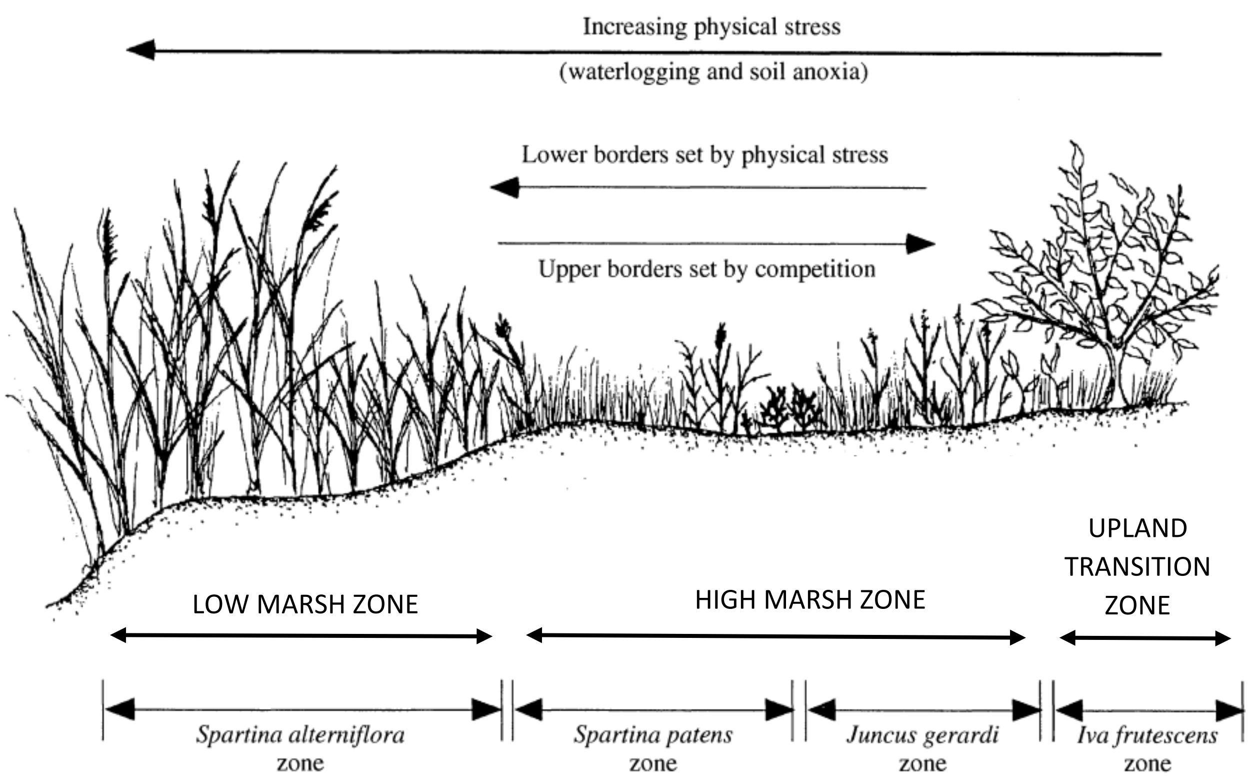

Figure 3. Cross-section of a typical New England salt marsh showing the low, high, and upland transition marsh zones. Figure modified from Emery et al. (2001)[8].

After normalizing the plant categories, the marsh zone (low marsh, high marsh, and upland transition) for each plot was calculated using the following formulas:

- If percent cover of *Spartina alterniflora* > 70%, then marsh zone = low marsh;
- If percent cover of non-halophytes > 30%, then marsh zone = upland transition;
- If percent cover of *Spartina alterniflora* < 70% and non-halophytes < 30%, then marsh zone = high marsh.

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[7] Burdick, D., C. Peter, B. Fischella, M. Tyrrell, J. Allen, J. Mora, K. Raposa, J. Goldstein, C. Feurt, L.Crane. 2020. Synthesizing NERR Sentinel Site Data to Improve Coastal Wetland Management Across New England Data Report. NERRS Science Collaborative. 37pp.
[8] Emery, N., P.J. Ewanchuk, and M.D. Bertness. 2001. Competition and salt marsh plant zonation: Stress tolerators may be dominant competitors. *Ecology* 82(9): 2471-2485.

Stacked column plots displaying average percent cover by major vegetation type by year monitored were generated for each marsh zone within the reference and study marshes at each of the eight sites. Decisions regarding data inclusion in the bar plots were based on quality control checks (as described above) and the consistency of sampling over years. In other words, the same plot had to be sampled in the first *and* last year of monitoring to be included in the bar plots. Additionally, where sample sizes within marsh zone were greater than or equal to three, statistical t-tests (two sample, assuming unequal variances) were run, using the same selected plots as those included in the bar plots, in Excel to determine: 1) whether there were significant ($p < 0.05$) changes in plant community categories over time within the reference and study marsh areas by comparing the first and last year of monitoring, and 2) whether there were significant ($p < 0.05$) differences between the reference and study areas of the marsh at the beginning and end of the monitoring period.

Phragmites is an invasive species of concern and was monitored as an indicator of brackish or disturbed conditions. When present in a plot, the height of the 10 tallest stems of *Phragmites* was measured. These stem heights were averaged by plot. Average stem heights were plotted to compare changes over time between the reference and study marsh areas within each site.

Salinity Monitoring

Salinity monitoring was conducted during low tide when marsh sites were most accessible on foot. Salinity monitoring stations were located every 60 feet along transects located in the reference and study marsh. Pore water and surface water samples were tested for salinity concentrations at stations using a handheld temperature-compensated refractometer. Pore water sippers were utilized to obtain marsh pore water samples from a depth of 10 centimeters (cm). At the zero station, (zero feet from creek edge) surface water was collected from the tidal creek and analyzed for salinity. Salinity measurements were taken at least twice per month during the summer months or year-round as capacity allowed.

To evaluate changes in salinity before and after restoration, average annual salinities for surface water and pore water were calculated for the reference and study marshes. Average annual salinity was calculated separately for surface water (measured in the stream channel, e.g., 0 feet plots) and pore water (measured at plots established within the marsh) for the reference and study marsh. Annual averages were then plotted across all years. The results from the salinity data collection and analysis are available in Appendix D.

Site Assessment and Photo-Documentation

Most of the pre- and post-monitoring data from the eight restoration sites were collected years ago. To obtain more current information on marsh conditions, APCC visited each of the eight sites in late July or early August of 2019 to conduct visual assessments of the current state of the marshes and to obtain photos. This information was used in combination with analysis of monitoring data to provide a summary evaluation of each site and recommendations for potential future actions. A detailed summary of the field site assessment methods and results are available in Appendix E.

RESULTS

By comparing the number of selected plots (i.e., those that passed quality control checks and were surveyed consistently during first and last year of monitoring) within each salt marsh zone (Table 3), one can get a sense of how much the reference and study marsh areas differed in plant community structure prior to restoration. This difference in species composition and abundance also provides an indication of the flooding period. High marsh species generally occur above the elevation of mean high water where tidal flooding is less frequent (generally twice a month on spring high tides), while *Spartina alterniflora* tends to dominate areas that receive daily flooding (low marsh zone). Upland transition zone species are less flood- and salt-tolerant, so they are limited to the upper terrestrial border where flooding only occurs during extreme high tides. The restricted study areas of the marshes, which later received tidal flow restoration, commonly had a greater proportion of upland transition zone plots than the reference area. This was especially true at Sesuit Creek where most of the upstream marsh was covered by *Phragmites* and other non-halophyte species before restoration.

Table 3. Number of plots included in analysis by year one marsh zone designation. Note: in order to be included, plots had to pass quality control checks and be included in surveys during the first and last year of monitoring.

Site	Marsh	Low Marsh	High Marsh	Upland Transition	Total
Bass Creek	Reference	6	15	0	21
	Study	0	14	4	18
Bridge Creek	Reference	5	3	4	12
	Study	2	11	8	21
Namskaket Creek	Reference	1	7	4	12
	Study	0	1	8	9
Quivett Creek	Reference	0	11	1	12
	Study	2	7	4	13
Sesuit Creek	Reference	12	24	5	41
	Study	8	4	22	34
State Game Farm	Reference	1	23	1	25
	Study	6	0	4	10
Stony Brook	Reference	0	17	5	22
	Study	1	22	10	33
Wings Neck	Reference	12	7	0	19
	Study	3	27	1	31

1. Bass Creek, Yarmouth

Reference marsh (left) and study marsh (right) photos taken on July 25, 2019.

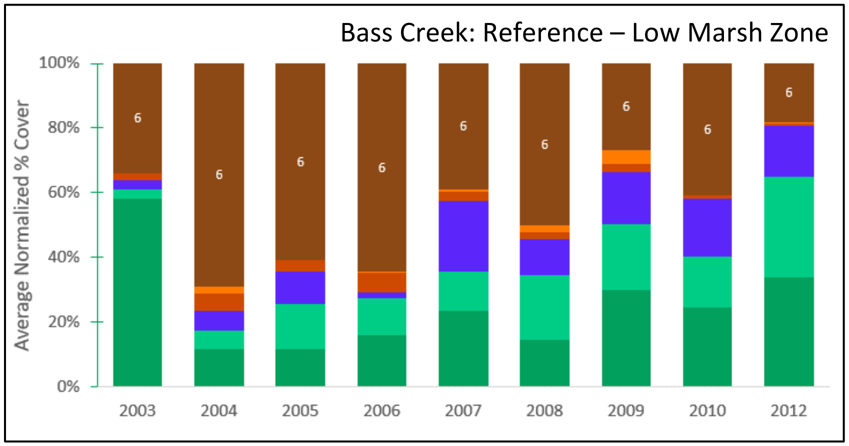
Bass Creek was restored in early 2008. Pre- and post-restoration monitoring of the reference and study areas occurred between 2003 and 2012. Figure 4 shows the average annual percent covers of the major vegetation types. Data from the first (2003) and last (2012) years of monitoring were used for all statistical comparisons. See Appendix A for a map of the plots in the reference and study marsh areas at Bass Creek.

Reference and study comparisons were only possible for the high marsh zone. At the start of monitoring (2003), *Phragmites percent* cover was greater in the study marsh than in the reference marsh (p = 0.03; Reference = 0%, n = 15; Study = 6%, n = 14). In 2012, four years post-restoration, there was no difference in *Phragmites* percent cover between the reference and study areas. Observations from the 2019 field visit note that *Phragmites* retreated into the upper areas of the marsh and that plants were relatively short (more site visit details provided in Appendix E).

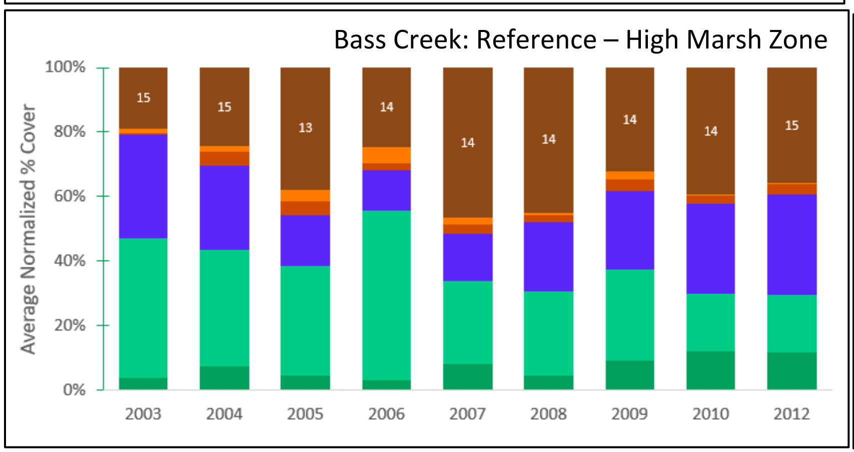
Between 2003 and 2012, there was a significant increase in other halophytes in the reference area low marsh zone ($p < 0.001$; 3% to 16%, n = 6) and a potential decreasing trend in *S. alterniflora* and potential increasing trend in *S. patens*. In the reference area high marsh zone, there was a significant decrease in high marsh species (p = 0.05; 42% to 18%, n = 15) and a potential increase in unvegetated areas, or "Other" .

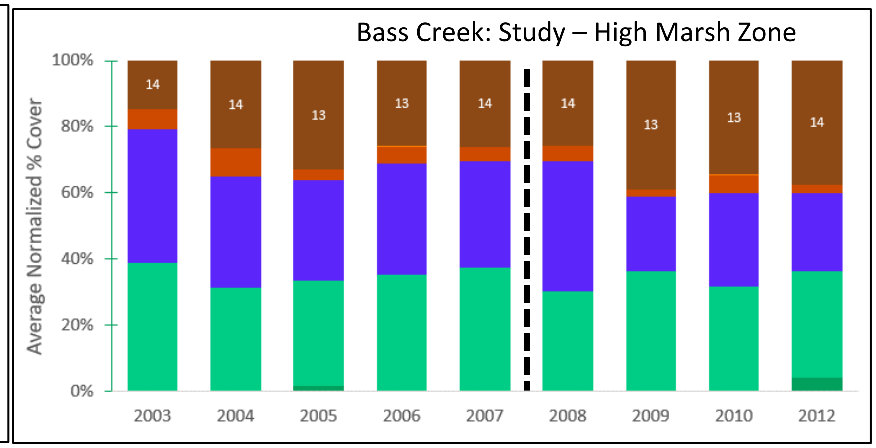
Between 2003 and 2012 in the study area high marsh zone there was a significant increase in unvegetated area or "Other" (p = 0.02; 15% to 37%, n = 14) and a potential decreasing trend in other halophytes (p = 0.06; 40% to 23%, n = 14).

During the 2019 field visit, erosion was observed along the tidal creek near the culvert in the reference and study marshes. Slumping was also observed in the reference marsh along the tidal banks farther away from the culvert. Additionally, clumps of peat were washed up on the surface of the study marsh with *S. alterniflora* growing on them, suggesting that the peat clumps eroded from the banks and floated onto the surface of the marsh during a high tide (for more details regarding the 2019 site visits, see Appendix E).



No plots in the low marsh zone of the restored marsh area.





No plots in the upland transition zone of the reference area.

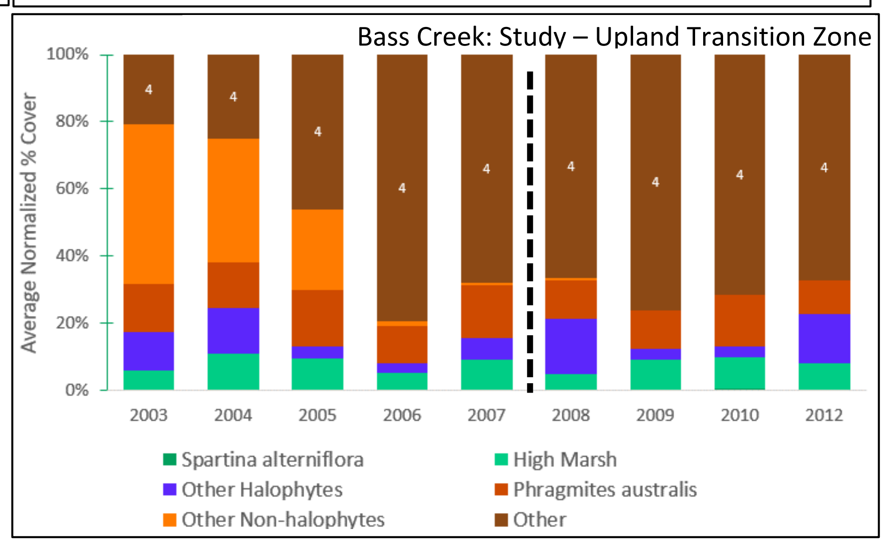


Figure 4: Average normalized percent cover for five major vegetation types across three marsh zones in Bass Creek, Yarmouth, MA. "Other" represents unvegetated area such as bare sediment, wrack, and/or dead plants. Black dashed line indicates when restoration occurred. Column numbers represent plot sample size. No monitoring occurred in 2011.

2. *Bridge Creek, Barnstable*

Reference marsh (left) and study marsh (right) photos taken on July 25, 2019.

Bridge Creek was restored in May 2005. Pre- and post-restoration monitoring of the reference and study areas occurred between 2003 and 2010. Figure 5 shows the average annual percent covers of the major vegetation types. Data from the first (2003) and last (2010) years of monitoring were used for all statistical comparisons. See Appendix A for a map of the plots in the reference and study marsh areas at Bridge Creek.

In 2003, there were no significant differences between the reference and study areas high marsh and upland transition zones. In 2010, five years after restoration, the study high marsh zone had a greater percent cover of *S. alterniflora* ($p < 0.01$; Reference = 10%, n = 3; Study = 50%, n = 11).

Between 2003 and 2010 there were no significant differences in major vegetation types in the reference marsh, however there was a potential increasing trend in *S. alterniflora* and potential decreasing trend in unvegetated or "Other" percent covers in the low marsh zone.

Between 2003 and 2010 in the study area high marsh zone there was a significant decrease in high marsh species percent cover ($p < 0.01$; 45% to 12%, n = 11) and a potential increasing trend in *S. alterniflora*. This trend was corroborated by field site records from 2019 which noted the transition of high marsh species to *S. alterniflora* in the middle interior of the study marsh. There were no other significant changes in major vegetation types in the study marsh. In the study area upland transition zone, *Phragmites* was consistently about 40% across all the monitoring years. The 2019 site visit corroborated this trend as recorded observations note that *Phragmites* appeared to remain in similar locations and height as seen in earlier monitoring years.

In 2019, APCC staff noted that both concrete box culverts under Route 6A and the train tracks were in good condition and showed no signs of degradation. There were also no signs of erosion along the creek edges of the reference or study marshes (for more details regarding the 2019 site visits, see Appendix E).

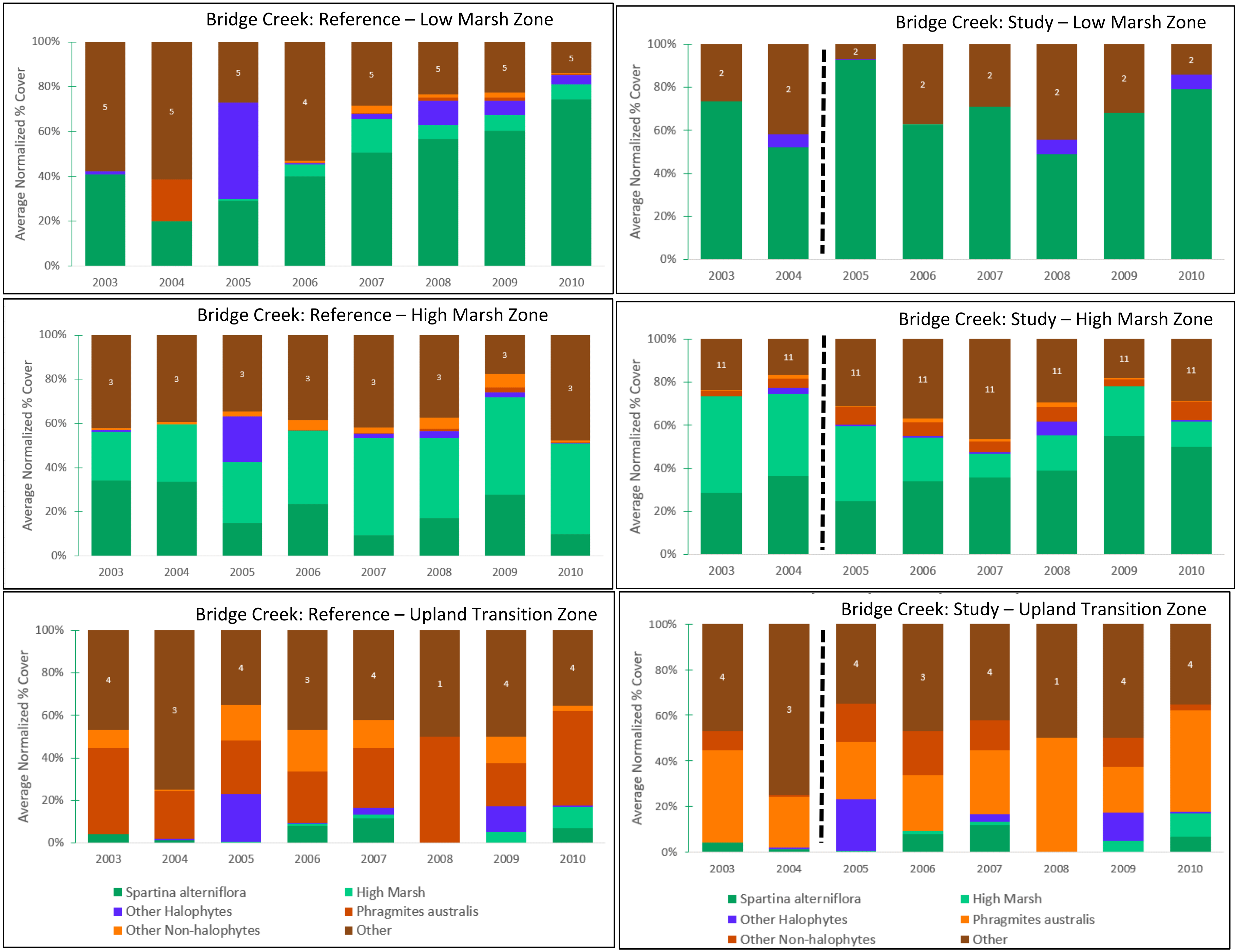


Figure 5: Average normalized percent cover for five major vegetation types across three marsh zones in Bridge Creek, Barnstable, MA. "Other" represents unvegetated area such as bare sediment, wrack, and/or dead plants. Black dashed line represents when restoration occurred. Column numbers represent plot sample size.

3. Namskaket Creek, Brewster


Reference marsh (left) and study marsh (right) photos taken on July 24, 2019.

Namskaket Creek was restored in January 2007. Figure 6 shows the average annual percent covers of the major vegetation types. Pre- and post-restoration monitoring of the study area occurred between 2006 and 2011. Monitoring of the reference area occurred between 2007 and 2011 (no data collected in 2006). Statistical comparisons involving the reference marsh used 2007 data as the first year of monitoring. For statistical comparisons between the first and last year of monitoring in the study marsh, 2006 was used as the first year of monitoring. Data from 2011 was used as the last year of monitoring for all statistical comparisons. See Appendix A for a map of the plots in the reference and study marsh areas at Namskaket Creek.

In 2007, there were no significant differences between the reference and study marshes in the high marsh zone, however in 2011 (four years post-restoration) the percent cover of high marsh species was greater in the high marsh zone of the reference area (p = 0.05; Reference = 65%, n = 3; Study = 20%, n = 3). The study marsh had significantly higher percent cover of *Phragmites* than the reference marsh in the upland transition zone in both 2007 (p = 0.01; Reference = 4%, n = 4; Study = 25%, n = 14) and 2011 ($p < 0.01$; Reference = 2%, n = 4; Study = 49%, n = 14). .

Between 2007 and 2011, there were no significant trends in any of the plant community types within the reference marsh. During the 2019 site visit, there was a build-up of wrack observed along the upland transition edge of the eastern side of the reference marsh. There was also noticeable bank slumping and some erosion on the reference side of the marsh. Most of the erosion was observed at the bends in the tidal creek.

Between 2006 to 2011 in the study marsh upland transition zone, other non-halophyte species declined significantly (p = 0.02; 38% to 1%, n = 8) and *Phragmites* cover increased significantly (p = 0.02; 21% to 59%, n = 8). Based on observations from the 2019 field visit, *Phragmites* was still dominant and appeared healthy on both sides of the creek in the study marsh. There was no evidence of creek bank erosion or slumping in the study marsh. Ten boards were blocking the two circular culverts (five boards on the upper portion of each culvert) which appeared to be reducing the tidal flow during high tide into the study marsh. Additional details from the 2019 site visit are available in Appendix E.

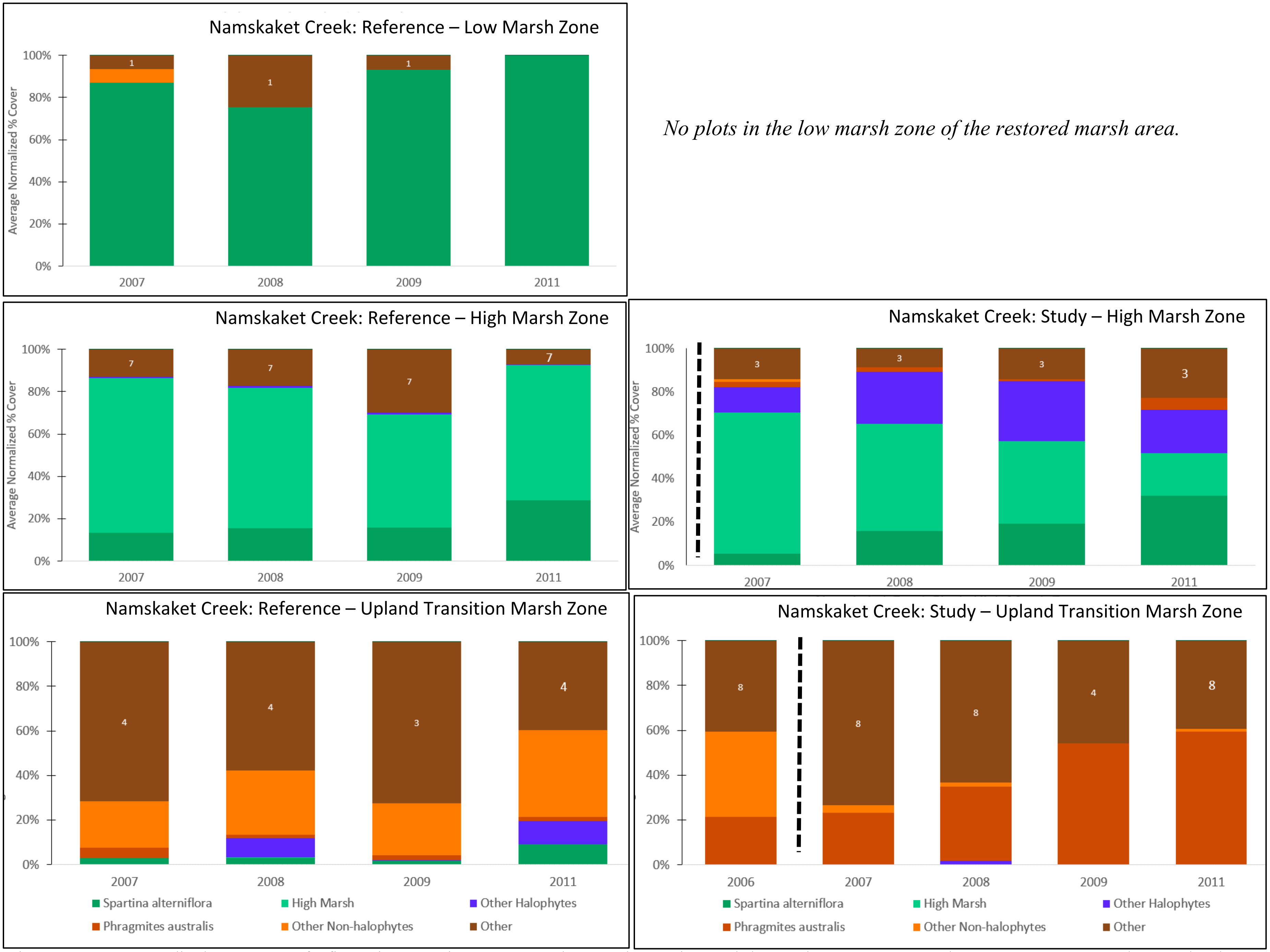


Figure 6: Average normalized percent cover for five major vegetation types across three marsh zones in Namskaket Creek, Brewster, MA. "Other" represents unvegetated area such as bare sediment, wrack, and/or dead plants. Black dashed line indicates when restoration occurred. Column numbers represent plot sample size. The reference marsh was not monitored in 2006. Only one plot in study marsh high marsh zone in 2006, not shown here. No monitoring occurred in 2010.

4. Quivett Creek, Dennis


Reference marsh (left) and study marsh (right) photos taken on August 15, 2019.

Quivett Creek was restored in March 2005. Pre- and post-restoration monitoring of the reference and study areas occurred between 2003 and 2011. Figure 7 shows the average annual percent covers of the major vegetation types. Data from the first (2003) and last (2011) years of monitoring were used for all statistical comparisons. See Appendix A for a map of the plots and transects.

There were no significant differences between the reference and study marshes in high marsh zone the first year of monitoring (2003) and the last year of monitoring (2011).

Between 2003 and 2011, there was a significant increase in S. alterniflora (p = 0.01, 10% to 45%, n = 11) and a significant decrease in high marsh species (p < 0.01, 56% to 22%, n = 11) in the reference marsh high marsh zone.

In the study marsh high marsh zone, there was a significant decrease in high marsh species percent cover (p = 0.01, 51% to 10%, n = 7) between 2003 and 2011 and a potential increasing trend in *S. alterniflora*.

During the 2019 field visit, APCC staff noted that *Phragmites* was still limited in its distribution to upland transition areas at the edges of the reference marsh. Also, *Phragmites* within the study marsh was still present in similar locations and approximately the same height. These observations corroborate the trends analysis which showed no change in *Phragmites* at Quivett. APCC staff also noted that although the box culvert appeared in good condition, there were three boards in place across the top of the culvert. Additional details from the 2019 site visit are available in Appendix E.

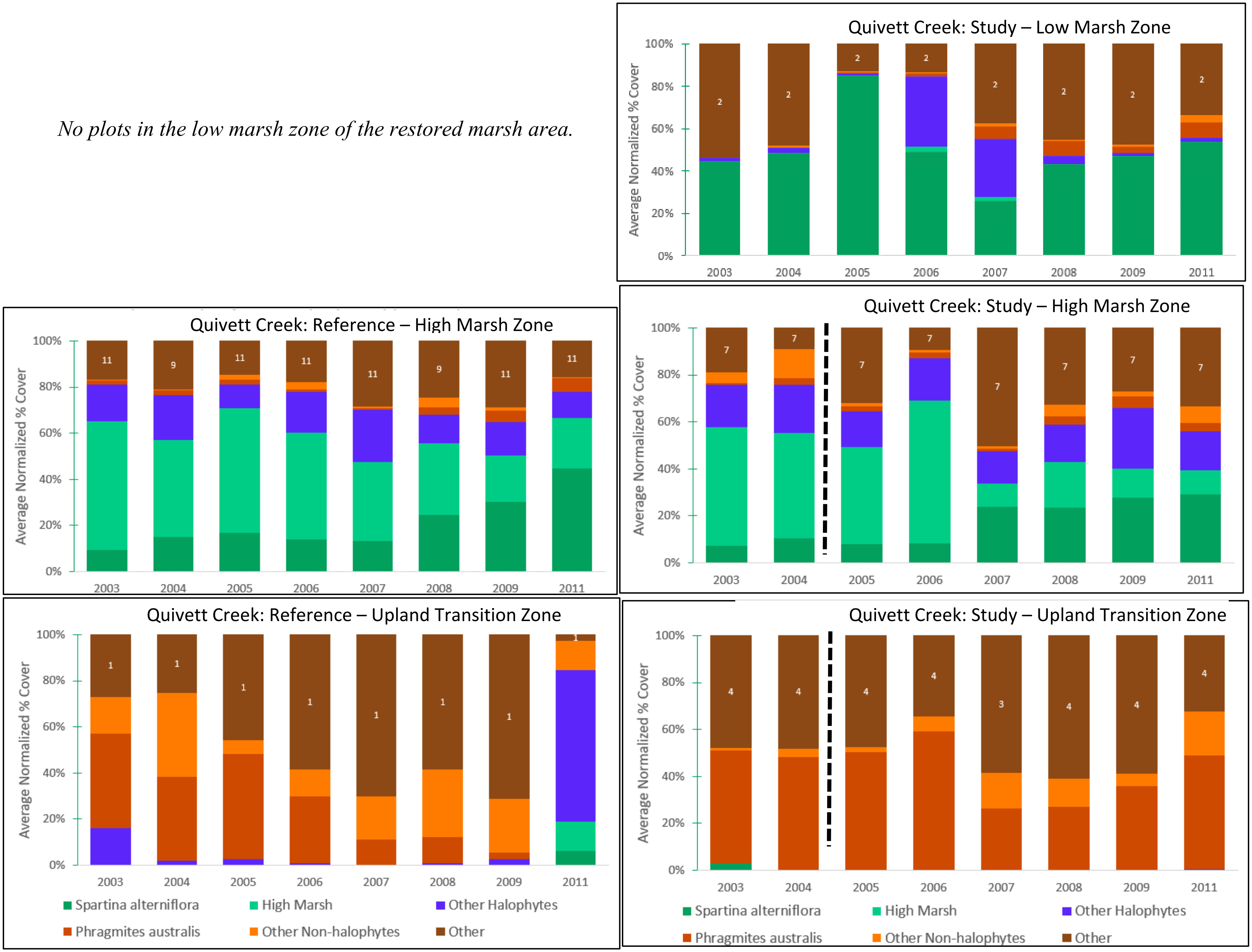


Figure 7: Average normalized percent cover for five major vegetation types across three marsh zones in Quivett Creek, Dennis, MA. "Other" represents unvegetated area such as bare sediment, wrack, and/or dead plants. Black dashed line indicates when restoration occurred. Column numbers represent plot sample size. No monitoring occurred in 2010.

5. *Sesuit Creek, Dennis*

Reference marsh (left) and study marsh (right) photos taken on August 20, 2019.

Sesuit Creek was restored in early 2008. Pre- and post-restoration monitoring of the reference and study areas occurred between 2007 and 2016. Note that post-restoration monitoring data was also collected in 2018 and 2020, however this monitoring was associated with a restoration planting area near the road crossing and did not include all study and reference transects. Figure 8 shows the average annual percent covers of the major vegetation types. Data from the first (2007) and last (2016) years of monitoring were used for all statistical comparisons. See Appendix A for a map of the plots and transects.

In 2007, *Phragmites* was significantly greater in abundance in the reference marsh than in the study marsh within the upland transition zone ($p < 0.001$; Reference = 75%, n = 5; Study = 17%, n = 22) and other non-halophytes were significantly greater in the upland transition zone of the study marsh ($p < 0.001$; Reference = 6%, n = 5; Study = 65%, n = 22). In 2016 (eight years post-restoration), high marsh species percent cover was greater in the reference marsh than in the study marsh in the low marsh zone ($p = 0.01$; Reference = 26%, n = 12; Study = 0%, n = 8) and the high marsh zone ($p < 0.001$; Reference = 43%, n = 24; Study = 0%, n = 4). In the upland transition zone, the study marsh had significantly more unvegetated cover ("Other") than the reference area in 2016 ($p < 0.001$; Reference 23%, n = 5; Study = 71%, n = 22) and significantly more *Spartina alterniflora* cover than the reference area ($p = 0.03$; Reference = 4%, n = 5; Study = 21%, n =22).

Between 2007 and 2016, there was a significant decrease in *S. alterniflora* ($p = 0.03$, 69% to 42%, n = 12) and significant increase in high marsh species ($p = 0.02$, 3% to 26%, n = 12) in the low marsh zone of the reference marsh. In the high marsh zone of the reference marsh, *S. alterniflora* ($p = 0.03$, 8% to 21%, n = 24) and unvegetated cover ("Other"; $p = 0.03$, 16% to 28%, n = 24) increased over time while high marsh species decreased over time (p < 0.01, 72% to 43%, n = 24).

In the study marsh high marsh zone, percent cover of high marsh species decreased significantly between 2007 and 2016 ($p = 0.01$, 61% to 0%, n=4). In the upland transition zone, *S. alterniflora* ($p = 0.01$, 1% to 21%, n = 22) and unvegetated area ("Other"; p < 0.001, 16% to 71%, n = 22) increased significantly over time while other non-halophytes dropped sharply post-restoration ($p < 0.001$, 65% to 0%, n = 22). The 2019 field assessment notes indicated that in some areas of the study marsh, *Phragmites* has been replaced by *S. alterniflora* and *Phragmites* also appeared to be migrating into upland areas where it may not have previously been growing.

Observations from the 2019 field site visit included a note regarding the culvert, which was found to be in good condition and was not blocked by sediment or rocks. APCC staff noted that in both the reference and study areas, the main creek channel appeared to have widened because of restoration (compared to photos from 2009), and there were also signs of erosion on the creek bank edges. Additional details from the 2019 site visit are available in Appendix E.

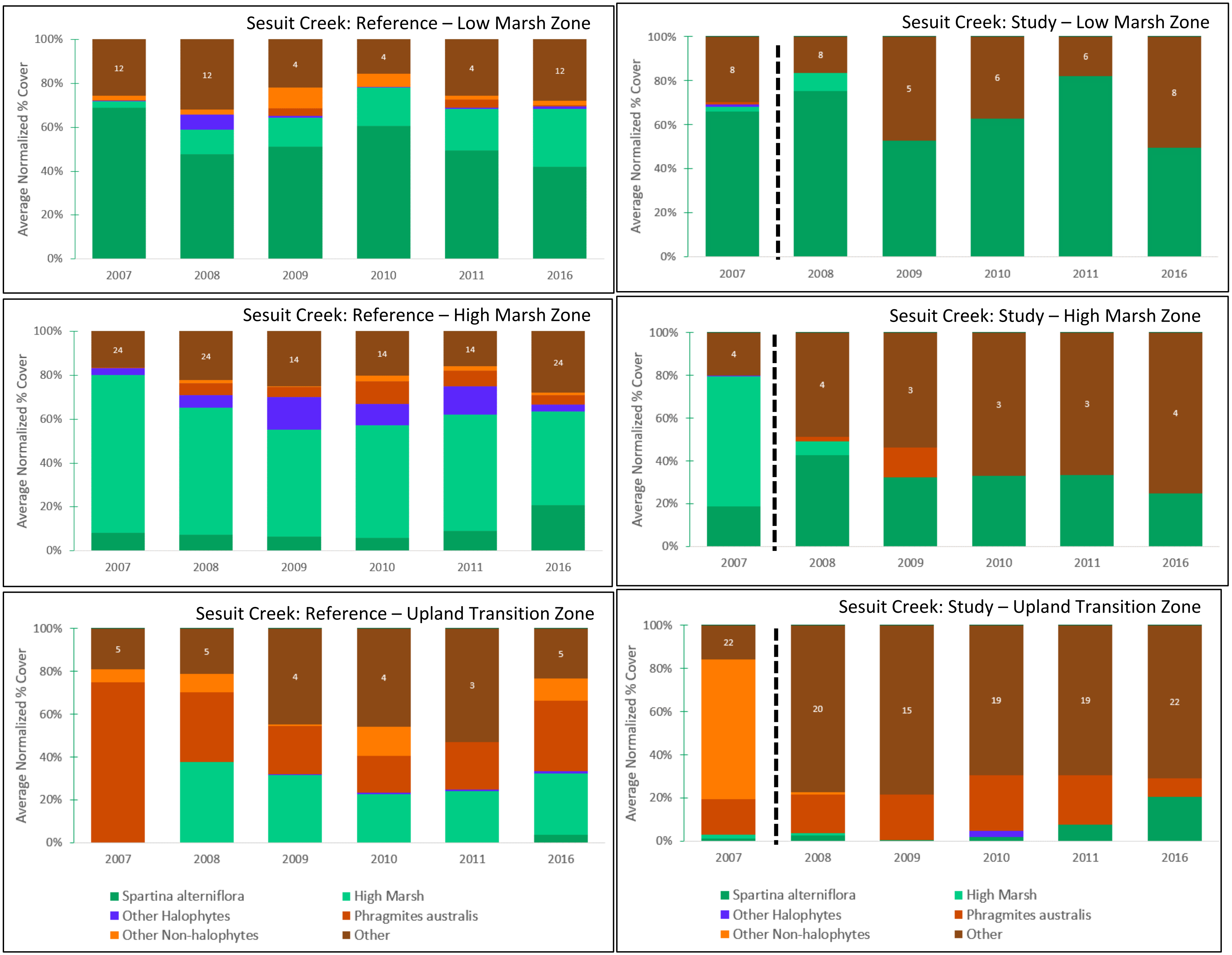


Figure 8: Average normalized percent cover for five major vegetation types across three marsh zones in Sesuit Creek, Dennis, MA. “Other” represents unvegetated area such as bare sediment, wrack, and/or dead plants. Black dashed line indicates when restoration occurred. Column numbers represent plot sample size. No monitoring occurred in 2012-2015.

6. *State Game Farm, Sandwich*

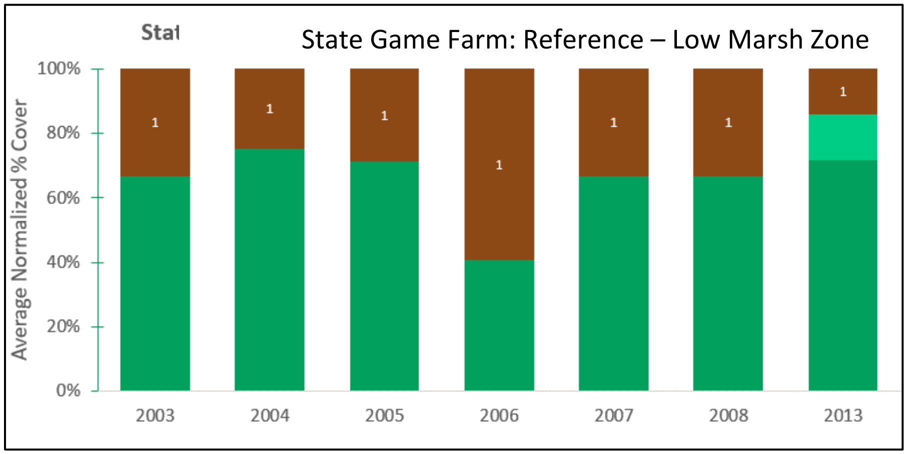

Reference marsh (left) and study marsh (right) photos taken on July 25, 2019.

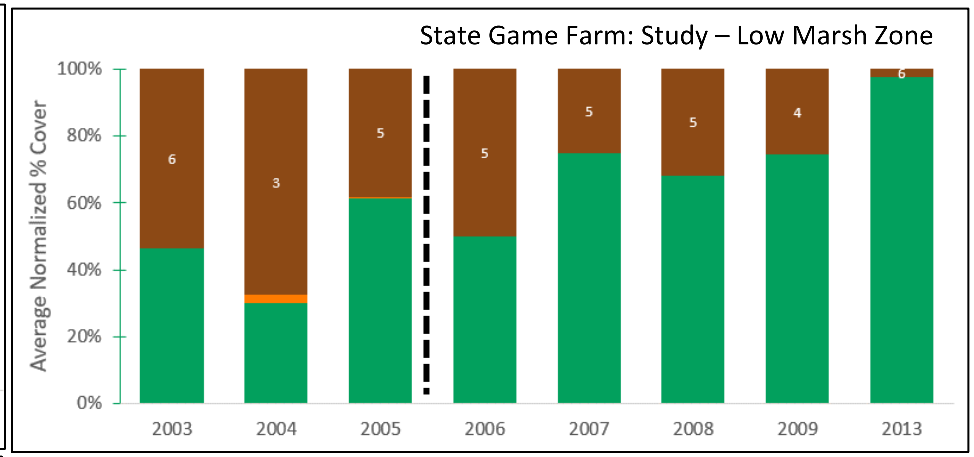
State Game Farm was restored in June 2006. Pre- and post-restoration monitoring of the reference and study areas occurred between 2003 and 2013. Figure 9 shows the annual average percent covers of the major vegetation types. Data from the first (2003) and last (2013) years of monitoring were used for all statistical comparisons. Statistical comparisons between the reference and study marsh were not possible due to the plot sample sizes within the respective zones. See Appendix A for a map of the plots and transects.

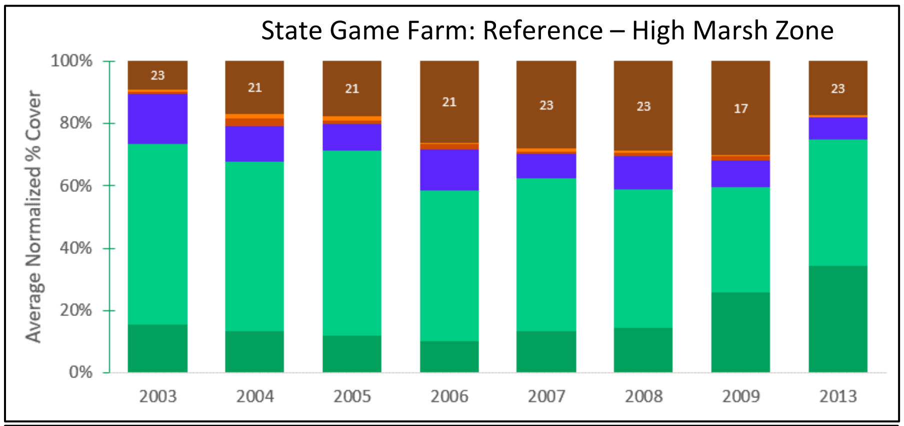
Between 2003 and 2013, *S. alterniflora* increased significantly in the reference marsh high marsh zone ($p = 0.03$, 16% to 34%, n = 23). While not significant, there appeared to be a decreasing trend in the other salt marsh categories (high marsh species and other halophytes) as well as an increasing trend in unvegetated area. *Phragmites* was barely present in the reference high marsh zone and showed no change over time.

In the study marsh, between 2003 and 2013 (7 years post-restoration), there was a significant increase in *S. alterniflora* (p = 0.02, 46% to 98%, n = 6) and a significant decrease in unvegetated area ("Other"; p = 0.02, 54% to 2%, n = 6) in the low marsh zone. In the study marsh upland transition zone, there was a significant decrease in other non-halophytes cover ($p = 0.01$, 81% to 26%, n = 4). It is important to note that the largest change in other non-halophytes occurred before the restoration occurred between 2003 and 2004.

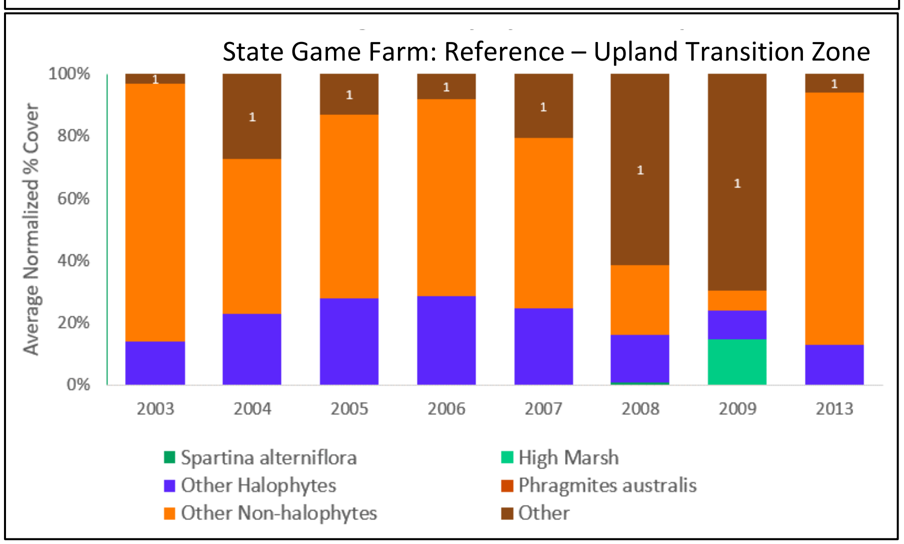
During the 2019 site visit, APCC staff noted that the culvert opening for the restoration project appeared to be in good condition, but some stones along the edges of the culvert had slumped into the tidal creek. On the reference side, there were some areas where the creek appeared to be undercutting the banks and causing erosion. However, the creek banks on the study marsh did not appear to show signs of erosion or change. Additional details from the 2019 site visit are available in Appendix E.







No plots in the high marsh zone of the restored marsh area.



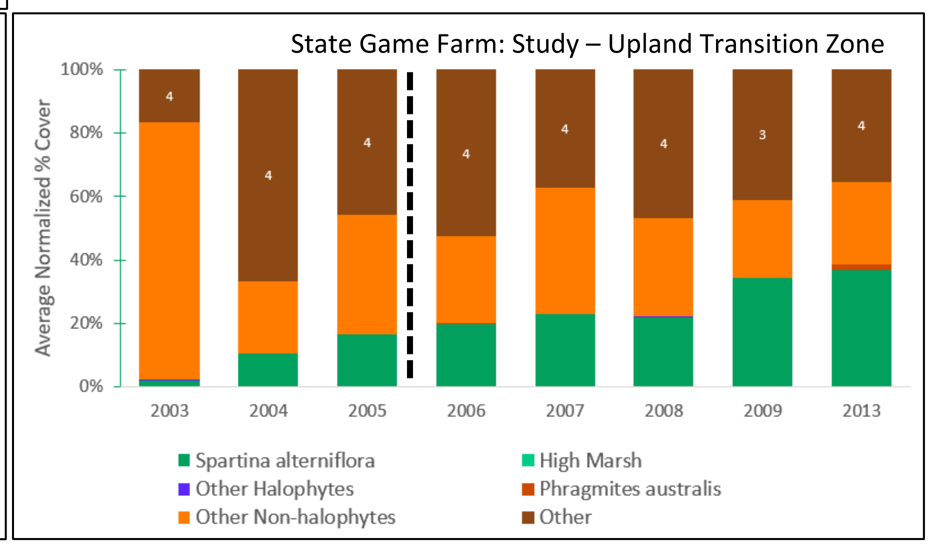


Figure 9: Average normalized percent cover for five major vegetation types across three marsh zones in State Game Farm, Sandwich, MA. "Other" represents unvegetated area such as bare sediment, wrack, and/or dead plants. Black dashed line indicates when restoration occurred. Column numbers represent plot sample size. No monitoring occurred in 2010-2012.

7. *Stony Brook, Brewster*

Reference marsh (left) and study marsh (right) photos taken on July 24, 2019.

Stony Brook was restored in the Fall of 2010. Pre- and post-restoration monitoring of the reference and study areas occurred between 2007 and 2013. Figure 10 shows the annual average percent cover of the major vegetation types. Data from the first (2007) and last (2013) years of monitoring were used for all statistical comparisons. See Appendix A for a map of the plots and transects.

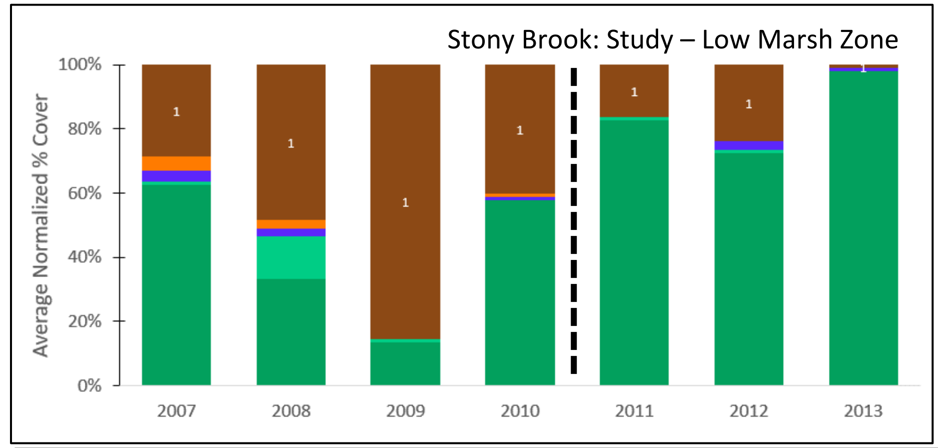
In 2007, the reference marsh had lower high marsh species percent cover ($p < 0.01$; Reference = 42%, n = 17; Study = 70%, n = 22) and higher unvegetated area percent cover ("Other"; $p = 0.02$; Reference = 45%, n = 17; Study = 23%, n = 22) than the study marsh in the high marsh zone. In 2013, three years post-restoration, there were no significant differences between the reference and study high marsh zone. In the upland transition zone in 2013, unvegetated area, "Other," was higher in the reference marsh than the study marsh ($p = 0.05$; Reference = 54%, n = 5; Study = 11%, n = 10).

In the reference area high marsh zone, *S. alterniflora* increased ($p = 0.01$, 4% to 28%, n = 17) and unvegetated area, "Other", decreased ($p < 0.01$, 45% to 17%, n = 17) between 2007 and 2013. The unvegetated area declined in the high marsh zone in the reference marsh. .

Between 2007 and 2013, in the study high marsh zone, *S. alterniflora* significantly increased ($p = 0.03$; 3% to 20%, n = 22) and there was a potential increasing trend in other halophytes and potential decreasing trend in unvegetated area "Other". 2019 field observations noted the transition from non-halophyte species to *S. alterniflora* in the study marsh. In the study upland transition zone high marsh species increased significantly ($p = 0.02$, 4% to 39%, n = 10) and unvegetated area decreased significantly ($p < 0.01$, 44% to 11%, n = 10). No other significant trends were found in the study marsh, however, observations from the 2019 field visit indicated that *Phragmites* was migrating up the tidal creek and away from the former tidal restriction.

During the 2019 field assessment visit, there was no visible evidence of bank erosion on the reference or study side of the marsh. The culvert was unblocked and in good condition. Additional details from the 2019 site visit are available in Appendix E.

No plots in the low marsh zone of the reference marsh area.



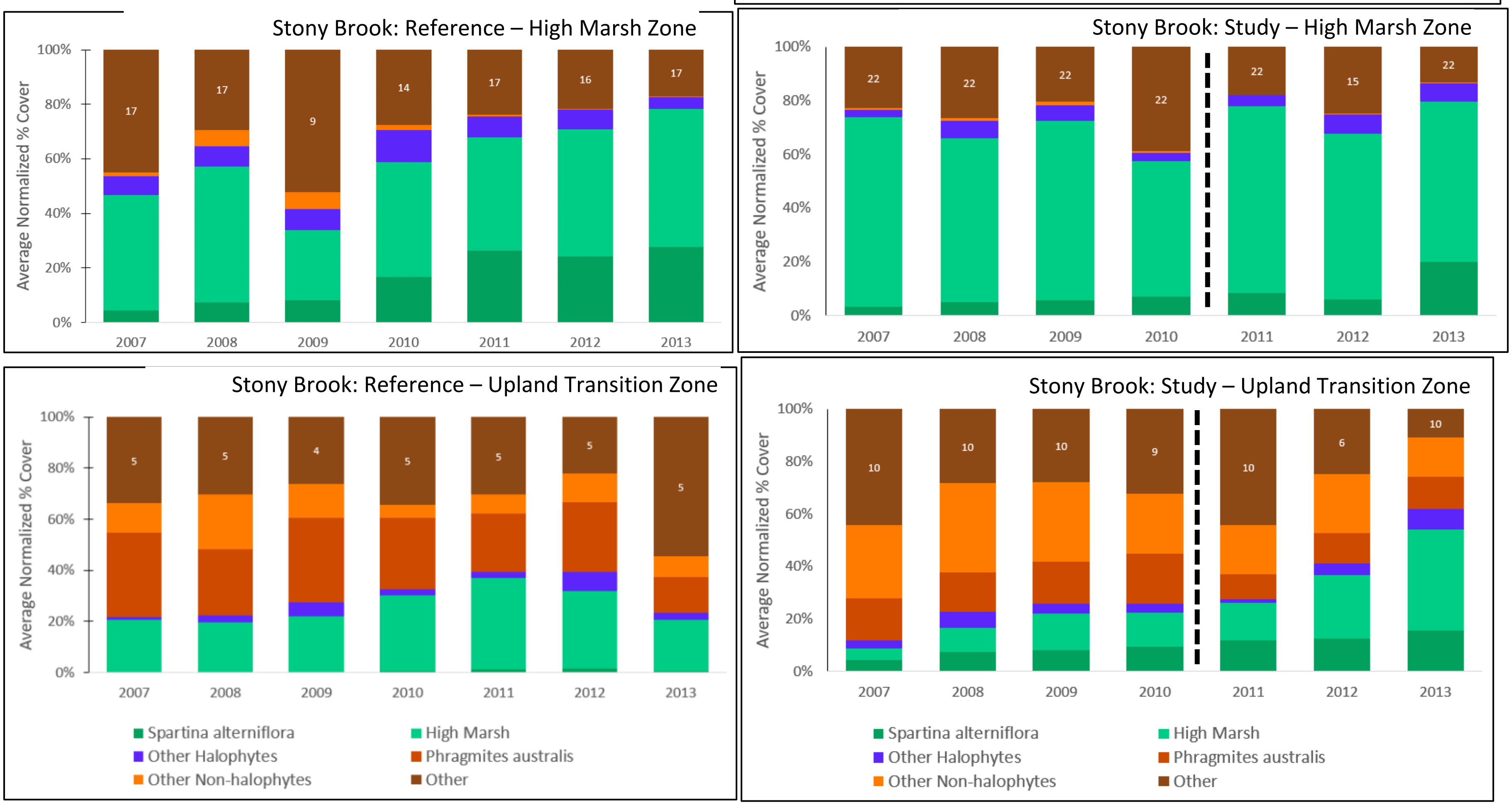


Figure 10: Average normalized percent cover for five major vegetation types across three marsh zones in Stony Brook, Brewster, MA. "Other" represents unvegetated area such as bare sediment, wrack, and/or dead plants. Black dashed line indicates when restoration occurred. Column numbers represent plot sample size.

8. Wings Neck, Bourne

Reference marsh (left) and study marsh (right) photos taken on July 31, 2019.

Wings Neck was restored in 2002. Figure 11 shows the average annual percent covers of the major vegetation types. No pre-restoration monitoring data was collected at this site. Post-restoration monitoring of the study area occurred between 2003 and 2013. Monitoring of the reference area occurred between 2004 and 2013. Statistical comparisons involving the reference marsh used 2004 data as the first year of monitoring. For statistical comparisons between the first and last year of monitoring in the study marsh, 2003 was used as the first year of monitoring. Data from 2013 was used as the last year of monitoring for all statistical comparisons. See Appendix A for a map of the plots and transects.

There were no differences in the low marsh or high marsh zones between reference and study marshes in 2004. However, in 2013, *S. alterniflora* was significantly greater in percent cover in the high marsh zone of the study marsh ($p < 0.01$; Reference = 10%, n = 7; Study = 31%, n = 31 in 2004).

Between 2004 and 2013, in the reference low marsh zone, *S. alterniflora* decreased significantly ($p = 0.04$, 66% to 46%, n =12) and there was a potential increasing trend in unvegetated area "Other".

In the study high marsh zone, between 2003 and 2013 (11 years post-restoration), there was a significant increase in *S. alterniflora* ($p < 0.001$, 9% to 35%, n = 27) and unvegetated area "Other" ($p = 0.01$, 16% to 26%, n = 27), and a significant decrease in high marsh species ($p < 0.001$, 58% to 25%, n = 27). *Phragmites* was not abundant at Wings Neck and showed no changes over time.

During the 2019 site visit assessment, APCC staff noted that the edges of the tidal creek in the reference marsh had bare areas and the stems of *S. alterniflora* had a shredded appearance, which can be indicative of *Sesarma reticulatum* (purple marsh crab) herbivory. The study marsh also showed signs of dieback along the creek banks. Most of this dieback was located closer to the culvert and was not noted farther up the tidal creek. *Phragmites* was observed on the edges of the study marsh and did not appear to be expanding into the marsh interior. Additional details from the 2019 site visit are available in Appendix E.

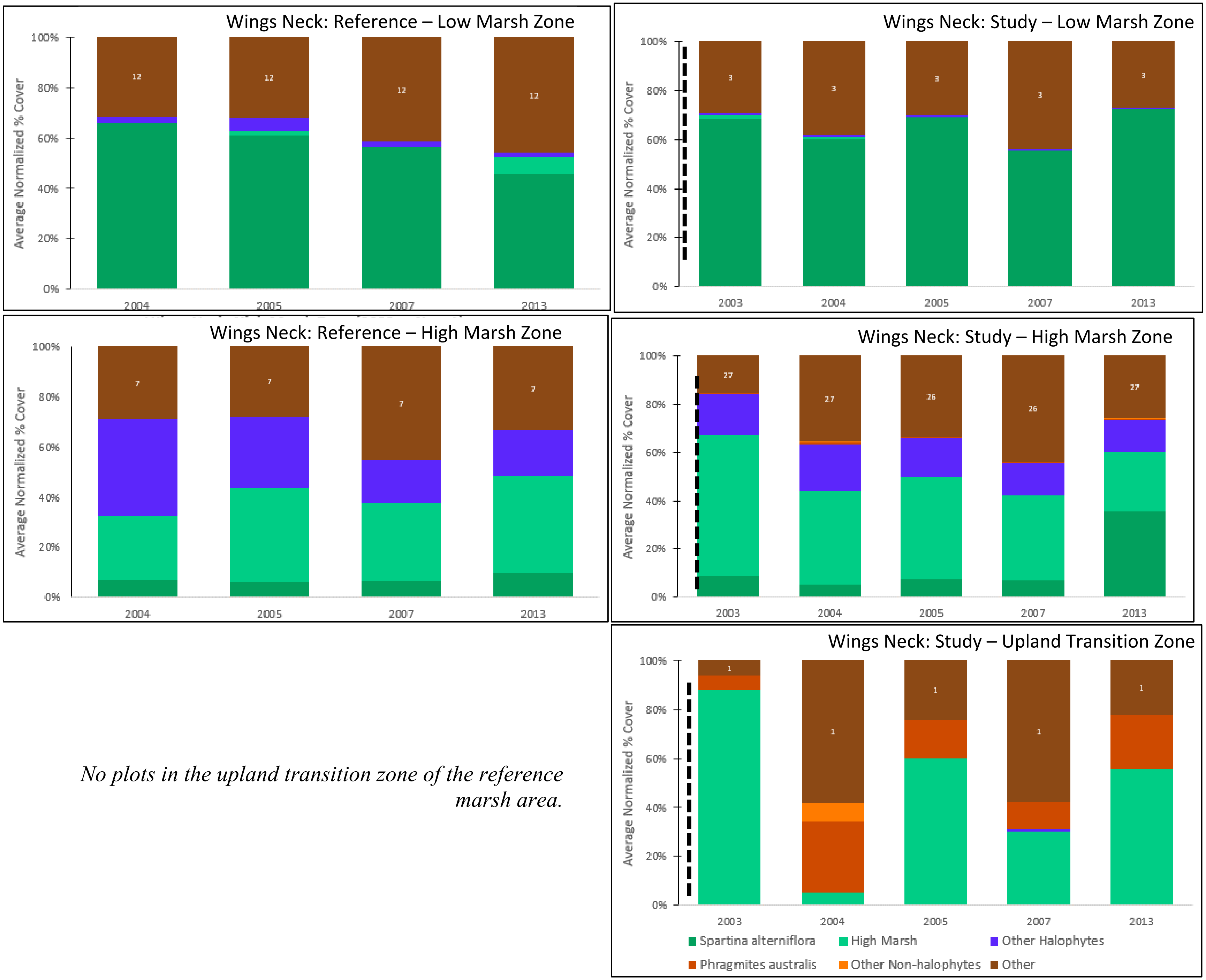


Figure 11: Average normalized percent cover for five major vegetation types across three marsh zones in Wings Neck, Bourne, MA. "Other" represents unvegetated area such as bare sediment, wrack, and/or dead plants. Black dashed line indicates when restoration occurred in 2002. Column numbers represent plot sample size. The reference marsh was not monitored in 2003.

Phragmites australis Stem Height

Figure 12 shows the results from the *Phragmites* stem height measurements. *Phragmites* height measurements were collected in all plots where *Phragmites* was present. Since there were no *Phragmites* stems in the reference plots at Wings Neck, no data were available for that reference marsh. Because the number of plots with *Phragmites* varied considerably over the years, t-tests were not an appropriate means of statistical analysis. Instead, standard error bars offer some insight into the confidence level of trends over time and between reference and study marshes within sites. For example, we can say with some confidence that at Namskaket Creek the stems of *Phragmites* in the study marsh were consistently taller than those in the reference marsh.

In most cases, the variability in sample size confounds the interpretation of change in height over time. Even at sites where sample size was fairly consistent over the years (e.g., Wings Neck), there are no obvious trends over time. The only two sites with somewhat consistent or robust sample sizes which showed trends over time were Namskaket Creek and Quivett Creek in the study marsh. However, the trends were the opposite from the expected outcome as *Phragmites* heights seem to have increased at these locations over time.

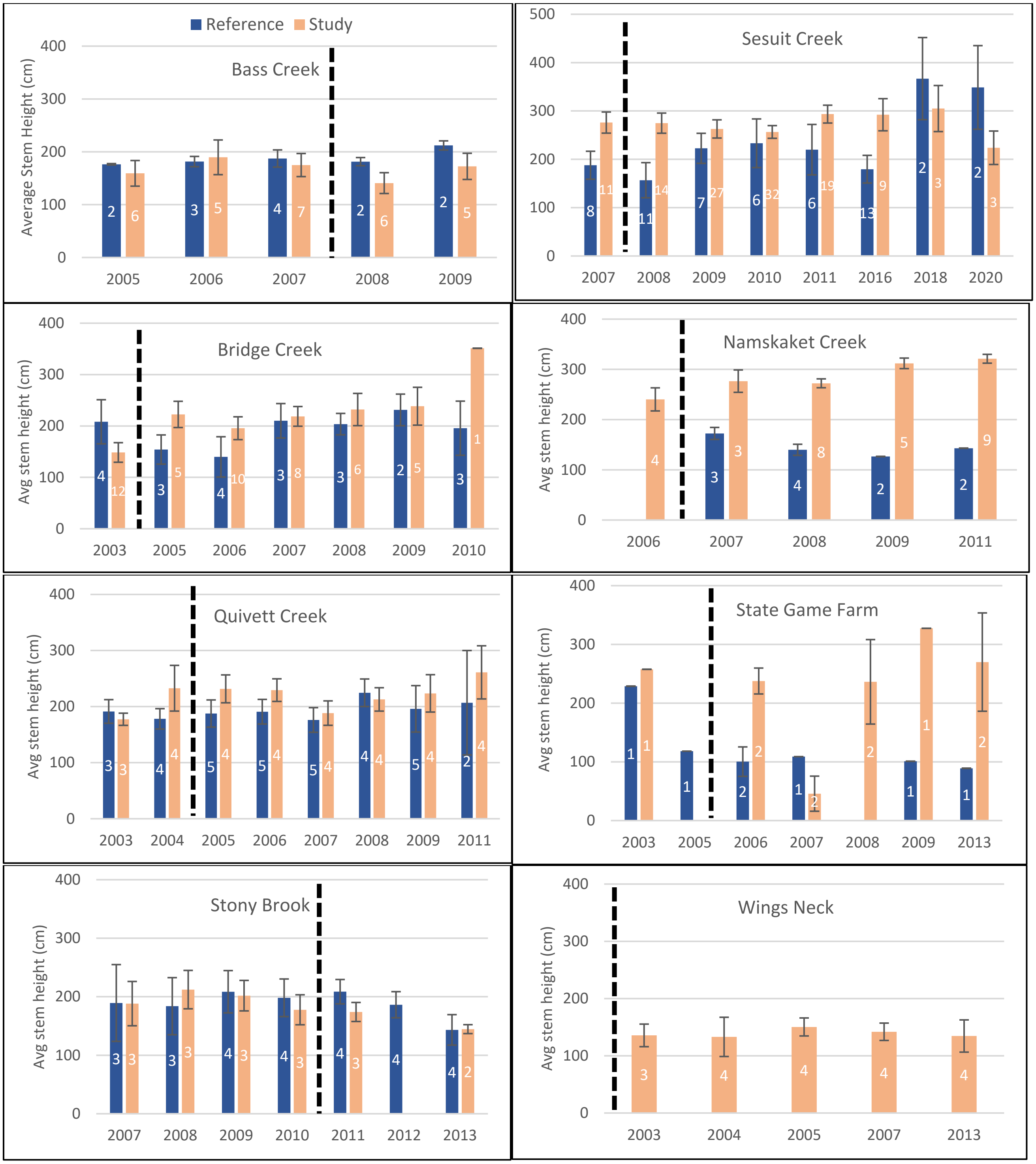


Figure 12: Average stem height of *Phragmites australis* within 1m^2 survey plot. The black dashed line indicates when the restoration occurred (in 2002 at Wings Neck). Column numbers represent number of plots sampled. Error bars represent 1 ±SE.

DISCUSSION

Overall Conclusions

The salt marsh restoration sites varied in terms of placement in the estuary (i.e., distance to head of tide and mouth of estuary or inundation source), year restored, number and span of years monitored, and other surrounding landscape-scale factors (e.g., upland slope, freshwater influence, nutrient inputs from wastewater or stormwater, etc.). The unique combination of external forces and internal processes at these sites necessitated an analytical approach which was designed to assess restoration and other impacts within sites rather than across sites. In other words, we can make broad, generalized statements about findings that are consistent across multiple sites, but the most valuable and useful findings are site-specific. Therefore, we will provide a few overarching conclusions from reviewing all eight sites but follow with site-specific assessments. Table 4 provides a summary of the analysis results for each site by marsh zone, indicating statistically significant changes between the first and last year of monitoring as well as potential trends over time.

First, the percent cover of *S. alterniflora* increased in the high marsh zone in four of the eight reference marshes (Quivett Creek, Sesuit Creek, State Game Farm, and Stony Brook) and four of the eight study marshes (Bridge Creek, Quivett Creek, Stony Brook, and Wings Neck). The increases in percent cover of *S. alterniflora* often coincide with decreases in percent cover of high marsh species in this zone. Since this trend was true not only for study marshes, but reference marshes as well, these findings suggest that the marsh plant communities may be adjusting to widespread increased inundation from sea level rise[9]. The rate of sea level rise has been especially high in the northeastern United States during most of the salt marsh monitoring period, 2005 through 2015, due to the phase of the metonic cycle. The metonic cycle is a nineteen-year cycle whereby the orientation of the moon and sun to the earth (and therefore gravitational pull) changes resulting in nine and a half-year periods of accelerated sea level rise followed by slower rates of sea level rise for another nine and a half years. As a result of these shifts in sea level rise rates, we may see slower or no landward migration of salt marsh plants during the period between 2015 and 2025.

Second, the most consistent impact of restoration appears to be reducing other non-halophytes (characteristic of more freshwater or upland conditions) in the upland transition zone of the study marsh. The results showed declines in these salt- and flood-intolerant species in the upland transition zone at three of the study marshes: Namskaket, Sesuit Creek, and State Game Farm. The data from Namskaket and Sesuit clearly show the reduction in other non-halophytes within the growing season immediately following the tidal restoration, suggesting that this change was a direct effect of the restored tidal flow. At State Game Farm, the drop occurred before the restoration, but the percentage of other non-halophytes remained low following restoration. A similar phenomenon occurred during the same year (2003-2004) at Bass Creek where other non-halophytes dropped sharply prior to restoration. Given that these trends occurred in the same year at two different sites, it’s possible that there was a strong storm event which pushed a large volume of saltwater into the upper reaches of these study marshes. The high salinity water was likely slow to drain out due to the tidal restriction causing dieback of the less salt and flood tolerant plants. The restoration of tidal flow, which occurred a few years after, probably prevented the non-

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[9] Burdick, D., C. Peter, B. Fischella, M. Tyrrell, J. Allen, J. Mora, K. Raposa, J. Goldstein, C. Feurt, L.Crane. 2020. Synthesizing NERR Sentinel Site Data to Improve Coastal Wetland Management Across New England Data Report. NEERS Science Collaborative. 37pp.

halophytes from returning in this area of the marsh. At State Game Farm and Sesuit, the non-halophytes have been partially replaced by migrating *S. alterniflora* which was an intended outcome of the restoration.

Third, as part of the restoration benefits, we expected to see declines in the height and percent cover of *Phragmites* as increased tidal inundation induced more physiological stress on the plant. However, this was not a consistent finding from these eight sites. Reduction of invasive species, such as *Phragmites,* is often a goal of tidal restoration, however, once established, *Phragmites* can be resistant to die-off due to its clonal growth. *Phragmites'* response to tidal restoration will be dependent on each unique site, its conditions (e.g., elevation, groundwater influences, nutrient inputs, etc.) and extent of tidal restoration (e.g., tidal range, duration of inundation, and salinity). For instance, *Phragmites* can be difficult to manage in the higher elevations and upstream areas of a salt marsh because of an increased freshwater influence from stormwater runoff and groundwater discharge.

If one of the goals of restoration is to remove *Phragmites*, then the management plan should be proactive and adaptive. Removal of *Phragmites* can result in loss of marsh elevation if the area remains unvegetated or is slow to revegetate with *S. alterniflora* or other salt marsh species. *Phragmites*, while not a desirable species, does provide stability to the soil and can help maintain or add to the marsh elevation through sediment accretion and biomass accumulation[10]. Thus, it is important to acknowledge that different sites need different management strategies based on the goals of the project and pre-existing conditions of the site. The main take home is that there was no clear impact on *Phragmites* (positive or negative/increasing or decreasing) due to restoration at these sites.

Lastly, the 2019 field assessment identified several sites with apparent creek erosion and sought to identify the possible source(s). However, further monitoring of the natural and imposed influences on the marsh, including detailed mapping, elevation surveys, soil analysis of creek edges, and study of the crab populations at these sites, is needed to confirm the cause and extent of change. Without a greater regional and site-specific understanding of the influence of these factors on the marsh, the link between tidal restoration and this erosion is not clear.

[10] Rooth, J., Stevenson, J. Sediment deposition patterns in *Phragmites australis* communities: Implications for coastal areas threatened by rising sea-level. *Wetlands Ecology and Management* 8, 173–183 (2000). https://doi.org/10.1023/A:1008444502859

Table 4: Summarized results from the salt marsh vegetation percent cover t-Test analyses comparing the first year of monitoring to the last year of monitoring by marsh zone. The black bold arrows represent a significant ($p \leq 0.05$) increase or decrease. The gray arrows represent potential trends that are not significant ($p > 0.05$). The dashed lines indicate no change. NP = community type not present. NA = Not applicable because sample size less than three.

Site	Marsh	Zone (n)	Spartina alterniflora	High Marsh Species	Other Halophytes	Phragmites australis	Other Non-Halophytes	Un-vegetated area
Bass Creek	Reference	Low Marsh (6)	↓	↑	**↑**	---	---	↓
		High Marsh (15)	---	**↓**	---	---	---	↑
		Upl Transition (0)	NA	NA	NA	NA	NA	NA
	Study	Low Marsh (0)	NA	NA	NA	NA	NA	NA
		High Marsh (14)	---	---	↓	---	---	**↑**
		Upl Transition (4)	---	---	---	---	---	---
Bridge Creek	Reference	Low Marsh (5)	↑	---	---	---	---	↓
		High Marsh (3)	---	---	---	NP	---	---
		Upl Transition (4)	---	---	---	---	---	---
	Study	Low Marsh (2)	NA	NA	NA	NA	NA	NA
		High Marsh (11)	↑	**↓**	---	---	NP	---
		Upl Transition (8)	---	NP	---	---	---	---
Namskaket	Reference	Low Marsh (1)	NA	NA	NA	NA	NA	NA
		High Marsh (7)	---	---	---	NP	NP	---
		Upl Transition (4)	---	NP	---	---	---	↑
	Study	Low Marsh (0)	NA	NA	NA	NA	NA	NA
		High Marsh (1)	NA	NA	NA	NA	NA	NA
		Upl Transition (8)	NP	NP	---	**↑**	**↓**	---
Quivett Creek	Reference	Low Marsh (0)	NA	NA	NA	NA	NA	NA
		High Marsh (11)	**↑**	**↓**	---	---	---	---
		Upl Transition (1)	NA	NA	NA	NA	NA	NA
	Study	Low Marsh (2)	NA	NA	NA	NA	NA	NA
		High Marsh (7)	↑	**↓**	---	---	---	---
		Upl Transition (4)	---	---	NP	---	---	---
Sesuit Creek	Reference	Low Marsh (12)	**↓**	**↑**	---	---	---	---
		High Marsh (24)	**↑**	**↓**	---	↑	---	**↑**
		Upl Transition (5)	---	↑	---	↓	---	---
	Study	Low Marsh (8)	↓	---	↓	NP	---	↑
		High Marsh (4)	---	**↓**	---	NP	NP	↑
		Upl Transition (22)	**↑**	---	NP	---	**↓**	**↑**
State Game Farm	Reference	Low Marsh (1)	NA	NA	NA	NA	NA	NA
		High Marsh (23)	**↑**	↓	↓	---	---	↑
		Upl Transition (1)	NA	NA	NA	NA	NA	NA
	Study	Low Marsh (6)	**↑**	NP	NP	NP	NP	**↓**
		High Marsh (0)	NA	NA	NA	NA	NA	NA
		Upl Transition (4)	---	---	---	---	**↓**	---
Stony Brook	Reference	Low Marsh (0)	NA	NA	NA	NA	NA	NA
		High Marsh (17)	**↑**	---	---	NP	---	**↓**
		Upl Transition (5)	---	---	---	↓	---	---
	Study	Low Marsh (1)	NA	NA	NA	NA	NA	NA
		High Marsh (22)	**↑**	---	↑	NP	---	↓
		Upl Transition (10)	---	**↑**	---	---	↓	**↓**
Wings Neck	Reference	Low Marsh (12)	**↓**	---	---	NP	NP	↑
		High Marsh (7)	---	---	---	NP	NP	---
		Upl Transition (0)	NA	NA	NA	NA	NA	NA
	Study	Low Marsh (3)	---	---	---	NP	NP	---
		High Marsh (27)	**↑**	**↓**	---	---	---	**↑**
		Upl Transition (1)	NA	NA	NA	NA	NA	NA

Conclusions by Site

The following section provides a summary of the trends seen at each of the eight salt marsh restoration sites along with recommendations for future monitoring or management based on the vegetation data analysis and the 2019 field assessment. Table 5 displays the number of years of pre- and post-restoration vegetation monitoring at each site and also provides the number of years between when restoration occurred and the final year of monitoring data. The bolded text in Table 5 indicates which years were used in the t-test analyses. The vegetation plots included in the t-tests and graphs represent a subset of the total plots surveyed and the selection was based on quality control checks and inclusion in the first and last year of monitoring. As shown in Table 5, the number and range of monitoring years varied considerably across the eight restoration project sites. This difference in timeline is an important consideration when interpreting the results from the data analyses. We acknowledge and discuss the influence of the respective timelines in the site-specific summaries below.

Table 5. List of pre- and post-restoration vegetation monitoring completed for each site by year. Pre: vegetation monitoring that occurred prior to tidal restoration at the study and reference marshes (except where noted otherwise); Post: vegetation monitoring that occurred after tidal restoration at the study and reference marshes (except where noted otherwise). Gray highlights show the years that elapsed between when restoration occurred, and the final year of vegetation monitoring included in analysis.

Year	Bass Creek	Bridge Creek	Namskaket	Quivet	Sesuit	SGF	Stony Brook	Wings Neck
2003	Pre**	Pre**		Pre**		Pre**		Post ** (study only)
2004	Pre	Pre		Pre		Pre		Post**
2005	Pre	Post		Post		Pre		Post
2006	Pre	Post	Pre ** (study only)	Post		Post		
2007	Pre	Post	Post**	Post	Pre**	Post	Pre**	Post
2008	Post	Post	Post	Post	Post	Post	Pre	
2009	Post	Post	Post	Post	Post	Post	Pre	
2010	Post	Post**			Post		Pre	
2011			Post**	Post**	Post		Post	
2012	Post**						Post	
2013						Post**	Post**	Post**
2014								
2015								
2016					Post**			
2017								
2018					Post*			
2020					Post*			
No. of Years Elapsed b/w Restoration and Final Monitoring	**5**	**6**	**5**	**7**	**9**	**8**	**3**	**11**

* Sesuit Creek post-restoration monitoring data collected in 2018 and 2020 was not included in the analysis since it did not include all of the study and reference transects.

** First and last year of monitoring data that were used for statistical t-test analyses.

1. Bass Creek

Although the statistical t-test comparing *Phragmites* percent cover over time did not yield significant results, there was a substantial decline in *Phragmites* in the study marsh such that the difference between reference and study was significant at the start of monitoring (in 2003) but was not significantly different by 2012. These findings suggest that the tidal restoration to the upstream section of the marsh in 2008 was somewhat successful in reducing the cover of the invasive species.

There was a dieback of *S. alterniflora* in the low marsh reference area between 2003 and 2004. One possible explanation for the dieback could be impacts of wrack or other debris which settled in the reference low marsh zone in 2004 causing significant die-off of *S. alterniflora* which slowly revegetated over time. The fact that high marsh species, namely *D. spicata* and *S. patens* based on a review of the data, moved into the low marsh at this site further suggests that wrack buildup may have reduced the cover of *S. alterniflora* and provided an opportunity for these high marsh species to temporarily spread into this lower zone. Wrack accumulation is a natural phenomenon in the salt marsh and not generally a cause for concern. Salt marsh plants have evolved to cope with these dynamic systems adjusting to the constant changes in physical stress and interspecies competition, so shifts like this are part of the normal variability of the marsh plant community.

The non-halophyte species that disappeared from the upland transition zone of the study marsh prior to restoration included *Clethra alnifolia*, *Kalmia* spp., and *Rhododendron* spp.; observations from the field suggests that these plants died, and the area converted to dead plants and wrack. *Phragmites* is present in these upland transition plots but did not take over, which suggests that the area became too stressful for non-flood tolerant species prior to and following restoration. There may have been a strong storm that caused saltwater to flood higher reaches of the marsh from the low air pressure and wind (often referred to as storm surge). Combined with slow drainage from tidal restrictions, an event like this may have caused die-off of non-halophytes prior to restoration.

The reference and study marsh at Bass Creek appeared productive with dense vegetation in 2019 but both sides of the marsh had areas of eroding creek edge that may need to be monitored to track change and better understand the cause.

2. Bridge Creek

The eight years of monitoring data from Bridge Creek indicate that there were more differences in plant community between the reference and study marshes after restoration than before because *S. alterniflora* increased in the high marsh zone of the study marsh following restoration in 2005. One possible explanation for this disparity between the *S. alterniflora* in the reference and study marsh is a difference in elevation. Due to the tidal restriction, the study marsh may have subsided over time resulting in a lower salt marsh platform elevation. Once the tidal flooding was restored, *S. alterniflora* expanded into the high marsh zone. However, more vegetation monitoring and elevation data collection are needed to confirm this theory.

There was no clear trend in *Phragmites* at this site, although following restoration, the study marsh had more *Phragmites* cover than the reference area (which was not true at the start of monitoring). There was also a decline in high marsh species in the high marsh zone at this study marsh site which may have provided an opportunity for *Phragmites* to expand. Because *Phragmites* can withstand saltwater stress by dispersing resources through its robust rhizome network, this species can persist even when tidal flooding is restored. More data collection is needed to determine the best strategy for managing *Phragmites* at this site. With only six years between the restoration and the last year of monitoring, additional vegetation surveys are needed to determine the long-term impact of the tidal restoration on the upstream plant communities.

3. *Namskaket Creek*

The data did not show much change in plant community in the reference or study marshes at Namskaket Creek over the monitoring period. One likely reason for this is the short timeframe that monitoring occurred (2006-2011 for the study site and 2007-2011 for the reference and only five years of post-restoration data). More years of monitoring data are needed to track changes over time.

The one obvious impact from the restoration occurred in the upland transition zone of the study marsh. There was a significant decline in other non-halophyte species in the study upland transition zone. *Phragmites* took advantage of the dieback and increased in cover in this zone. The stem height results also indicate the *Phragmites* may have increased in size. Because of *Phragmites'* clonal growth and ability to share resources across large stands, it can spread rapidly especially at the upland border where flooding is less frequent.

Management of this site has varied over time with disagreement about how to maintain the culvert opening. The addition of boards observed in 2019 has created a partial restriction. The data as well as observations made in 2019 would suggest that placement of the boards should be reconsidered as this may be contributing to persistence of *Phragmites* in the study marsh. The creek edge erosion observed in the reference marsh in 2019 should also be assessed and tracked over time to determine the extent and cause.

4. *Quivett Creek*

The reference and study marshes at Quivett Creek both experienced changes in the high marsh zone whereby *S. alterniflora* expanded into this higher elevation zone displacing high marsh species. Since this trend was consistent across the reference and study marsh, these findings suggest that the changes were driven by sea level rise. No other major changes or trends were discovered at Quivett Creek across the nine-year monitoring period which included seven years following restoration. The partial restriction of the culvert observed in 2019 may be contributing toward the persistence, and possible increasing height, of *Phragmites*. Removal of boards should be considered as an option to improve the upstream salt marsh habitat.

5. *Sesuit Creek*

The percent cover of non-halophytes dropped rapidly in the study marsh after the restoration as a result of the higher salinity concentrations and gradient associated with the restored tidal flooding. Due to the sharp decline in percent cover of non-halophytes following restoration and the slow recovery of halophyte plants, the study marsh still had a high percentage of unvegetated area in 2016, nine years after restoration occurred. The non-halophytes previously composed most of the study marsh area, so when the natural flooding cycle was reintroduced, there was a relatively large area of unvegetated marsh. However, it's also important to note that bare areas are a normal part of a healthy salt marsh ecosystem as mud flats are valuable feedings areas for shore birds. Natural processes such as wrack, sediment deposition and winter ice can create bare areas that recolonize with plants over time.

One possible explanation for the persistent bare area relates to the elevation of the marsh surface. The study area was found to have a lower average elevation (data collected by the UNH research team) than the reference marsh. Lower elevation results in longer and more frequent flooding and this flooding stress may hinder the revegetation of halophytes in the study marsh.

The persistent bare cover in the study marsh may also be due in part to impacts of sea level rise based on findings from the reference marsh. In the downstream reference area, the high marsh zone experienced considerable changes that would not have been influenced by the restoration of the upstream area. First, *S. alterniflora* expanded into the high marsh zone. Second, the unvegetated, or bare, area also increased in the high marsh zone. The expansion and development of bare areas within the interior of the salt marsh platform is a common phenomenon seen across salt marshes in New England and has been attributed to rising sea levels[11,12,13]. Given these findings, it is likely that the study marsh is not only recovering from restoration but also adjusting to rising sea level. The rate of sea level rise has been especially high over the course of the Sesuit monitoring period (2005 – 2015) due to the phase of the metonic cycle.

Although some bare area persists, there are signs in the data that the marsh is revegetating with native halophytes as *S. alterniflora* has increased in what was previously upland transition zone. Furthermore, from 2015 through 2025, during a relatively slower sea level rise period, we expect to see a faster rate of revegetation in the study marsh as the native grasses will experience less severe flooding. During the 2019 site visit, APCC staff observed some of the greatest expansion of *S. alterniflora* in areas outside of transect locations (Appendix E). A pilot planting of *S. alterniflora* plugs, completed by APCC in 2018, has already resulted in growth and survival through 2020.

6. State Game Farm

Sea level rise impacts were also seen in the data collected between 2003 and 2013 at State Game Farm. In the reference marsh, *S. alterniflora* increased into the high marsh zone displacing high marsh species over the eleven years of monitoring. The impacts of sea level rise combined with the restored tidal flooding likely influenced the changes seen in the study marsh. In the low marsh zone of the study marsh, there was an increase in *S. alterniflora* cover and a decrease in unvegetated area. Additionally, the upland transition zone of the study marsh experienced a reduction in other non-halophytes.

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[11] Burdick, D., C. Peter, B. Fischella, M. Tyrrell, J. Allen, J. Mora, K. Raposa, J. Goldstein, C. Feurt, L.Crane. 2020. Synthesizing NERR Sentinel Site Data to Improve Coastal Wetland Management Across New England Data Report. NEERS Science Collaborative. 37pp.

[12] Raposa, K.B., K. Wasson, S. Lerberg, E. Smith, J. Crooks, P. Delgado, S. Fernald, M. Ferner, A. Helms, L.A. Hice, J. Mora, B. Puckett, D. Sanger, S. Shull, L. Spurrier, R. Stevens, S. Lergerg. 2016. Assessing tidal marsh resilience to sea-level rise at broad geographic scales with multi-metric indices. *Biological Conservation* 204(B): 263–275.

[13] Smith, S.M., 2020. Salt marsh migration potential at Cape Cod National Seashore (Massachusetts, U.S.A.) in response to sea-level rise. Journal of Coastal Research, 36(4), 771–779. Coconut Creek (Florida), ISSN 0749-0208.

These findings suggest that the restoration was largely successful in restoring native salt marsh grasses to the upstream portion of the marsh. However, during the 2019 assessment, APCC noted there was some erosion of the creek edge in the reference marsh and movement in the rocks surrounding the culvert. This transport of materials and sediments should be reviewed to see if additional management measures need to be taken.

7. *Stony Brook*

With only three years of post-restoration monitoring, survey results from Stony Brook indicate that the study marsh has responded positively to restoration, exhibiting a decline in non-halophyte species in the upland transition zone and an increase in *S. alterniflora* cover in the high marsh zone. The study marsh also had higher *S. alterniflora* and lower percentage of unvegetated area in the upland transition zone than the reference area, which suggests that the restored tidal flow has resulted in robust and healthy regrowth of native species. Since the reference marsh also experienced an increase in *S. alterniflora* in the high marsh zone, the expansion of *S. alterniflora* is likely driven by sea level rise. Paired with the increases in *S. alterniflora,* was a decline in unvegetated area in both the study and reference marshes, which suggests the Stony Brook marsh is keeping up with sea level rise above and below the former tidal restriction.

Although the plot percent cover analyses showed no clear trends, photo-documentation and mapping of *Phragmites* patches has shown a decline in the area immediately upstream of the former restriction with some observed migration of the invasive further upstream (Figure 13).

8. *Wings Neck*

Wings Neck had the longest span of post-restoration vegetation monitoring of the eight sites with eleven years between when the restoration occurred and the last site survey. The monitoring analyses suggest that *S. alterniflora* cover has significantly declined in the reference low marsh zone resulting in a higher percentage of bare, or unvegetated, area. Similarly, the high marsh zone in the study marsh also experienced decreased high marsh species cover and increased unvegetated area and S. *alterniflora* cover. However, *Phragmites* has remained low in percentage of the plant community cover.

The trends of increasing bare patches, paired with the 2019 observation of indicators of purple marsh crab herbivory, are cause for concern. Wings Neck is the only site, of the eight restoration sites presented here, in Buzzard's Bay and is also located the furthest downstream in its respective estuary (as evidenced by the high surface salinity readings around 30 ppt, Appendix D), so it may be experiencing more pronounced impacts from sea level rise. The exposure to higher salinity levels may also help to keep *Phragmites* from spreading.

While the bare areas and migration of the plant species may be an indication of sea level rise and other natural processes, the field observations of possible crab impacts warrant further investigation into the cause of the dieback areas. Further monitoring of this site is recommended to determine the current state of the marsh and possible management measures to control the crab.

Lessons Learned and Recommendations

1) *Reduce distance between plots in narrow zones (e.g., low marsh and upland transition zone) to capture changes in these plant communities and make sure all transects go into the upland when designing monitoring study.*

   Where marsh zones are particularly narrow, it's important to reduce the distance between plots to adequately represent these zones in the vegetation monitoring data. Without a robust sample size per marsh zone in the reference and study marsh, inferences are limited as to how the various marsh components are responding to restoration or other environmental factors (such as sea level rise). Without this information, managers cannot make informed decisions about future restoration projects or adaptive management strategies.

2) *Employ best practices: take photos of plots during survey and enter data promptly.*

   By taking photos of each plot during every annual salt marsh survey, data can be better controlled for quality assurance. For example, if there's an error on the field datasheet, having the photo can often resolve the mistake. Additionally, photos provide a great visual representation of change in the salt marsh over time.

   Lastly, entering field data promptly following field survey is extremely helpful as confusing data or missed plots can be quickly rectified.

3) *Develop detailed and standardized plot cover types.*

   Based on the review of this monitoring data, we do not recommend using "other" as a cover type as it lacks critical detail. We recommend specifying the various types of cover in the field and including those in the data collected, such as bare sediment, wrack, and/or dead plants. For even more detail, dead plants can be further broken down into "last year's growth" (commonly the underlying thatch layer) and "dead" for plants that have not survived the current growing season. We also suggest that surveyors include the percent of standing water within the plot, so changes in standing water (i.e., pooling) can be analyzed as part of the long-term assessment. Additionally, short-form and tall-form Spartina alterniflora should be distinguished from each other as they indicate different habitat types and inundation frequency (short-form often occurs in salt water pannes on the marsh platform, while tall-form occurs along the edges of creeks and within ditches).

4) *Consider tracking large-scale changes in vegetation communities using different methods*

   Transects and percent cover monitoring capture species changes within the salt marsh plant community while other methods such as mapping from aerial images may provide a better big picture understanding of how the entire study area is revegetating over time (e.g., increasing or decreasing bare or pooled areas). Furthermore, it is important to recognize that the methodology used for overall vegetation monitoring by transect and plot is not necessarily the best method to show change in *Phragmites*. Because plots represent small proportion of the overall marsh, changes in the extent and density of *Phragmites* can be missed.

Mapping the perimeter of *Phragmites* in the field using a GPS tracking device is another option for monitoring change. In addition to percent cover monitoring, the perimeter mapping method was employed at Stony Brook pre- and post- restoration. Whereas the plot data shows no significant change in percent cover of *Phragmites* in the study marsh, the mapping was able to detect decline and elimination of several patches of *Phragmites* as well as some expansion into new areas further upstream, both results that are important in understanding the impact of tidal restoration on this invasive (Figure 13).

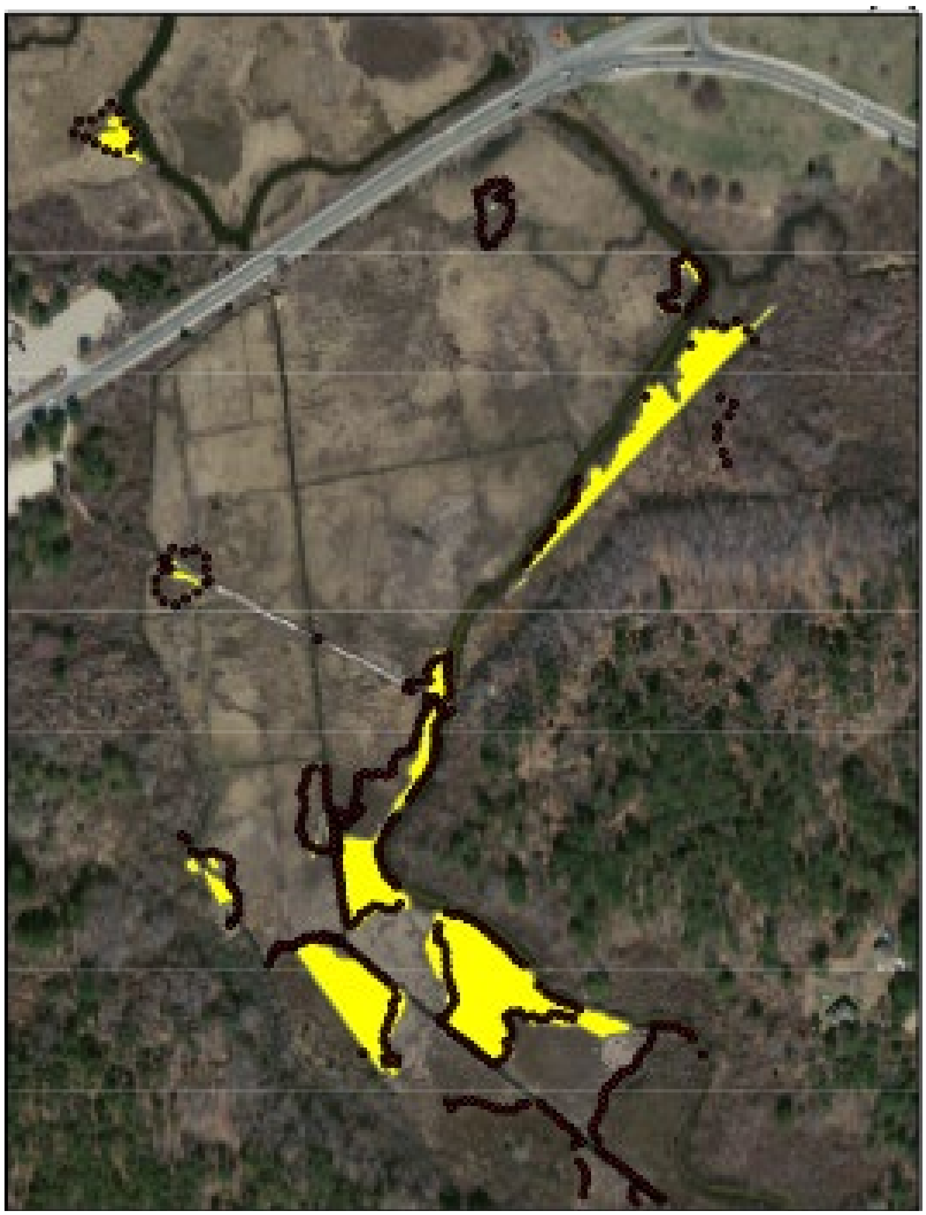


Figure 13. Change in perimeters of *Phragmites*, 2007 – 2013, at the Stony Brook restored salt marsh in Brewster, MA. The 2007 area of *Phragmites* three years before restoration is outlined by dark red dots, while the area covered by *Phragmites* in 2013, three years following restoration, is shown in yellow.

5) *When collecting raw percent cover, force total cover to 100%.*

   Using cover classes can be an effective means of standardizing observations and reduces survey time spent per plot. However, the combined total should not exceed 100% to prevent biases related to plots with multiple canopies (i.e., plots which include plants of widely different heights, such as *Phragmites* and *Eleocharis sp.*). In particular, bare or unvegetated area tended to be over-estimated when tall (>35cm) plants were present in the plot.

6) *Understanding immediate restoration impacts requires at least three years of monitoring data but continued monitoring every five or ten years is preferred.*

   Tidal flow to many of these Cape Cod salt marshes had been restricted for decades or hundreds of years. To measure the full impact of restoration, monitoring these marshes over a long timescale is critical. To track the near-term and long-term impacts of restoration, monitoring efforts should cover the first three years of rapid change as well as longer-term monitoring every five to 10 years.

7) *If possible, collect elevation data to inform interpretation of trends in vegetation.*

   If time and funding allow, obtaining elevation data in the reference and study marsh, through real-time kinematic GPS, laser level, or optical level, prior to and following restoration can provide valuable information about how the marsh platform responds to the changed hydrology. This elevation data can help with interpretations of plant community recovery over time. For example, if the elevation is much lower in the study marsh, this would help inform the management strategy of that upstream habitat. Additionally, understanding the long-term changes in inundation time (calculated by modeling the tidal range against the elevation of each plot) could help distinguish impacts from sea level rise versus tidal restoration. Conducting additional elevation surveys in the reference and study marshes every 5 years can be a useful way to see how the marsh is adjusting to restoration over the long-term as well.

8) *Recommendations for monitoring and analyzing salinity data:*

   Each salt marsh has a different upstream watershed that will also influence the changes seen in vegetation and salinity over time. The lack of response in pore water and surface water salinity post-restoration, for example, may be a result of freshwater influences on the system and the methodology of sampling at low tide as opposed to failure to restore tidal flow and increase salinity in the study marsh (see Appendix D for salinity results). We recommend collecting salinity data using automatic loggers. If possible, combine water level and salinity measurements in a multi-parameter device and deploy before and after restoration. Deployments should last for at least one month to capture a full lunar cycle including two neap and two spring tide phases. Additionally, if pore water samples are collected, plot the salinity data against elevation (or plot distance from tidal creek) of the marsh to determine the salinity gradient along your plant survey transects. This will also help inform interpretations of percent cover data.

9) *Suggestions for vegetation analysis and data interpretation:*

To improve the statistical power of plant community analyses, group plots by the year one marsh zone. This is best accomplished by assigning the marsh zone while in the field during the first year of monitoring. However, the calculation presented here for this analysis can be applied to other monitoring efforts that started in the past.

We recommend analyzing vegetation change using the percent cover metric. This was an effective measure of change in the reference and study salt marshes. Whereas, assessing restoration impacts through species richness yielded less conclusive results (Appendix B). Tidal restoration to a salt marsh normally results in lower species richness because plant growth is limited in these ecosystems to those species that have evolved to handle salinity stress in addition to flooding. Thus, after the initial flooding and dieback of non-halophytes, species richness is not expected to change dramatically after the first one to three years following restoration.

Additionally, when interpreting your results, consider the phase of the metonic cycle. Since high-accuracy long-term water level monitoring is difficult to obtain for these restoration projects, understanding the trajectory of sea level rise for your specific site is a challenge. If you consider the phase of the metonic cycle while analyzing and interpreting the results, at least you are better prepared to draw conclusions regarding the changes seen in your marsh.

Lastly, if you are analyzing multiple sites to understand general trends across sites, consider holding the number of monitoring years constant. For instance, compare changes across sites within three years, five years, and ten years of restoration. This may improve one's understanding of the different stages following restoration and may be another worthy next step for the data presented here.

There are many other factors influencing the marsh plant community structure in addition to the impacts of tidal restoration including freshwater inputs, nutrient inputs from wastewater and stormwater, sediment supply, sea level rise (and rate of sea level rise which varies depending on the metonic cycle), marsh surface elevation, extent and period of inundation, crab species range shifts, historical ditching and current management of ditches, and the distance of the marsh from the tidal source (i.e., mouth of estuary). With extended long-term monitoring and improved field and analysis methods (such as mapping the extent of *Phragmites*), we can begin to achieve a better understanding of the timeline and trajectory for recovery.

APPENDIX A: Site-specific maps of monitored vegetation survey plots.

Note: The accuracy of the GPS units used to record the plot points varied, so the maps below offer the reader a general sense of where plots were located but do not always represent the plots' exact location.

Figure A1: Vegetation plots at Bass Creek salt marsh restoration site in Yarmouth, MA. Yellow marker indicates location of former tidal restriction.

Figure A2: Vegetation plots at Bridge Creek salt marsh restoration site in Barnstable, MA. The yellow marker represents the former tidal restriction removed in 2005. The Bridge Creek restoration project occurred in two phases. In 2003 an under-sized culvert beneath an active railroad line was replaced. In 2005 an under-sized culvert beneath Route 6A was replaced. The restoration monitoring data presented in this report were collected for the second phase of the project.

Figure A3: Vegetation plots at Namskaket Creek salt marsh restoration site in Brewster, MA. The yellow marker represents the former tidal restriction.

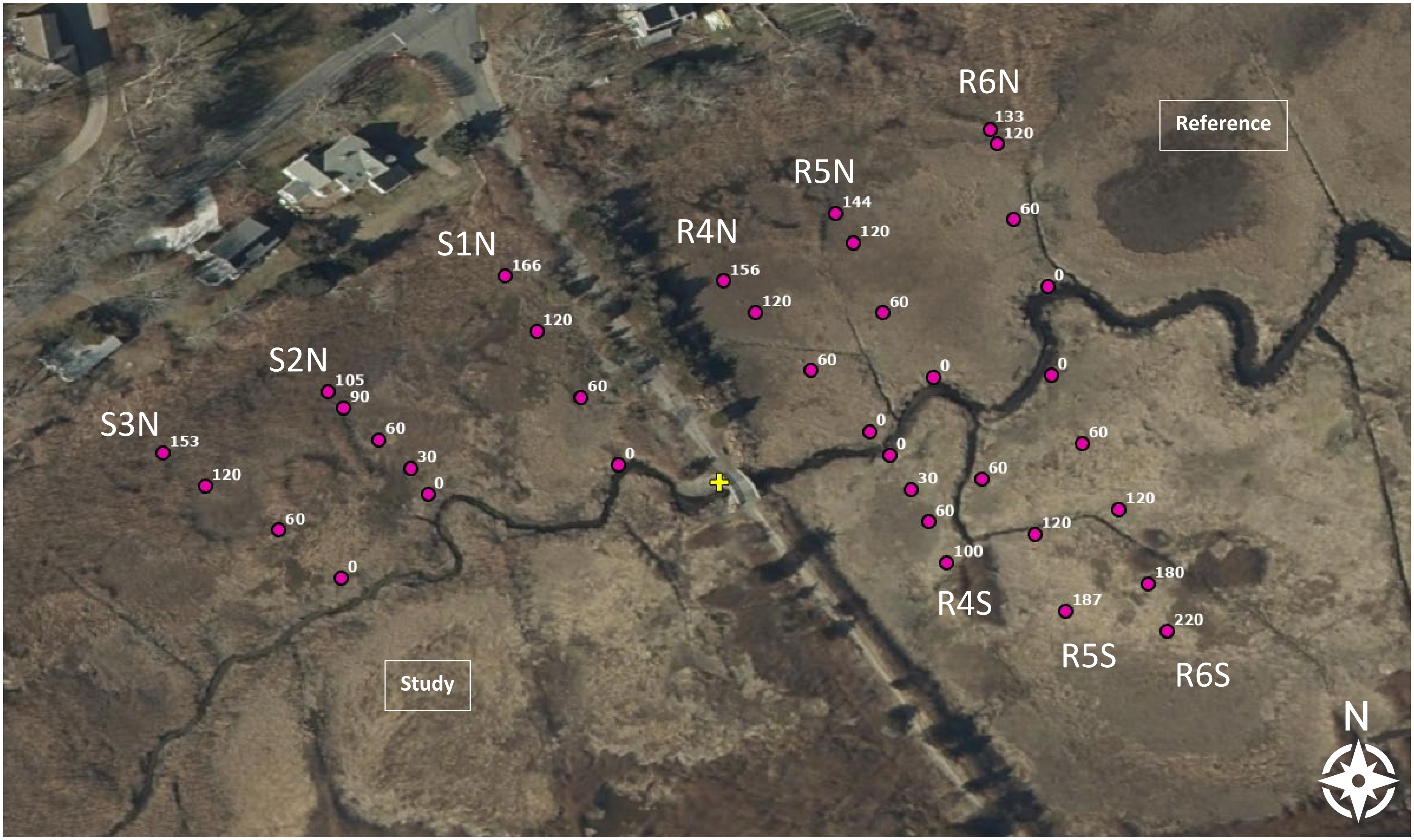


Figure A4: Vegetation plots at Quivett Creek salt marsh restoration site in Dennis, MA. The yellow marker represents the former tidal restriction.

Figure A5: Starting point for each transect at State Game Farm in Sandwich, MA. The yellow marker represents the former tidal restriction. Note: plot points are unavailable.

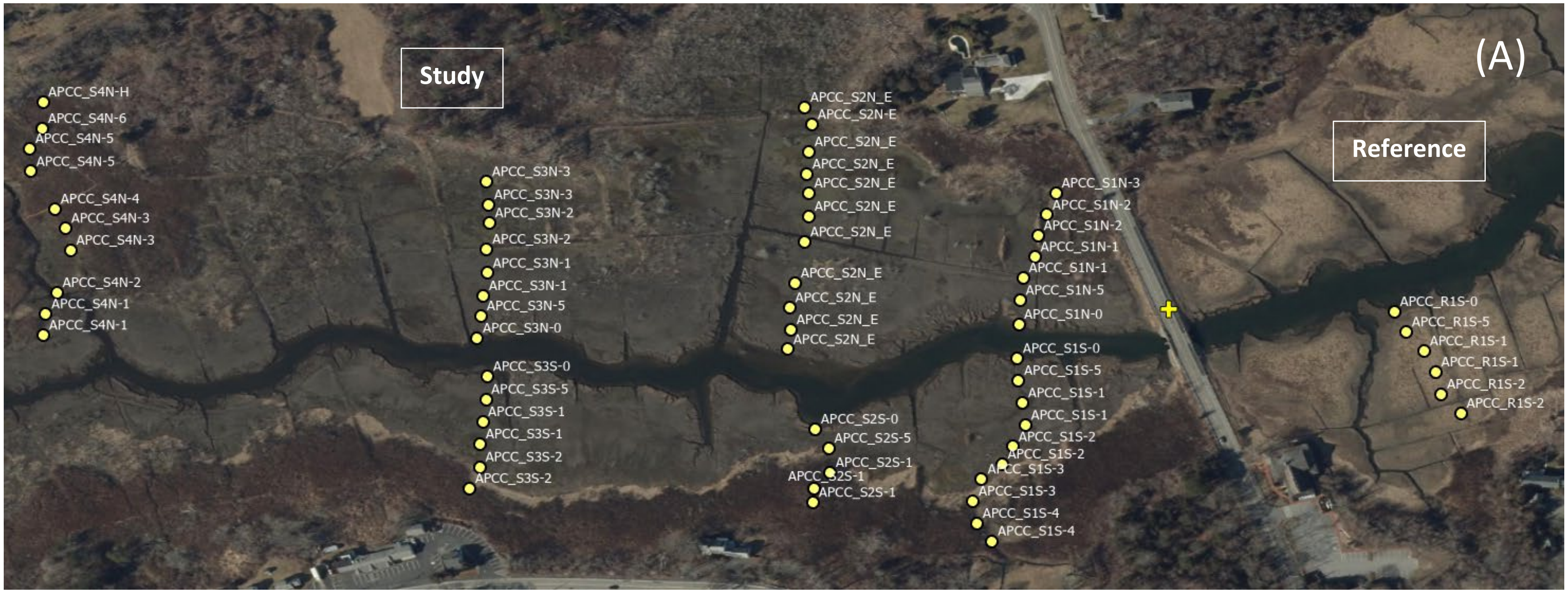


Figure A6: Vegetation plots at Sesuit Creek salt marsh restoration site in Dennis, MA. The yellow marker (+) represents the former tidal restriction. A: western extent; B: eastern extent; C: overview. Transect R2S was not monitored consistently over time; some years not included in analysis.

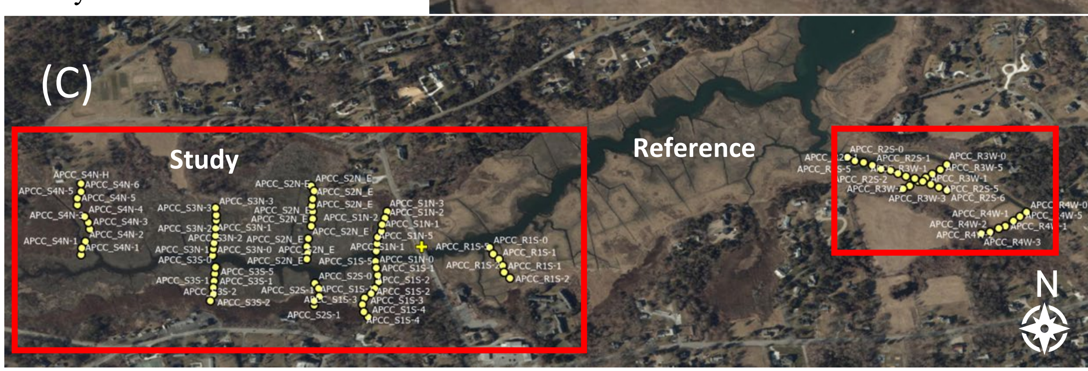


Figure A7: Starting point for each transect at Stony Brook in Brewster, MA. The yellow marker represents the former tidal restriction.

Figure A8: Starting point for each transect at Wings Neck in Bourne, MA. The yellow marker represents the former tidal restriction.

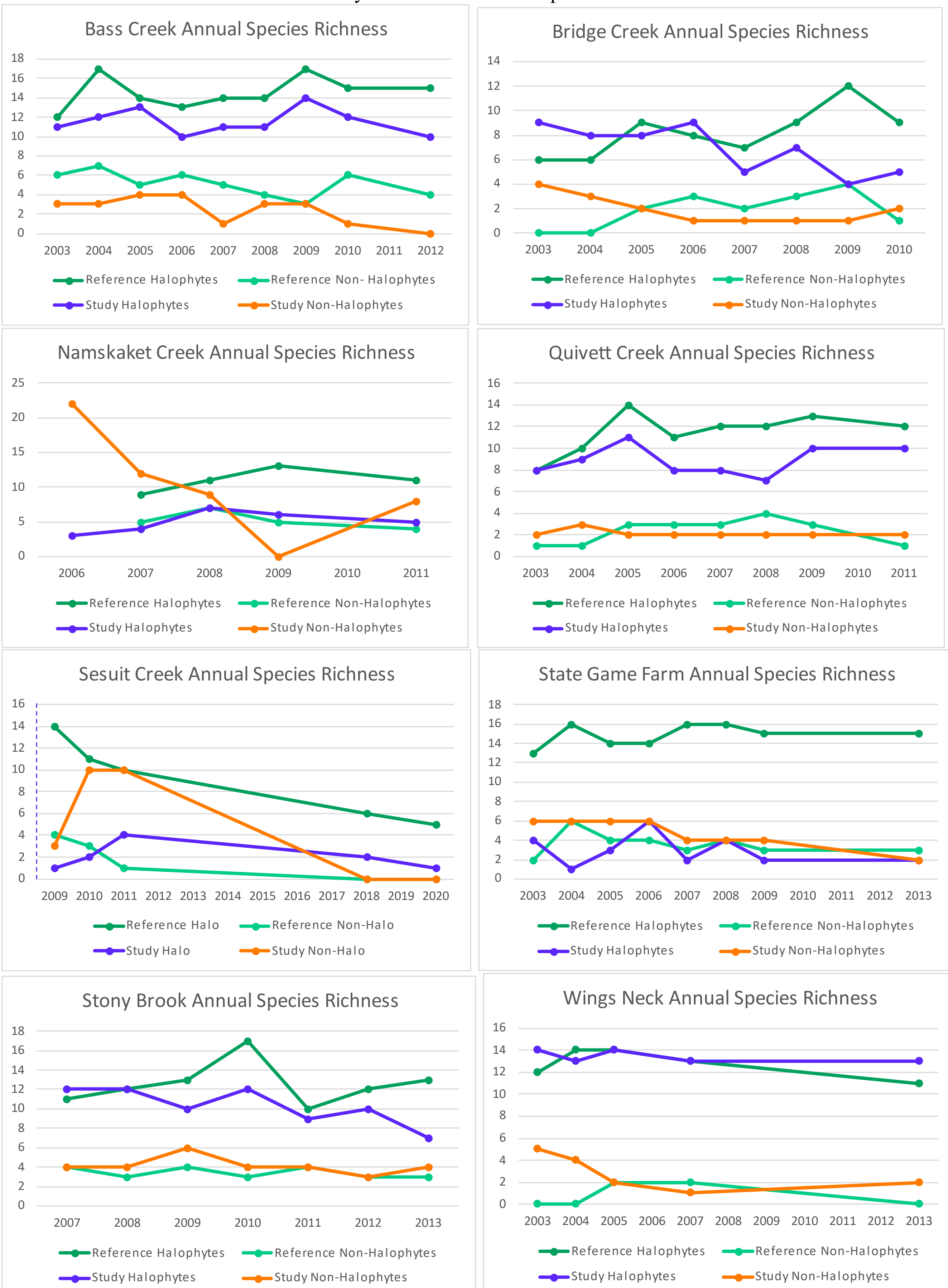
APPENDIX B: Annual Species Richness

Species Richness Results

While some restored sites showed an initial increase in species richness following restoration, almost all restored sites showed a trend towards declining species richness overall. To further explore this trend, species (excluding *Phragmites*) were categorized as halophytes or non-halophytes according to reference and study site (Figure B1). A majority of the sites (Bass Creek, Namskaket Creek, Sesuit Creek, State Game Farm, Wings Neck and, to a lesser degree, Bridge Creek and Quivett Creek) show overall reduction in restored marsh non-halophyte species richness over time. Comparing this to the more stable species richness for reference marsh non-halophytes, this would suggest that restoration was the driver for this decline in non-halophyte species richness and explains the overall trend toward declining species richness noted above.

A consistent trend was not evident for halophyte species richness. In three of the restored marshes (Bridge Creek, Quivett Creek, and Wings Neck), species richness of halophytes in the restored marsh approaches or surpasses that of the reference marsh over longer periods (e.g., 6-10 years post-restoration). The rate at which this occurs varies by site, but the more predominant trend across the eight marshes during the monitoring period is decreasing species richness in the restored marsh following restoration.

Figure B1. Annual species richness for the reference and restored marsh at each of the eight sites. Note: The gray dotted line indicates the time of restoration. Analysis includes all marsh plots.



Discussion of Species Richness Results

Across all eight sites there was an overall decline in total species richness in the study marsh following restoration. Since there are fewer species that are found in salt marshes than fresh/brackish areas, and salt marshes are dominated by only a few species, we don't expect to see increases in species richness following restoration in the study marsh. Prior to restoration the study marshes were a mix of freshwater, brackish and salt marsh species. Post-restoration the species composition shifted as freshwater and brackish species died off due to increased salinity from the restored tidal flow resulting in a reduction in total species richness. The observed pattern of species richness reflects an initial increase in species during a period of transition when the system supported both freshwater/brackish and salt marsh vegetation, followed by a reduction or elimination of freshwater (non-halophyte) vegetation after restoration an increased salinity and tidal flow. Thus, the net result was a trend towards decreasing species richness as native salt marsh grasses recover in the study marsh.

The shorter period of monitoring available for these sites was sufficient to demonstrate the initial decline and die back in freshwater non-halophytic vegetation. The response in non-halophyte species richness supports the conclusion that the upstream marsh is responding to restoration of tidal flow with the salt marsh community shifting from freshwater/brackish species to more salt-tolerant, native salt marsh species. Although the species richness trends demonstrate changes in the plant community, species richness as an indicator of change is extremely limited and not recommended for assessing restoration impacts.

APPENDIX C: Master Species List

Species Name	Type	State Game Farm	Stony Brook	Bridge Creek	Bass Creek	Namskaket	Wings Neck	Quivett	Sesuit Creek
Acer sp.	non-halophyte					x			
Acer rubrum	non-halophyte					x			
Agalinis maritima	halophyte	x	x	x	x		x		x
Agropyron pungens	halophyte	x		x	x	x			
Agrostis stolonifera	non-halophyte	x	x		x		x	x	x
Amaranthus cannabinus	non-halophyte		x	x		x		x	
Amelanchier canadensis	non-halophyte								x
Apios americana	non-halophyte					x			
Ascophyllum nodosum var. scorpiodes	Other								x
Aster tenuifolius	halophyte	x	x	x	x	x	x	x	x
Atriplex patula	halophyte	x	x	x	x	x	x		x
Atropa belladonna	non-halophyte	x							
Baccharis halimifolia	halophyte				x	x			
Baptista tinctora	non-halophyte					x			
Robinia pseudoacacia	non-halophyte						x		
Calystegia sepium	non-halophyte	x							
Carex lurida	non-halophyte					x			x
Carex paleacea	halophyte	x							
Celastrus orbiculatus	non-halophyte								x
Chenopodium rubrum	non-halophyte								x
Chimapholia maculata	non-halophyte					x			
Clethra alnifolia	non-halophyte				x				x
Club Moss	non-halophyte					x			
Convallaria majalis	non-halophyte					x			
Convolvus sepium	non-halophyte								x
Distichlis spicata	halophyte	x	x	x	x	x	x	x	x
Duchnesnea indica	non-halophyte					x			
Eleocharis rostellata	non-halophyte	x							
Eleocharis sp.	non-halophyte	x		x					
Epilobium palustre	non-halophyte								x

Festuca rubra	non-halophyte								x
Fimbristylis castanea	halophyte							x	
Glaux maritima	halophyte							x	
Vitis sp.	non-halophyte	x							x
Hibiscus moscheutos	non-halophyte			x					
Lonicera sp.	non-halophyte	x							
Impatiens capensis	non-halophyte								x
Iva frutescens	halophyte	x	x	x	x	x	x	x	x
Juncus balticus	halophyte	x		x					
Juncus effusus	non-halophyte			x					
Juncus gerardii	halophyte	x	x	x	x		x	x	x
Juniperus sp.	non-halophyte						x		
Kalmia sp.	non-halophyte				x				
Leersia oryzoides	non-halophyte								x
Lilaeopsis chinensis	non-halophyte		x					x	
Limonium nashii	halophyte	x	x	x	x		x	x	x
Limosella subulata	halophyte			x					
Lobelia cardinalis	non-halophyte								x
Lonicera tatarica	non-halophyte								x
Lythrum salicaria	non-halophyte	x							
Lysimachia quadrifolia	non-halophyte								x
Maianthemum canadense	non-halophyte					x			
Ipomoea sp.	non-halophyte	x				x			
Moss*	Other	x			x	x	x	x	x
Myrica sp.	non-halophyte								x
Myrica cerifera	non-halophyte					x			
Myrica gale	non-halophyte								x
Myrica pensylvanica	non-halophyte				x				
Onoclea sensibilis	non-halophyte					x			x
Osmunda cinnamomea	non-halophyte								x
Other	Other	x	x	x	x	x	x	x	x
Panicum virgatum	halophyte	x		x	x		x	x	x
Parthenocissus quinquefolia	non-halophyte					x			x
Phalaris arundinacea	non-halophyte								x
Phragmites australis	non-halophyte	x	x	x	x	x	x	x	x
Phytolacca americana	non-halophyte								x

Plantago maritima	halophyte	x			x		x		x
Pluchea purpurascens	non-halophyte	x	x	x	x	x	x	x	x
Polygonum arifolium	non-halophyte								x
Polygonum ramosissimum	halophyte	x			x				
Potentilla anserina	non-halophyte	x						x	
Quercus sp.	non-halophyte				x	x			
Rhododendron viscosum	non-halophyte								x
Rhododendron sp.	non-halophyte				x				
Rosa multiflora	non-halophyte	x							x
Rosa palustris	non-halophyte	x							x
Rosa sp.	non-halophyte	x				x			
Rosa virginiana	non-halophyte	x			x				
Rosas cerallis	non-halophyte	x			x		x		
Rubus idaeus	non-halophyte								x
Rubus sp.	non-halophyte					x			x
Rumex acetosella	non-halophyte								x
Sabatia stellaris	halophyte						x		
Salicornia spp.	halophyte	x	x	x	x	x	x	x	x
Sarcocornia	halophyte				x		x		
Scirpus americanus	non-halophyte	x	x	x		x		x	
Scirpus maritimus	non-halophyte								x
Scirpus pungens	non-halophyte	x	x			x			x
Scirpus robustus	non-halophyte	x	x	x	x	x		x	x
Scirpus validus	non-halophyte	x							x
Smilax sp.	non-halophyte					x			
Smilax glauca	non-halophyte	x							
Smilax rotundifolia	non-halophyte					x			
Solanum dulcamara	non-halophyte	x							
Solanum sp.	non-halophyte	x							
Solidago sempervirens	halophyte	x	x	x	x	x	x	x	x
Solidago graminifolia	non-halophyte				x				x
Solidago rugosa	non-halophyte								x
Solidago sp.	not available								x
Spartina alterniflora	halophyte	x	x	x	x	x	x	x	x
Spartina cynosuroides	halophyte	x	x		x	x		x	
Spartina patens	halophyte	x	x	x	x	x	x	x	x

Spartina pectinata	non-halophyte				x				
Spergularia marina	halophyte				x				x
Sphagnum sp.	non-halophyte								x
Spiraea latifolia	non-halophyte								x
Suaeda calceoliformis	halophyte				x				
Suaeda linearis	halophyte	x	x	x	x	x	x		x
Suaeda maritima	halophyte				x				
Suaeda sp.	halophyte		x	x					
Symplocarpus foetidus	non-halophyte								x
Teucrium canadense	non-halophyte					x			
Thelypteris palustris	non-halophyte					x			
Thelypteris thelypteroides	non-halophyte								x
Toxicodendron radicans	non-halophyte	x	x		x	x	x		x
Triglochin maritimum	halophyte				x		x		x
Typha angustifolia	non-halophyte	x	x	x	x	x		x	x
Typha latifolia	non-halophyte	x				x			x
Typha sp.	non-halophyte			x		x		x	
Unknown algae	Other		x						
Upland grass	non-halophyte	x			x	x	x		x
Vaucheria sp.	Other								x
Viburnum dentata	non-halophyte								x
Viburnum dilatatum	non-halophyte								x
Viburnum sp.	non-halophyte					x			
Vinca minor	non-halophyte								x

*It was unclear whether “Moss” referred to an upland *Sphagnum* species or *Vaucheria*, a mat-forming filamentous algae, so it was not included in the analysis.

** Unknown species or species with a genus level that can be found in salt marshes or upland could not be confidently designated to a plant community category, so they were not included in the analysis.

*** Where observed, algae was considered “Other” because it indicated non-vascular vegetation cover.

APPENDIX D: Salinity Monitoring Results

The expected outcome of tidal restoration is an increase in salinity in the restored marsh approaching or equaling that of the reference site. We analyzed data from surface water and pore water samples separately, as we anticipated seeing a more immediate response in surface water than pore water.

Surface Water

Salinity levels in the stream in the restored marsh were expected to very quickly approach or equal the salinity in the reference site. Across all sites, surface water salinity in the restored marsh effectively mirrored that of the reference site, but salinity levels at each site were unique due to their connections to different watersheds and influences. At Bridge Creek, Sesuit Creek, and State Game Farm, salinity in the restored marshes proved to be equal to or slightly greater than salinity in the reference marshes. Hypersaline conditions were not observed at any site; on the contrary, surface water salinity levels were very low in all sites except Sesuit, Bass Creek and Wings Neck. This is likely due to the sampling being done at low tide. At low tide, the surface water appears to be mostly influenced by upstream freshwater inputs. Thus, overall, the expectation that surface water salinity in the restored marsh would equal that of the reference site was not clearly observed through this method of monitoring (Figure D1).

Pore Water

For pore water sampling, we anticipated seeing a similar trend in the data but perhaps over a longer time. Across all sites, salinity at the restored sites again tended to mirror those of the reference sites, but salinity at restored sites did not approach those of the reference sites. For example, while four out of the seven sites (Namskaket, Sesuit, State Game Farm, and Stony Brook) showed increasing salinity post-restoration, this change mirrored that of the reference site rather than approaching an equivalent level to the reference site as anticipated. Bridge Creek had higher salinity measurements in the restored marsh both before and after restoration. This may be a result of longer residence time in the restored marsh from partial restoration of tidal flow or accidental mix-up between the restored and reference site data. Compared to surface water samples, pore water samples had much higher salinity, suggesting that this method might be more useful to measure change over time for some locations but that, for these marshes, this method was not effective in demonstrating the expected impact of restoration likely due to the method of sampling at low tide and the impact of freshwater inputs into these systems (Figure D2).

Figure D1. Average annual surface water salinity in the reference and restored marsh for each site. Note: The gray dotted line indicates the time of restoration.

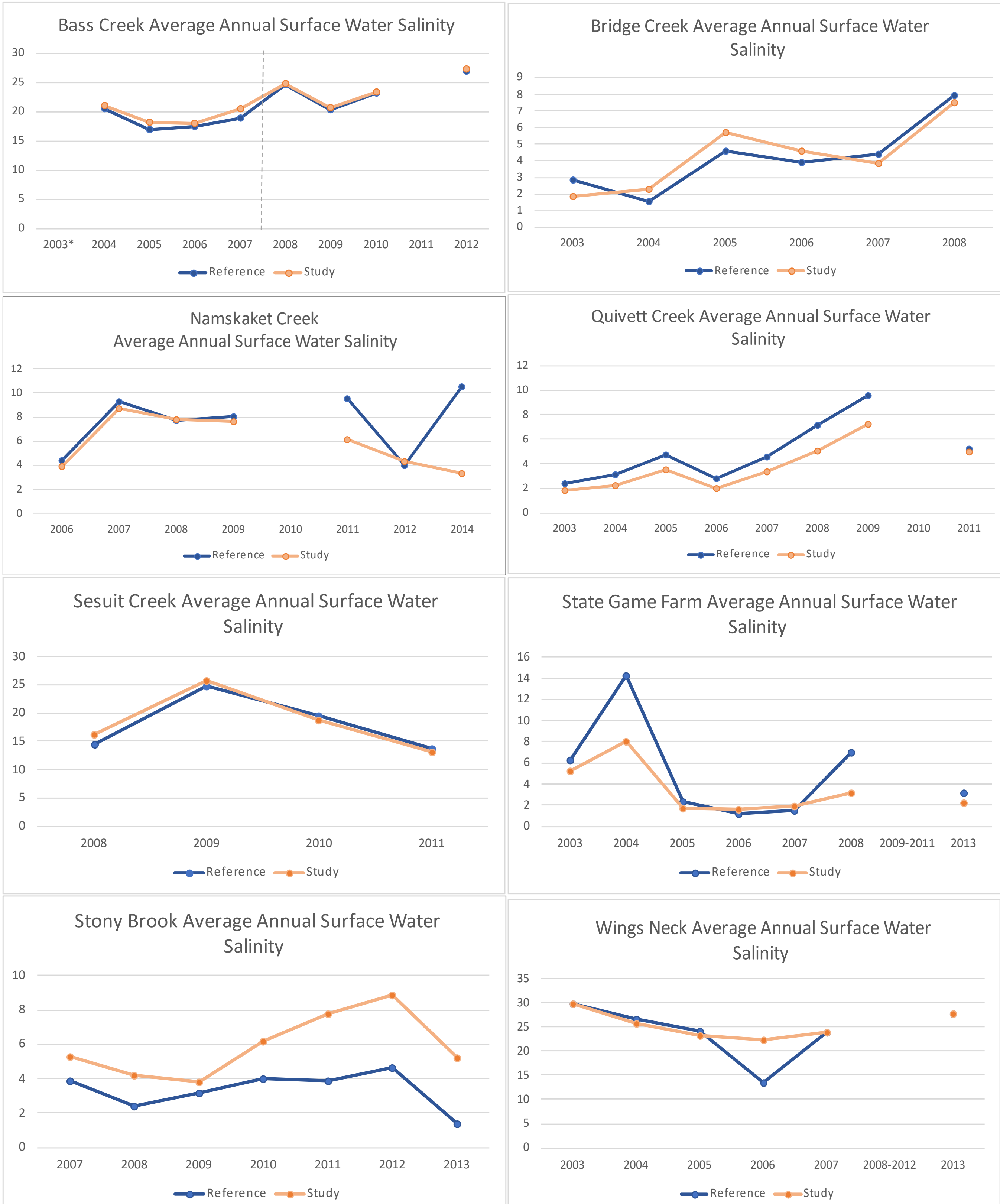
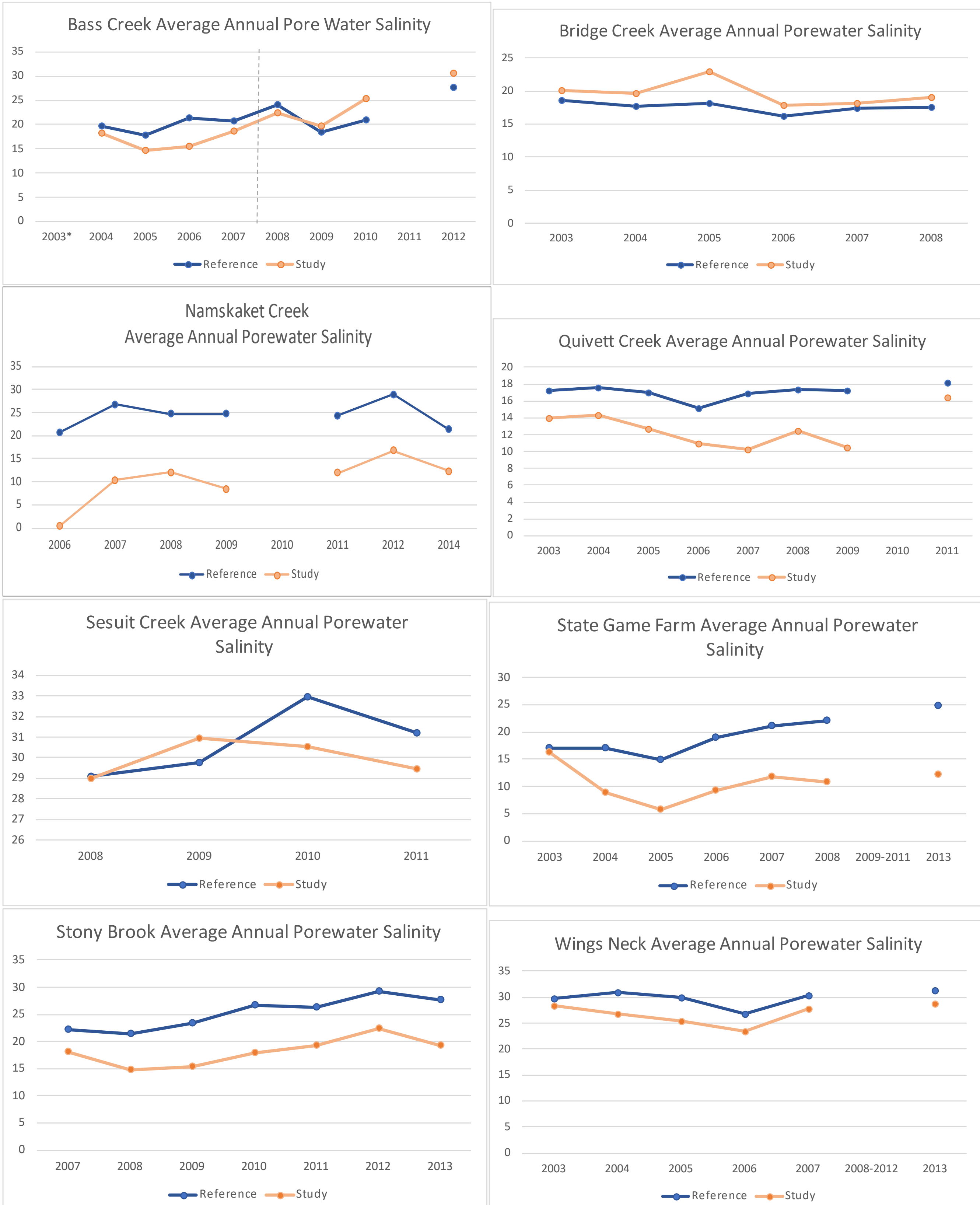


Figure D2. Average annual pore water salinity in the reference and restored marsh for each site. Note: The gray dotted line indicates the time of restoration.



Discussion of Salinity Results

Cape Cod has significant fresh groundwater discharge into estuaries, salt marshes and shoreline areas due to permeable soils. This input of freshwater appears to be confounding measurements of salinity during low tides. As a result, it would appear that the sampling method used for tracking changes in salinity is not a good measure of restoration of tidal flow. Spot sampling in stream by boat during high tide may provide a better measure of salinity as impacts of freshwater would be diminished. However, time-series datalogger monitoring of salinity and water level would likely provide the best data to document the impact of tidal restoration. Continuous monitoring over a tidal cycle using dataloggers would allow for observation over more refined intervals including daily fluctuations. By just looking at spot samples taken once a month or biweekly, there is too much variability with changing tides to generalize or draw conclusions. To effectively measure the change in salinity, APCC recommends either employing a more labor-intensive sampling protocol or deploying an automated data logger.

APPENDIX E: Site observations of eight Cape Cod salt marsh restoration projects

Methods

Field assessments were conducted during the summer of 2019. Before site visits were conducted, APCC reviewed background information for each site. Transect locations from maps, trends in vegetation and salinity, and general site information were used to inform site visits. Wings Neck was the only site that did not have an existing draft monitoring report summarizing past work and results, so information collected for this site was based on direct observations and recollections from previous visits. At all eight sites, visits were conducted during low tide with additional site visits at high tide at Bass Creek, Quivett Creek, Sesuit Creek, and Stony Brook. At each site, the following information was collected:

- Landscape-oriented photos were taken from the former tidal restriction looking downstream to the reference marsh and upstream to the restored marsh.
- Culverts or restored tidal openings were examined for signs of erosion or sedimentation, culvert condition, and flow. Photographs of culverts were taken if there were blockages or other issues of concern.
- Creek banks on both the reference and study sides of the marsh were examined and photographed to document any erosion, sloughing, or evidence of herbivory by the purple marsh crab, *Sesarma reticulatum*.
- The marsh was assessed immediately upstream and downstream of the restriction in order to document any observable changes in vegetation. Bare spots, marsh die back, changes in *Phragmites*, and changes in halophyte presence or composition were documented.
- Notes were taken to document any observed wildlife (birds, crabs, etc.).
- All vegetation monitoring transects and stakes for plots were searched for in the field. Stakes and transects were relocated using maps and notes from previous monitoring. Existing stakes that remained in the marsh were re-stabilized and documented. If stakes for transects were located, photos were taken from the creek bank looking along the transect to the upland transition border to document current plant communities.
- Vegetation along previous transects was visually assessed taking note of species present and marsh community types. If transect markers were not located, notes on vegetation were made in the general areas where prior transects were located based on site maps.
- Field notes were compared to prior monitoring data.
- General evaluations and recommendations were provided for each salt marsh site that may be used to guide future management actions.

Observations

1. ***Bass Creek, Yarmouth, MA.***

Site visits were conducted on 7-25-19 at 2:00 pm (low tide) and 7-30-19 at 1 pm (high tide).

Reference Marsh

Erosion was observed along the tidal creek on both the reference side and restored side. Slumping was also observed along the tidal banks farther away from the culvert. There were no visible signs of purple marsh crab grazing on plants; however, large holes were observed along the creek banks. The middle marsh and upper marsh remain covered with a variety of different halophytes (*J. gerardii, S. patens, Iva frutescens, and Baccharis halimifolia* were observed). Two stakes at the end of transect R5N remain in place (see Appendix A for map of plots and transects). No other stakes were found on the reference side of the marsh.

The upper border located between the upper part of the marsh and the terrestrial edge on the south side of the marsh showed signs of undercutting. This upper area is mostly composed of sand and *Spergularia marina* was found growing there. Areas directly below the bridge and above the rock rip rap showed signs of erosion. The rocks used to stabilize the banks of the culvert remain in place and showed no signs of erosion.

Study Marsh

Tidal creek edges and mosquito control ditch creeks appear to be adjusting to restored tidal flow. A large basin near the culvert on the study side, that was present before restoration, remains. *Phragmites* has retreated into the upper areas of the marsh and are relatively short in height. Stakes for transects S3N-60 and S3N-90 were still in place and *D. spicata* was present (see Appendix A for map of plots and transects). Clumps of peat were washed up on the surface of the marsh with *S. alterniflora* growing on them, suggesting that the peat clumps eroded from the banks and floated onto the surface of the marsh during a high tide. The salt marsh plant communities in the middle to upper parts of the restored side remain densely vegetated. Targeted tracking and observation of creek and bank adjustments may be considered for future monitoring.

Summary Evaluation

Both the study and reference marshes appeared healthy with dense vegetation, especially the middle to upper marsh. The *Phragmites* on the restored side continues to be limited in height and percent cover compared to data collected prior to 2011. The changes, including erosion along the tidal creek banks on both the restored and reference side and deposition of peat upstream of the marsh, could be monitored to document future evolution of the site. Also, more information may need to be collected to determine the causes of creek edge erosion at Bass Creek. Possible causes include the altered tidal hydrology, purple marsh crab herbivory, sea level rise, high nutrient concentrations, or a combination of the above factors.

2. *Bridge Creek, Barnstable, MA.*

Site visit was conducted on 7-25-19 at 12:00 pm (low tide).

Reference Marsh

The creek banks were well vegetated and there were no signs of erosion on the reference side. Both concrete box culverts under Route 6A and the train tracks were in good condition and showed no signs of degradation. The *Phragmites* growing on the edges of the marsh appear to be unchanged compared to the approximate equivalent locations of transects from past monitoring data. No stakes were found on the reference side of the marsh, and the plant communities near the transects appeared similar to the data presented in past monitoring.

Study Marsh

There were no signs of erosion along the creek banks. Robust *S. alterniflora* was found growing along the banks and throughout the middle to upland transition areas of the marsh. The *S. alterniflora* was found growing up to the edge of stands of *Phragmites*, and there was very little evidence of middle to high marsh plant species within the restored area. Halophytic species found throughout the marsh was dominated by *S. alterniflora*. The *Phragmites* appears to remain in similar locations and height along transects S1E, S2E, and S3E (see Appendix A for a map of plots and transects). The *Phragmites* did not appear to be migrating into lower locations along the transects on the eastern side of the marsh. Stakes were found at S1E-30, S2E-0, 2SE-15, S3E-End, S2W-120, and S3W-60 (see Appendix A). Based on observational data, areas on the western side of the marsh near the culvert have developed salt pannes with standing water where tidal wrack used to accumulate. Marsh wren calls were observed.

Summary Evaluation

The culvert was in good condition and there did not appear to be any issues with the Bridge Creek marsh. The transition of mid marsh to low marsh species is likely the result of restored tidal range. Evaluation of marsh plain elevations as compared to tidal range and long-term monitoring of vegetation transitions might be considered. Vegetation monitoring stakes remain in place on the eastern side of the marsh in the event that future vegetation monitoring is desired.

3. Namskaket Marsh. Brewster, MA.

Site visit was conducted on 7-24-19 at 10:00 am. (low tide).

Reference Marsh

A large bare sandy area was present on the eastern side of the marsh near transect R5E (see Appendix A for transect locations). Small plants of *Suaeda maritima* and *S. marina* were growing in this bare sandy area located on the upland transition side of R5E. A large population of fiddler crabs was observed along the banks on the reference side where muddy areas were present. There was no evidence of *Sesarma reticulatum* grazing or signs of their larger burrowing holes in the peat.

There was a build-up of wrack along the upland transition edge of the eastern side of the marsh which may be limiting the expansion of halophytes into this area. One stake remained at R6E-120 at the edge of a *Phragmites* stand which was previously monitored. Another stake was found at R5W-60 in an area that had a mix of halophytes and most notably *Schoenoplectus robustus*. One stake was also found at R7W which was approximately 15 feet from the creek bank.

No stakes were found along transects R6W, R6E, and R7E. There was noticeable evidence of bank slumping and some erosion on the reference side of the marsh. Most of the erosion was observed at the bends in the tidal creek. Based on data from monitoring up to 2011, many of the halophytes seem to be unchanged on the reference side, and there was a healthy middle to high marsh plant community growing on the reference side. Native *Phragmites* was found on the western side of the reference marsh during past mapping efforts. Two river otters were observed in the tidal creek on the reference side. Also, salt reedgrass (*Spartina cynosuroides*) was growing along transect R6E. Ten boards were blocking the two circular culverts (five boards on each culvert) which appeared to be reducing the tidal flow during high tide into the restored side of the marsh (see photo).

Study Marsh

There was an island of halophytes (approximately 600 square feet in area) growing on the western side of the marsh near the culvert. This area appeared bare during previous visits. The *Phragmites* was still dominant and appeared healthy on both sides of the creek on the restored side. The height and distribution of the *Phragmites* appears to be unchanged from prior monitoring from previous site visits. Some stakes remained along transects S1W, S3E, and S3W. The large unvegetated bare area on the western side of the marsh near the culvert (outside the monitoring area) was now vegetated with a community of halophytes. There were dead trees observed along the edges of the marsh and farther upstream outside of the monitoring area. Halophytes were growing along transects S1W and S3W. Surface water salinity in the tidal creek near S1E was 0 parts per thousand (ppt) during an outgoing low tide. There was no evidence of creek bank erosion or slumping on the restored side of the marsh.

Summary Evaluation

Based on our 2019 observations, it appears that the *Phragmites* on the restored side remains as abundant and tall as in 2011. The small areas of halophytes located on the restored side have not expanded and replaced the Phragmites, suggesting that the average annual percent cover of halophytes has not increased since 2011. The bare area on the restored side near the culvert has filled in with halophytes, suggesting that salt marsh plants are able to thrive on the restored side but may be limited in their expansion because of competition from *Phragmites*. The elevation on the restored side appears to be higher compared to the reference side which may benefit the *Phragmites*. The apparent erosion on the banks of the reference side may need to be monitored over time to determine if the bank and channel evolution has stabilized. Also, the tidal restriction from the boards across the culverts may need to be removed to allow more tidal flushing to help remove *Phragmites* and improve halophyte cover on the restored side.

4. ***Quivett Creek, Dennis, MA.***

Site visits were conducted on 8-1-19 at 11:00 am (low tide) and 8-15-19 at 9:00 am (high tide).

Reference Marsh

The plant community on the reference side of the marsh appeared very similar to the previous monitoring data at plots observed within the marsh. *Lileopsis chinensis* was present in the understory of taller salt marsh plants. *S. cynosuroides* was growing along the creek edges and up mosquito-control channels. The only stake found on the south side of the marsh was at R4S-0 (see Appendix A for plot and transect locations). The plant community at this stake consisted of *S. robustus, S. patens, and S. cynosuroides*. *Phragmites* was still limited in its distribution to upland transition areas at the edges of the marsh. More plot stakes were still in place on the northern side. R4N-120 had approximately 94% *S. alterniflora* growing nearby. Two end stakes were located at R5N which had mostly *S. alterniflora* (55-94%) growing nearby and a smaller percentage of *S. depressa* (15%). *Glaux maritima* was not observed on the reference side of the marsh like it was in the past. The salinity in the creek channel near the culvert during low tide was 0 ppt taken three times. The salinity during high tide with an incoming tide was an average of 10 ppt. There was no erosion on the banks, and healthy, tall stands of *S. alterniflora* and *S. cynosuroides* covered the banks. No stakes were found along transect R6N. The concrete box culvert appeared to be in good shape, and there were three boards in place across the top of the culvert. Salt marsh sparrows, *Ammospiza caudacuta*, were observed on the reference side.

Study Marsh

The *Phragmites* on the study marsh was still present in similar locations and approximately the same height. *S. cynosuroides* was located along the creek banks and in mosquito-control ditches. More *Amaranthus cannabinus* was growing along the banks near the culvert than in previous years. Mummichogs were present in the creek, and a frog was observed in the creek. There was some minor undercutting at the bend in the creek near the culvert but no other signs of bank slumping or erosion. Two stakes were found along transect S1N. S1N-60 had *S. alterniflora* and *S. depressa* growing nearby, and the last stake along this transect was located in the *Phragmites* which APCC monitored for height in the past. There was a buildup of wrack as well as salt pannes with standing water near the S1N transect. There were four stakes present along S2N including the last stake which was located in the *Phragmites*. The middle to the upper parts of this transect had *S. alterniflora* and *S. depressa* with no signs of middle to high marsh species. Transect S3N had a middle stake and an end stake located in the *Phragmites*. The middle stake had *S. depressa* and *Eleocharis* spp. (possibly *E. parvula*) growing nearby. No salt marsh sparrows were observed on the study marsh during the monitoring visit.

Summary Evaluation

The *Phragmites* on the study marsh was still healthy and was observed throughout the restored areas of the marsh. The lack of saltwater inundation and inputs of nutrients and freshwater from nearby septic systems are likely fostering continued *Phragmites* growth. Also, a partial tidal restriction from boards crossing the culvert may be keeping this marsh from becoming fully restored. An evaluation of the potential for flooding low-lying developed properties adjacent to the marsh may be needed in order to determine whether to proceed with removing the tidal restriction boards. One noticeable change is that *S. cynosuroides* is growing along the creek banks and may be expanding into the restored side of the marsh, indicating expansion of salt marsh. Overall, the plant communities appear similar compared to data collected through 2011.

5. *Sesuit Creek, Dennis, MA.*

Site visits were conducted on 8-20-19 and 8-21-19 at 10:00 am (low tide).

Reference Marsh

The culvert was in good condition and was not blocked by sediment or rocks. The creek on the reference side of the marsh appeared to have widened, (compared to images taken in 2009 for UNH's Sesuit Monitoring Report) and there appeared to be erosion on the edges of the creek banks. There were low-lying peat shelves along the creek edge that were previously vegetated with *S. alterniflora* as confirmed by old and new (2019) monitoring data, and no stakes were found along the creek edges at 0 feet where the shelves exist. The middle to upper areas of the reference marsh had large areas that were hummocky, located in areas where *S. patens* was growing. Some areas had dead *S. patens* (as indicated by black dead stems) along the lower, wetter areas of the hummocks. Many of the lower hummocky areas remained as bare ground. *Phragmites* appeared to be in approximately the same areas along the edges of the marsh. Stakes were found at approximately R1N-60, R1N-90, R2N-30, and R2N-60 (refer to Appendix A for plot and transect locations). R1N-60 had mostly *S. patens* (94%) and R1N-90 had mostly the short form of *S. alterniflora* (76%). R2N-30 and R2N-60 had 94% *S. patens* growing within the plots. Only one original PVC stake was found on the south side of the marsh at the farthest transects located on the eastern edge of the reference marsh close to Sesuit Harbor. Compared to previous site visits, some erosion and creek widening appeared to be occurring on a creek tributary located on the eastern side of the marsh where it approaches Quivett Creek.

Study Marsh

As with the reference side of the marsh, the creek banks on the study marsh appeared to be widening. Standing water was observed during low tide on some sections of the marsh surface. Low peat shelves were observed at the edges of the creek banks where, based on past monitoring data, *S. alterniflora* was previously growing. One salinity marking station located at S1S-10 remains in place. Three original PVC stakes remained in place on the S1N transect (possibly S1N-30, S1N-90, and S1N-120). In August 2018, APCC staff re-staked additional vegetation plots on S1N and the entire S2S transect using GPS coordinates that UNH used in their vegetation monitoring. The wooden stakes for these transects still remained in place.

In some areas of the marsh, *Phragmites* has been replaced by *S. alterniflora* based on the observation of dead *Phragmites* stalks on the marsh surface. *Phragmites* appears to be migrating into upland transition areas where it may not have previously been growing. However, overall, there was a reduction in *Phragmites* distribution compared to previous monitoring data. There was also evidence that a more brackish community of plants (areas along the end of transect of S3N had *S. robustus* and *T. angustifolia*) may have been replaced by tall forms of *S. alterniflora* (4-6 feet). One stake for S3N was still in place about 60 feet from the creek edge. There were still areas of the marsh that remain as bare unvegetated areas. Some areas of *S. alterniflora* along the creek banks is growing on elevated hummocks with a layer of established peat which may have been growing over longer periods of time before the restoration.

Some locations where healthy *S. alterniflora* was growing had younger plants growing nearby, suggesting that *S. alterniflora* is expanding into the marsh from underground rhizomes. There are large areas that were composed of only upland transition species (trees and shrubs) that are now dominated by fields of tall *S. alterniflora*. The end of transect S2N had only upland transition plants in previous monitoring years and now is covered with *S. alterniflora*. Overall, there appeared to be an increase in *S. alterniflora* in bare, unvegetated areas and a decrease in *Phragmites* and brackish marsh species at monitoring transects. *S. alterniflora* was growing in areas located at transect S4S where *Phragmites* was mostly found in the past. *S. depressa, S. maritima, and S. patens* were observed growing at a small transition zone between *S. alterniflora* and upland transition plants, suggesting that the low marsh extends to the edges of the marsh. *S. alterniflora* was also found growing across the second culvert under route 6A. Overall, *S. alterniflora* appears to have replaced *Phragmites* and has expanded its growth in large areas throughout the marsh. This was especially evident in more upland transition areas located outside the area of transect monitoring.

Summary Evaluation

While areas of Sesuit marsh remain as unvegetated mud flats based on the absence of vegetative growth, *S. alterniflora* was observed growing in areas of the middle to upper marsh where only brackish marsh, upland transition plants, and *Phragmites* were growing in the past. Some of the greatest expansion of *S. alterniflora* has occurred in areas outside of previous monitoring efforts. It may be useful to examine aerial photographs to estimate salt marsh expansion of *S. alterniflora*. It may also be important to continue monitoring the spread of *S. alterniflora* into bare areas that are located near the established restoration plantings and vegetation monitoring transects to evaluate where future restoration plantings may need to be focused. The possible widening of the creek may need to be analyzed and addressed. UNH's post-restoration monitoring report suggests that some lower areas of the marsh act as sources for sedimentation and may be eroding. More analysis may be needed to determine if these areas correlate with higher mortality in nearby restoration planting plots. These areas may need to be managed differently to effectively restore *S. alterniflora*. The reference marsh should be monitored further in the future as areas identified as hummocky with die back of *S. patens* could be impacted further if sea level rise occurs faster than accretion rates at this marsh.

6. *State Game Farm, Sandwich, MA.*

Site visit was conducted on 7-25-19 at 9:30 am (low tide).

Reference Marsh

The culvert opening for the restoration project appeared to be in decent shape. Some stones along the edges of the culvert had slumped into the tidal creek. There were some areas where the creek is undercutting the banks and causing erosion where the tidal creek bends. Stakes remained in place for transects R4N, R5N, and R5S-100 and 108 (see Appendix A for plots and transect locations). The reference side of the marsh still had a similar halophyte plant community as it did in previous monitoring data. One noticeable difference was a higher percent cover of halophytes growing at transect R5S-108 where more border/upland transition species were documented growing in this plot in the past.

Study Marsh

The creek banks on the study marsh did not appear to show signs of erosion or change. A small patch of unvegetated marsh remained near the culvert on the western side of the marsh. *Schoenoplectus americanus* was still growing and abundant between plots S1W-0 and S1W-60. The *S. alterniflora* seemed to be expanding on the restored side of the marsh when compared to previous monitoring data. The only stake found on the restored side was at S1W-60. The *Phragmites* growing along the end of S1W appeared to remain in the same location and at a similar height. The areas north of S1W appeared to have more *Cannabinus americanus* present. The second culvert running under the train tracks is concrete and showing signs of breaking apart, so this may need to be addressed. A halophyte community was observed upstream of the train tracks culvert.

Summary Evaluation

The slumping on the banks on the reference side of the marsh may need to be monitored to determine if the creek is widening over time. The *S. alterniflora* has become more abundant on the restored side of the marsh. The reduction in species richness across the middle marsh may be the result of competitive exclusion. Also, *Phragmites* is found in a few areas on the restored side where it was not previously identified. The second culvert under the train bridge is starting to show signs of the concrete breaking apart and may need to be addressed in the future. The stones that have fallen into the creek channel under the foot bridge may need to be moved onto the bank.

7. *Stony Brook Marsh, Brewster, MA.*

Site visits were conducted on 7-24-19 at 1:00 pm (low tide) and 7-30-19 at 12:00 pm (high tide).

Reference Marsh

There was no visible evidence of bank erosion on the reference side of the marsh. There was also no evidence of *S. reticulatum* herbivory. *S. cynosuroides* was still growing in areas along transect R1N on the refence side of the marsh. Stakes were found in the marsh at R1N-30, R1N-60, R3E-120, R4E-30, and 3 stakes along R5E (refer to Appendix A for plot and transect locations). A large bare area located north of culvert BR-5 was photographed by APCC staff in the past and has now become vegetated with low growing *S. alterniflora* and *Limonium nashii*. This area was previously observed to be bare and unvegetated. The large *Phragmites patch* near the observation rock appeared unchanged in size and height. The reference side of the marsh had a healthy and diverse halophyte plant community. The plant community appeared similar on the reference side of the marsh when compared with past Stony Brook monitoring data. The culvert was unblocked and in good condition.

Study Marsh

There was no visible evidence of bank erosion on the study marsh. An area formerly dominated by *Phragmites* west of the culvert appears to have been replaced by *S. alterniflora.* Also, it appeared that areas along the tidal creek that were covered with *Phragmites* now have *S. alterniflora*. A large mound of sand that formed after the restoration and accumulated upstream of the culvert now has *S. alterniflora, S. maritima,* and *S. patens* growing on it. There were still a few small patches of sand near the culvert. *S. alterniflora* was migrating and displacing *D. spicata and S. patens* was observed in the middle areas of the marsh along the transects coming off creek BR-5. *Lilaeopsis chinensis* was still found growing in some areas of the middle marsh.

Photographs taken by Don Schall in 2007 were used to compare changes in plant communities along the Stony Brook Creek banks. Areas along the creek bank where *Schoenoplectus tabernaemontani* was found growing now had *S. alterniflora* suggesting higher tidal flooding may be promoting the growth of halophytes displacing more freshwater tolerant plant communities. Also, *S. tabernaemontani* and *L. chinensis* were found growing in areas farther up the tidal creek where they were not observed before. Some *Phragmites* near the foot path (where tidal flow increased after improving footbridge crossings over salt marsh channels) that crosses the marsh were not as healthy and there were some areas with dead *Phragmites* stalks where *Spartina alterniflora* is now growing. Some areas of standing water were observed where dead stalks of *Phragmites* remained. Some areas along the foot path have wrack build up which may be causing these areas to remain unvegetated. *S. maritima* and *Iva frutescens* were growing in some locations on top of the wrack. The *S. cynosuroides* was healthy near the footbridges and was also growing in areas up the tidal creek where it was not documented before (communication with Don Schall). The Mitchell's sedge (*Carex mitchelliana*) populations appeared to have taller growth in an area where there is now less competition for light because large shrubs and trees have died. Salt marsh sparrows and schools of juvenile river herring were observed.

Summary Evaluation

The tidal restoration at Stony Brook has caused shifts in plant communities from brackish to salt marsh communities. Historical photos taken by Don Schall in 2007 as well as photographs taken by APCC and mapping of *Phragmites* stands as part of the restoration monitoring program were used to help determine changes in plant communities up the tidal creek and outside of the monitoring areas. *Phragmites* appears to be migrating up the tidal creek and growing in areas it was not documented growing in in the past, possibly displacing other plant communities. Areas that were once dominated by *S. tabernaemontani* have been replaced by *S. alterniflora*, suggesting that higher tidal salinities are driving the shifts in plant communities. Also, areas along the creek that once had freshwater plant species (*Hibiscus moscheutos*) are now dominated by *S. tabernaemontani*. Monitoring of *Phragmites* may be desirable to determine if it is retreating or migrating inland and displacing other plant communities outside the area of previous monitoring.

8. Wings Neck, Pocasset, MA.

Site visit was conducted on 7-31-19 at 9:30 am (mid to low tide).

Reference Marsh

The edges of the tidal creek on the reference side had dead areas at the transition zone between the low and high forms of *S. alterniflora*. The marsh had a "swiss cheese" appearance with many holes on the marsh surface. The stalks of *S. alterniflora* had a shredded appearance, suggesting crab herbivory by *S. reticulatum*. The dead areas were observed on previous site visits; however, no evidence has been collected to determine if these areas are expanding. Some areas on the northern side of the marsh were hummocky. Many fiddler crabs (*Uca spp.*) were present in the dead areas and throughout the marsh. The middle and upper areas of the marsh had a healthy community of halophytes. Numerous stakes remained on the northern and southern side of the marsh. The culvert was in good condition.

Study Marsh

The study marsh also showed signs of dieback and grazing along the creek banks. Most of this dieback was located closer to the culvert and was not occurring farther up the tidal creek. The dieback in the study marsh was not observed during previous visits. Many stakes remained in place on most transects of the restored side. *Phragmites* was located on the edges of the marsh and did not appear to be expanding into different areas of the marsh. The restored side had a variety of different species including *Agalinus maritima, Triglochin maritima, S. patens, S. alterniflora,* and *D. spicata.*

Summary Evaluation

The shredded stems of *S. alterniflora* may be a sign that *S. reticulatum* herbivory is causing the bare areas at Wings Neck. It appears that these areas are increasing in size; however, more monitoring is needed to see if the bare areas are expanding and if *S. reticulatum* populations are causing this dieback. The dead areas seem to be situated close to the mean high tide elevation. A combination of wave action from the open fetch and herbivory may be preventing vegetation growth in these areas.