Monitoring and Analysis of Five Salt Marsh Tidal Restoration Projects on the North Shore, Massachusetts

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Prepared by: Salem Sound Coastwatch

Prepared for: Massachusetts Division of Ecological Restoration

Report and associated data collected, analyzed, and compiled by
Alison Frye, Barbara Warren, Anna Sheridan, Lotus Carlson, and Rowan Mulder,
with support from the Division of Ecological Restoration.

Salem Sound COASTWATCH

COMMONWEALTH OF MASSACHUSETTS Division of Ecological Restoration

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PROJECT PURPOSE

The purpose of this project was to review and analyze pre- and post-restoration salt marsh vegetation monitoring data of five completed salt marsh restoration projects and compile a comprehensive report. Projects involved the upgrade or removal of previously undersized or inadequate infrastructure, such as culverts and tide gates, to restore tidal flow to marshes upstream of the restriction. Salem Sound Coastwatch (SSCW) completed pre- and post-restoration monitoring of the following sites: Conomo Point (Essex), Eastern Point/Good Harbor (Gloucester), Little Neck (Ipswich), Mill River (Gloucester), and Newman Road (Newbury). Marsh monitoring methods followed *A Volunteer's Handbook for Monitoring New England Salt Marshes* (Carlisle et al. 2002), which included periodically collecting data on parameters such as percent cover of vegetation, the presence and height of *Phragmites australis*, surface and porewater salinity, and abundance of macroinvertebrates, fish, and avian species between 1999 and 2023. The goal of this assessment project was to compile all existing raw vegetation monitoring data since 1999, conduct quality control of the data, collect an additional year (2023) of monitoring at all sites, and complete a comprehensive analysis to examine overall trends by site and across the North Shore. The effects of these restoration projects on plant communities were evaluated to provide recommendations for future salt marsh monitoring and restoration projects. This report focused on vegetation monitoring data, though results from porewater salinity monitoring are also provided and discussed.

TABLE OF CONTENTS

INTRODUCTION

Salt marshes are diverse and productive coastal wetlands that offer valuable ecosystem services and economic values. These blue carbon habitats reduce the impacts of climate change by storing excess carbon, filtering pollutants to improve water quality, and attenuating wave action and storm surge (Gedan et al. 2011; Watson et al. 2017; Mora et al. 2024; Kutcher & Raposa 2023). They provide nursery habitat for fish and shellfish species of commercial and recreational value, supporting ecological diversity while granting economic benefits (Roman et al. 1984; Gedan et al. 2011; Mora et al. 2024; Kutcher & Raposa 2023). Salt marshes promote the production of halophytic (salt-tolerant) plants used as crops, building materials, and fuel, as well as facilitate the exchange of organic and inorganic material between marine and estuarine areas (Roman et al. 1984; Gedan et al. 2011). Furthermore, they maintain coastal aesthetics and encourage recreation (Gedan et al. 2011; Mora et al. 2024; Kutcher and Raposa 2023). Estuaries are among the most valuable and biologically productive of all global ecosystems, with their annual services estimated over (2007) $24.8 trillion dollars (Costanza et al. 2014; Kelleway et al. 2017).

While regulations have instituted salt marsh protections for decades, these ecosystems are still subject to the indirect impacts of climate change and human development (Burdick et al. 1996; Gedan et al. 2011; Mora et al. 2024). In New England marshes, these stressors have led to vegetation losses as high as 17.3% over the last forty years (Watson et al. 2017). During the American Industrial Revolution, such losses were often due to filling and dredging projects that destroyed wetland resources (Roman et al. 1984; Gedan et al. 2011). More recently, factors including global warming, eutrophication, sea level rise, and vegetation die-offs have led to decreased biodiversity and diminishing marshland (Gedan et al. 2011; Field et al. 2016; Watson et al. 2017). Although salt marshes are capable of accumulating sediment and organic material to gain elevation, rapid rates of sea level rise threaten to outpace natural accretion and drown coastal wetlands. Coastal development, steep elevation gradients, and forest growth also prevent salt marsh vegetation from migrating inland, narrowing high marsh regions as sea level rise continues (Gedan et al. 2011; Field et al. 2016; Watson et al. 2017; Mora et al. 2024).

Among the most notable stressors on salt marsh ecosystems are tidal restrictions. Tidal restrictions reduce the range and extent of natural tidal flooding to areas upstream of restriction sites such as culverts, tide gates, and dams. Historically, some of these restrictions were intentionally placed for practices including salt hay farming, managing mosquito populations, and reducing storm surge by draining salt marsh habitat (Roman et al. 1984; Gedan et al. 2011), while other restrictions are incidental restrictions as a result of undersized openings being designed for transportation and other crossings through salt marsh systems. It is estimated that man-made tidal restrictions may affect more than 28% of salt marshes in Massachusetts (Crain et al. 2009), and these restrictions are having adverse effects on ecosystem health today. As a consequence of reduced saltwater flooding, low-salinity conditions encourage monocultures of invasive species – including the common reed *Phragmites australis* – that thrive in brackish or freshwater areas. These stands outcompete native marsh grasses (i.e. *Spartina spp.*) and do not provide suitable habitat for species of conservation concern (Roman et al. 1984; Roman et al. 2002; Konisky & Burdick 2004; Buchsbaum et al. 2006; Mora et al. 2024; Kutcher & Raposa 2023). Furthermore, tidal restrictions reduce sediment transport and inhibit the exchange of nutrients between the restricted marsh and downstream estuary, slowing elevation gain and accretion (Burdick et al. 1996; Watson et al. 2017; Mora et al. 2024).

Tidal restoration projects reduce or remove restrictions like culverts and tide gates, returning tidal flooding to its natural extent. These efforts have been shown to restore salt marsh ecosystem services in New England. For instance, a 17-year monitoring initiative at eight restoration sites on Cape Cod, MA found a consistent reduction in non-halophytic (salt-intolerant) plants at several locations (Mora et al. 2024). Similarly, restoration projects in New Hampshire and Maine have rapidly raised mean high water levels and salinity of restricted marshes, causing greater fish usage and more abundant salt marsh vegetation (Burdick et al. 1996). After a tidal restoration in Rhode Island, Roman et al. (2002) found significant increases not only in *Spartina* salt marsh plant populations but also in nekton density and species richness within a single growing season. A four-year restoration project in Ipswich, MA also gave rise to notable vegetation changes, 80% of which are attributed to the growth of *S. alterniflora* and a lower density of *Phragmites* (Buchsbaum et al. 2006). These previous efforts (among others) attest to the viability and efficacy of New England tidal restorations, as well as the importance of short- and long-term monitoring initiatives to assess their impacts.

As salt marsh plants are uniquely adapted to the hydrologic conditions in which they naturally occur, vegetation distribution acts as a useful metric by which to track ecosystem health (Mora et al. 2024). In this study, we monitored salt marsh vegetation as an indicator of changing species composition at five tidal restoration sites on the North Shore of Massachusetts. Data were collected using a before-after control-impact design comparing reference (unrestricted) and restricted sites over the course of restoration; transects were analyzed within multiple marsh zones to document species distribution between the low, high, and upland marsh. Monitoring efforts took place over multiple growing seasons with the intention of documenting the short-term response of vegetation communities to tidal restoration and longer-term recovery of the restored salt marsh.

METHODS

Evaluation Areas

Marshes selected for monitoring were either impacted by a tidal restriction (culvert or tide gate) or served as a reference site for an impacted marsh. Six marshes located in four different towns along the North Shore of Massachusetts were monitored and analyzed for this report (Figure 1).

Conomo Point (Essex) was monitored before and after the tidal restriction restoration project and consisted of both a study site, upstream of the tidal restriction, and a reference site, downstream of the tidal restriction. Eastern Point and Good Harbor (Gloucester) were paired as a study site and reference site, respectively, and were monitored before and after the tidal restriction restoration project at Eastern Point. Little Neck (Ipswich) was monitored before and after the tidal restriction restoration project and consisted of both a study site and a reference site. Mill River (Gloucester) was monitored after tidal restriction restoration and only consisted of a study site, as no marsh exists downstream of its tide gate. Newman Road (Newbury) was monitored after tidal restriction restoration and consisted of both a study site and reference site.

Table 1 provides additional information about the six marshes, including the date and type of restoration and the estimated area of affected wetland upstream of the former tidal restriction. A summary of background information for each marsh is provided in Appendix E.

Figure 1: Map of the six salt marsh sites analyzed for this report, North Shore, Massachusetts.

Table 1: Descriptions of six salt marsh restoration or reference sites on the North Shore, Massachusetts.

Name of Salt Marsh	Town	Site Type	Water Body	Latitude	Longitude	Estimated Upstream Affected Wetland Area (acres)	Date of Restoration	Pre-restoration Culvert	Post-restoration Culvert
Conomo Point	Essex	Study and Reference	Essex Bay	42°38'39.57"N	70°44'45.11"W	1.5	Nov. 2000	1-ft by 1.5-ft stone box culvert	1.5-ft by 2.5-ft box culvert
Eastern Point	Gloucester	Study	Massachusetts Bay	42°34'51.66"N	70°39'48.50"W	5.0	Nov. 2003	1.5-ft by 2-ft box culvert	3-ft by 4-ft box culvert
Good Harbor	Gloucester	Reference	Massachusetts Bay	42°37'16.88"N	70°38'1.28"W	N/A	Reference	N/A	N/A
Little Neck Road	Ipswich	Study and Reference	Plum Island Sound, Ipswich Bay	42°42'17.54"N	70°48'38.11"W	6.0	Fall 2000	2-ft diameter corrugated metal pipe	Two 4-ft wide arch culverts
Mill River	Gloucester	Study	Annisquam River	42°37'49.17"N	70°40'40.11"W	33.3 (2/3 mudflat)	2004-2017*	3-ft by 6-ft sluice tide gate	Three tide gates measuring 13-ft by 12-ft
Newman Road	Newbury	Study and Reference	Little River to Ipswich Bay	42°46'13.32"N	70°51'32.12"W	33.0	Sept. 2009	4-ft diameter corrugated metal pipe	6-ft by 12-ft box culvert

*Restoration of the Mill River included the gradual opening of the existing tide gate, starting in 2004, and subsequent replacement of the water control structures over several phases to further increase tidal influence to the marsh.

Pre- and Post-Restoration Monitoring Data Collection and Analysis

Between 1999 through 2023, Salem Sound Coastwatch conducted monitoring of select salt marsh restoration sites and reference sites on the North Shore of Massachusetts. Salt marsh monitoring was conducted following methodology from *A Volunteer's Handbook for Monitoring New England Salt Marshes*, developed by the Massachusetts Office of Coastal Zone Management and the Executive Office of Environmental Affairs (Carlisle et al., 2002). Parameters for salt marsh monitoring included collecting data on Plants, Salinity, Nekton (Fish), Avian Species, *Phragmites*, and Invertebrates. A summary of the monitoring parameters that were completed for each of the six sites is shown in Table 2. Vegetation and salinity were the focus of this report, and therefore, nekton, avian species, *Phragmites*, and invertebrate data were not analyzed or included.

Table 2: Summary of salt marsh monitoring parameters at six sites on the North Shore, Massachusetts between 1999-2023. All data were collected by Salem Sound Coastwatch.

Name of Salt Marsh	Years of Pre-restoration monitoring	First year of post-restoration monitoring	Years of Monitoring by Parameter					
			Plants	Salinity (Surface and/or Porewater)	Nekton	Avian Species	*Phragmites*	Inverts
Conomo Point, Essex	1999-2000	2001	1999-2001, 2007*, 2013*, 2023	2000-2001, 2007, 2023	2007	2007	2007	2007
Eastern Point, Gloucester	2001-2003	2004	2001-2005, 2007-2008, 2010-2011, 2023	2001-2005, 2007-2008, 2010-2011, 2023	2001-2005, 2007-2008, 2010	2001-2005	2001-2005, 2007-2008, 2010	2001-2005
Good Harbor, Gloucester (Reference)	2001-2003	Reference	2001-2005, 2012, 2015, 2022-2023	2001-2005, 2012, 2015, 2022-2023	2001-2005, 2012	2001-2005	Absent from marsh	2001-2005, 2012
Little Neck, Ipswich	2001	2002	2001-2005+, 2007, 2023	2000-2003, 2007, 2023	2007	2007	2007	2007
Mill River, Gloucester	None	2010	2010-2011, 2013*, 2023	2010-2011, 2013, 2023	No	No	Yes	benthic - mud
Newman Road, Newbury	2007*	2010	2010, 2012, 2023	2007, 2010, 2023	2007-2008, 2010, 2012	No	No	2007-2008, 2010, 2012

*Data for these years were collected and entered into a now defunct database and were not included in this report as the file type was unsupported and, therefore, inaccessible.
+Reference site was not completed in 2005 due to inclement weather.

Vegetation Monitoring

Marsh vegetation was monitored following protocols from *A Volunteer's Handbook for Monitoring New England Salt Marshes* (Carlisle et al., 2002). All vegetation monitoring was completed during peak growing season, July-October, before plant senescence.

To establish permanent transects, each evaluation area was divided into three 100-foot sections along the main tidal creek. Within each of the three sections, the start of two transects were randomly assigned using a random number generator. These permanent transects ran perpendicular to the creek edge and extended to the salt marsh border. Six transects were established within each Reference Site (i.e., downstream of the culvert replacement) and six transects were established within each Study Site (i.e., upstream of the culvert replacement). The exception to this is the Newman Road Reference Site, which had two established transects. Transects were located each monitoring year by measuring known distances from the road's edge along the creek. Known compass headings were used to run each transect towards the upland border.

To monitor plots each year, a $1m^2$ quadrat was placed every 60 feet along each transect, starting at the bank edge and progressing towards the upland edge. Plots were placed in 30-foot increments for transects less than 120 feet in length. The final plot was placed in the salt marsh border regardless of whether it was located on the 30ft or 60ft interval. Since the transects' starting point was placed at the bank edge, plots may not have been monitored in the exact same location each year due to the possibility of bank erosion. Site-specific maps showing the transect and plot locations are available in Appendix A.

All plants within each $1m^2$ plot were identified to the genus and species. The percent cover of each species was estimated using nine standardized cover class midpoints (1%, 3%, 7%, 15%, 25%, 38%, 55%, 76%, 94%). Abiotic components within the plot were listed as "Other;" categorized as standing water, bare sediment, wrack, and/or dead vegetation; and the percent cover of each was estimated using the same cover class midpoints. Labelled photos were taken of each plot and, in 2023, GPS coordinates were also recorded at the start, midpoint, and end of each transect.

Vegetation Data Analysis

The vegetation abundance data were compiled in one dataset per site. Each dataset included percent cover data for both the Reference and the Study sites for all monitoring years. Each dataset was carefully checked for errors, such as incorrect spelling of species names, misidentifications, or inconsistent cover class midpoints. The cover class percentages were totaled for each plot, and any plots that were under 70% or over 150% cover were double checked by consulting the hard-copy data sheets and/or photo-documentation, if available. Any suspect data that could not be verified were excluded from further analysis. If a single plot contained more than one "Other" category, they were combined and the total percent cover was listed to the nearest cover class midpoint. No raw data were altered; all corrected data were listed in a new column and utilized in further analysis.

The quality-assured datasets were reformatted to calculate yearly species richness per site, as well as the dominant plant community types and marsh zone for each plot per year. Each plant species was designated as a halophyte or a non-halophyte using professional resources that considered each species' tolerance to salt and flooding (Tiner 1987). A master species list that includes each species' designation, as well as the species identified at each site, is included in Appendix B. Species richness was calculated by totaling the number of unique halophyte species and non-halophyte species per evaluation site each monitoring year. Results for species richness are provided in Appendix C. The dominant plant community types were categorized as "*Spartina alterniflora"* (low marsh), "High-marsh Species" (*Spartina patens, Juncus gerardii, Distichlis spicata*), "Other Halophytes" (salt-tolerant species other than *S. alterniflora, S. patens, J. gerardii, and D. spicata*), "*Phragmites australis*" (an invasive species of concern), "Other" (abiotics including bare sediment, standing water, wrack, and dead vegetation), or "Other Non-halophytes" (salt-intolerant species excluding *Phragmites*). The cover percentages for each plot were totaled for each plant community type and then normalized to 100% to standardize the total plot cover. Plots were then categorized by major marsh zone, "Low," "High," or "Upland" based on the following formulas:

- If normalized percent cover of *Spartina alterniflora* > 70%, then marsh zone = "Low;"
- If normalized percent cover of non-halophytes > 30%, the marsh zone = "Upland;"
- If normalized percent cover of *Spartina alterniflora* < 70% and non-halophytes < 30%, then marsh zone = "High."

If a plot was not assigned to a marsh zone due to a high percentage of abiotic "Other," it was excluded from analysis unless it was located at Plot 0 (along the creek bank), in which case, it was manually assigned to the "Low" marsh zone.

Bar charts were generated for each marsh zone within the Reference and Study sites at each of the five restored marshes. Only data that passed quality assurance checks were included in the bar charts. Additionally, the same plot needed to be sampled in the first year and last year, at minimum, to be included in the bar charts and statistical analysis. Two-sample t-tests (assuming unequal variances) were run in Excel for marsh zones that had a sample size greater than or equal to three. These t-tests were used to determine 1) if there were significant ($p < 0.05$) changes in plant community categories over time by comparing the first and last year of monitoring and 2) if there were significant ($p < 0.05$) differences between the Reference and Study sites at the beginning and end of the monitoring period.

Salinity Monitoring and Data Analysis

Porewater salinity was measured during the July-October monitoring season no more than three hours on either side of low tide using methods described in Portnoy and Valiela 1997. Porewater was sampled at the mid-point of each transect, either at a permanent well or via a sipper. If porewater was sampled from a well, stagnant water was first removed with a bilge pump, and only water that refilled the well was sampled. Porewater sippers were used to sample water from a depth of 20cm, ideally, though some areas were quite dense, which prevented the sipper from reaching that depth. A calibrated, handheld temperature-compensated refractometer was used to measure salinity in the field.

All raw porewater salinity data for each evaluation site was averaged for each monitoring year. Sample sizes ranged from 2 to 52 unique samples per evaluation site per monitoring year. Samples were collected over a range of one to five days in the study season. Annual average porewater salinities were plotted for both the Reference and Study sites across all available monitoring years. The results from the salinity monitoring area available in Appendix D.

RESULTS

Plots that were included in the analysis are provided in Table 3. The number of plots that were categorized as low marsh zone, high marsh zone, and upland zone in the first year of monitoring at each site are shown. This data is helpful in visualizing the difference in vegetation composition between the study marsh and reference marsh, and at some sites, shows the shift in vegetation cover over time. Plot numbers per marsh zone are provided for each evaluation area in this section.

Table 3: Number of plots included in analysis, grouped by year one marsh designation. Selected plots had to pass quality control checks and be included in both the first and last years of monitoring.

Marsh	Site	Low Marsh	High Marsh	Upland	Total
Conomo Point	Reference	5	6	0	11
	Study	0	8	1	9
Eastern Point	Study	0	13	2	15
Good Harbor	Reference	1	35	0	36
Little Neck	Reference	5	27	0	32
	Study	3	15	0	18
Mill River	Study	4	14	8	26
Newman Road	Reference	3	5	1	9
	Study	16	18	0	34

Conomo Point, Essex


Conomo Point's reference marsh (left) and study marsh (right). October 2023.

In year one of monitoring at Conomo Point (1999), the reference area plots consisted mostly of high marsh (n = 6) and low marsh vegetation (n=5) (Table 3). While the study area had a similar number of high marsh plots (n=8), it contained no low marsh plots (Table 3). See Appendix A for a map of the plots in the reference and restored marsh areas at Conomo Point.

The high marsh was the only marsh zone where comparisons between the reference and study marshes were possible due to an insufficient number of plots within the low marsh and upland zones. Statistical analyses showed no significant differences in any vegetation categories between the reference and study marshes in the first year of monitoring (1999), as well as following restoration (2023). However, the abundance of *Phragmites* showed an increasing trend in the study marsh with no *Phragmites* present prior to restoration (1999 and 2000) and becoming present immediately in 2001, the year immediately following restoration and maintaining presence in 2023.

Reference Marsh:

The Conomo Point reference marsh showed a significant decrease in unvegetated "other" in the low marsh zone (*p=0.1*; 82% to 43%, n=5) between 1999 and 2023, while other halophytes significantly increased in the low marsh zone (*p=0.02*; <1% to 22%, n=5) and *S. alterniflora* showed an increasing trend (*p=0.1*; 15% to 35%, n=5). There was a significant decrease in high marsh species in the reference marsh's high marsh zone between 1999 and 2023 (*p=0.02*; 73% to 24%, n=6). Other halophytes (*p=0.08*; 3% to 18%, n=6) and unvegetated "other" areas (*p=0.1*; 14% to 48%, n=6) showed an increasing trend in the high marsh zone in the same timeframe, though the results were not statistically significant.

During the 2023 site visit, SSCW staff observed large, muddy die-off areas mid-marsh (Image F2), as well as an expanding creek (Image F3) in the reference site. However, the culvert was clear and unobstructed (Image F4).

Study Marsh:

In the study marsh, high marsh species significantly decreased in the high marsh zone following restoration, from 1999 to 2023 ($p=0.03$; 76% to 38%, n=8). Other halophytes ($p=0.1$; 5% to 15%, n=8) and *Phragmites* ($p=0.09$; 0% to 24%, n=8) showed trending increases in the same timeframe. Observations from the 2023 site visit note poison ivy and tall *Phragmites* stands near the culvert opening and along the road, as well as standing pools of water at the end of the creek (Image F1). Additional notes from the 2023 site visit are provided in Appendix E.

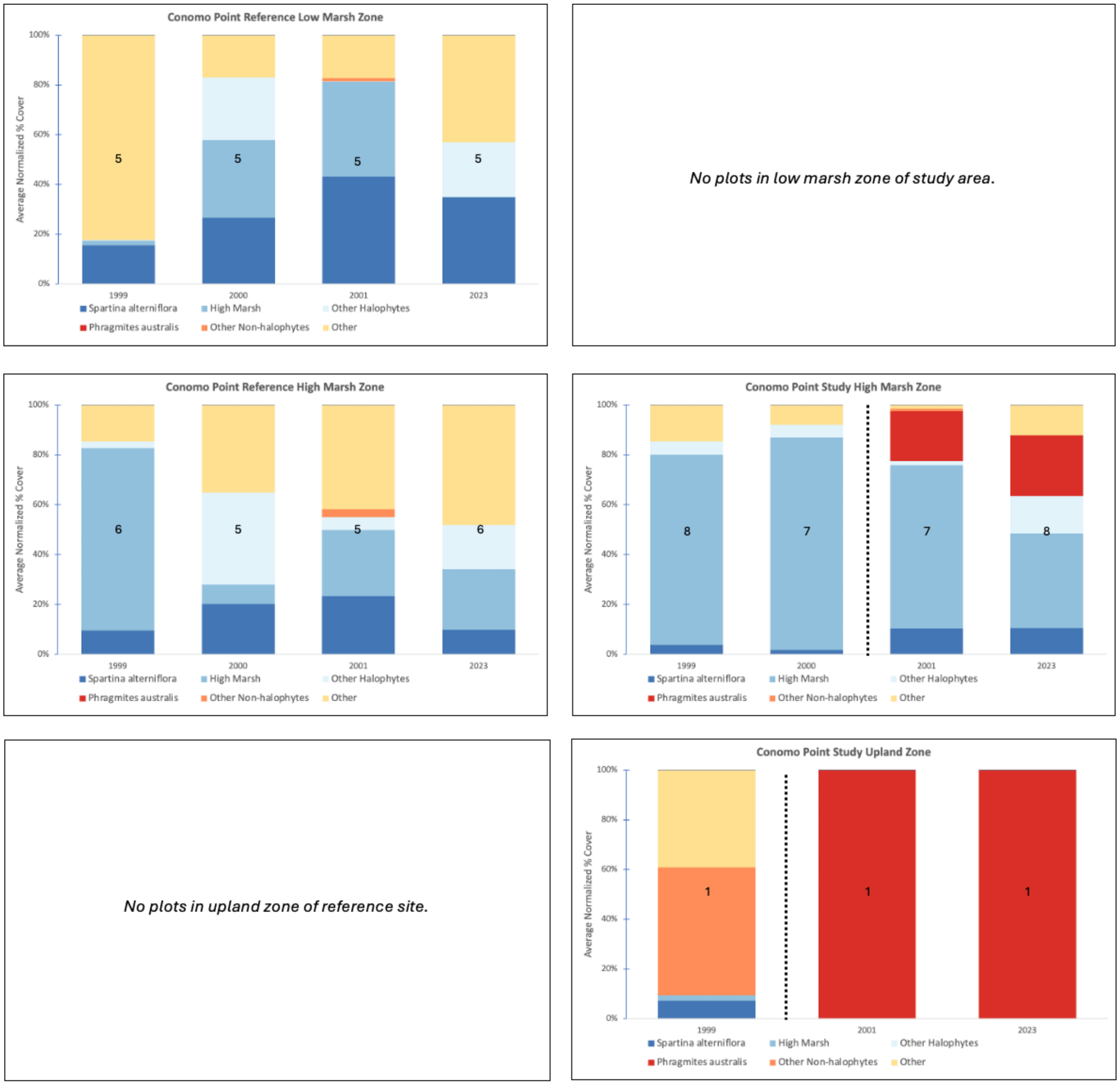

Figure 2: Average normalized percent cover for five dominant plant community types across three marsh zones within the reference and study areas of Conomo Point, Essex, MA. "Other" represents unvegetated area, such as bare sediment, wrack, standing water, and/or dead vegetation. Column numbers represent plot sample size. The vertical dotted line indicates when tidal restriction restoration occurred.

Eastern Point & Good Harbor, Gloucester

Good Harbor's reference marsh (left) and Eastern Point's study marsh (right). August 2023.

During the first year of marsh vegetation monitoring (2001) and prior to the restoration, the study marsh at Eastern Point was dominated by high marsh zone plots (n=13, Table 3) with no plots in the low marsh zone and only two in the upland transition zone. Similarly, the reference marsh at Good Harbor was composed primarily of high marsh plots (n=35, Table 3), with one plot within the low marsh zone and no plots in the upland transition zone. See Appendix A for a map of the plots in the reference and restored marsh areas at Eastern Point and Good Harbor.

In 2001, the reference and study marshes showed significant differences within the high marsh zone. *Spartina alterniflora* was in significantly greater abundance in the reference marsh at Good Harbor ($p<0.01$; Reference=6%, n=35; Study=0%, n=13). Unvegetated areas were significantly greater in the study marsh of Eastern Point ($p=0.01$; Reference=9%, n=35; Study=25%, n=13), while other halophytes were significantly more abundant in the reference marsh ($p<0.01$; Reference=16%, n=35; Study=0.2%, n=13).

In 2023, 20 years post-restoration, there were significantly more high marsh species in the high marsh zone of the Good Harbor reference marsh ($p=0.05$; Reference=70%, n=35; Study=43%, n=13), compared to the Eastern Point study marsh. There were no other statistical differences between the reference high marsh and the study high marsh present for the other vegetation cover types.

Vegetation in the high marsh zone of the Good Harbor reference marsh remained fairly stable over the monitoring time period (2001-2023), though other halophytes significantly decreased ($p=0.02$, 16% to 7%, n=35). During the 2023 site visit, SSCW staff noted slumping of the marsh platform at the end of a distributary channel that led to a panne

(Image F8). The creek in the Good Harbor marsh had widened in some areas (a permanent stake on the marsh platform was located in the creek; Image F9) and die-back of the bank edge was evident in some locations.

In the high marsh zone of the Eastern Point study marsh, the abundance of *S. alterniflora* significantly increased from 2001 to 2023 following restoration ($p=0.01$; 0% to 30%; n=13), as well as other halophytes ($p=0.03$; 0.2% to 13%, n=13). Conversely, the abundance of high marsh species significantly decreased ($p=0.02$; 75% to 43%; n=13). Observations from the 2023 site visit noted that the Eastern Point culvert was partially blocked by slumping mud and *S. alterniflora* (Image F6). Additional notes from the 2023 site visit are provided in Appendix E.

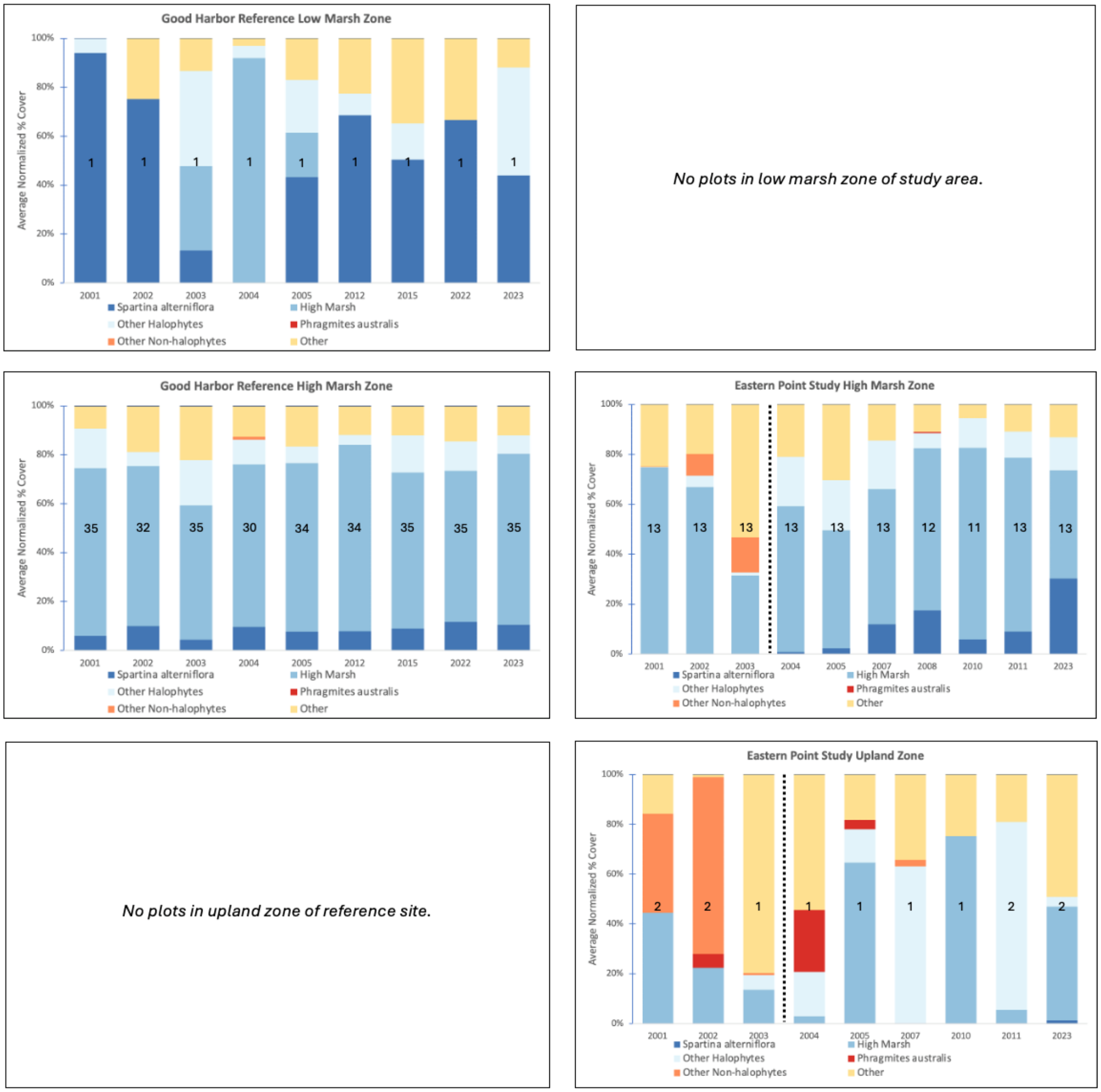

Figure 3: Average normalized percent cover for five dominant plant community types across three marsh zones in Good Harbor, Gloucester, MA (reference) and Eastern Point, Gloucester, MA (study). “Other” represents unvegetated area, such as bare sediment, wrack, standing water, and/or dead vegetation. Column numbers represent plot sample size. The vertical dotted line indicates when tidal restriction restoration occurred.

Little Neck, Ipswich

Little Neck's reference marsh (left) and study marsh (right). September 2023.

In the first year of monitoring at Little Neck (2001), the most prevalent vegetation community in the reference marsh was the high marsh zone (n=27; Table 3) and low marsh zone (n=5, Table 3), with no plots within the upland transition zone. Little Neck's study marsh was structured similarly, with mostly high marsh zone plots (n=15; Table 3) and few low marsh zone plots (n=3). See Appendix A for a map of the plots in the reference and restored marsh areas at Little Neck.

The high marsh zones of the reference and study marshes were quite different in composition at the start of monitoring (2001) before restoration. The study marsh had significantly lower abundances of *Spartina alterniflora* (*p<0.01*; Reference=9.8%, n=27; Study<1%, n=15) and other halophytes (*p<0.01*; Reference=12%, n=27; Study=2%, n=15). The study marsh also had significantly more areas of unvegetated "other" (*p<0.01*; Reference=9%, n=27; Study=48%, n=15). However, in 2023, following restoration, the high marsh zones of the reference and study marshes were similar in composition, with no statistical differences between vegetation types. The low marsh zones of the reference and study marshes followed a similar trend, with significantly more *S. alterniflora* in the reference marsh (*p<0.01*; Reference=66%, n=5; Study=3%, n=3) and significantly more unvegetated "other" in the study marsh (*p<0.01*; Reference=32%, n=5; Study=96%, n=3) in 2001. In 2023, the composition of the low marsh zones of the reference and study marshes were similar, with no statistical differences.

While the low marsh zone of the reference marsh had no statistical differences between vegetation types over the monitoring timeframe (2001 to 2023), the high marsh zone changed in several ways. The abundance of *S. alterniflora* significantly increased (*p<0.01*;

10% to 31%; n=27), while the abundance of high marsh species significantly decreased (*p<0.01*; 69% to 51%; n=27). The abundance of other halophytes also decreased (*p=0.05*; 12% to 7%; n=27).

In the low marsh zone of the study marsh, the abundance of high marsh species significantly increased (p=0.05; 0% to 64%, n=3), while the abundance of unvegetated "other" significantly decreased (p<0.01; 96% to 8%, n=3). In the high marsh zone of the study marsh, the abundance of *S. alterniflora* significantly increased (*p<0.01*; <1% to 27%, n=15), while the amount of "other" unvegetated area decreased (p<0.01; 48% to 11%, n=15). Comparisons between the study marsh's upland transition zone was not possible using t-test analysis due to the low sample size of plots within each zone. During the 2023 site visit, SSCW staff noted that the Little Neck culvert was clear and unobstructed (Image F11). Additional notes from the 2023 site visit are provided in Appendix E.

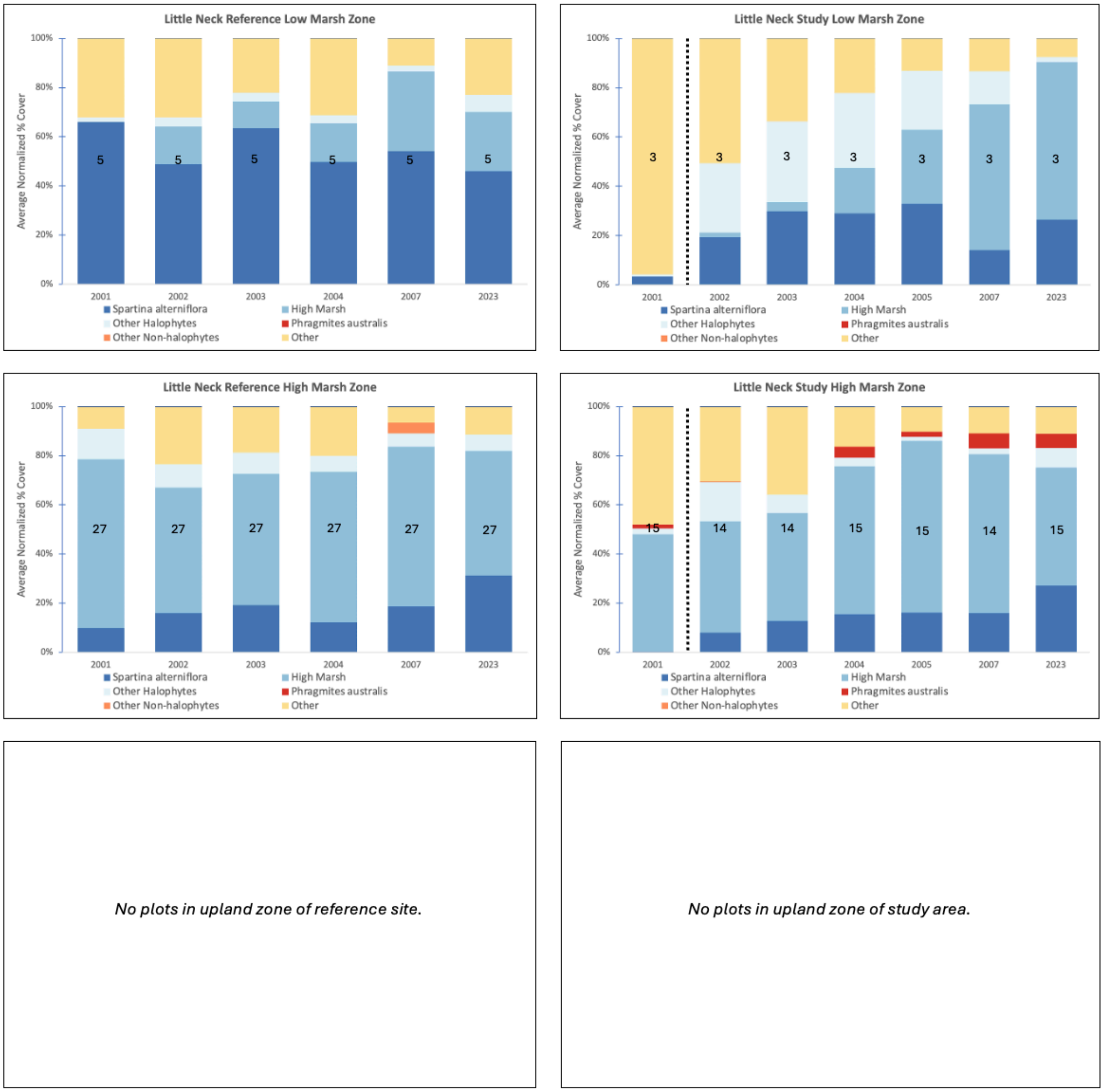

Figure 4: Average normalized percent cover for five dominant plant community types across three marsh zones within the reference and study areas of Little Neck, Ipswich, MA. "Other" represents unvegetated area, such as bare sediment, wrack, standing water, and/or dead vegetation. Column numbers represent plot sample size. The vertical dotted line indicates when tidal restriction restoration occurred.

Mill River, Gloucester

Mill River's study marsh (left) and peninsula of study marsh (right). Both taken June 2023.

The plant community composition in year one (2010) of monitoring at the Mill River study marsh was composed primarily of high marsh (n=14; Table 3), with four plots located in the low marsh zone and eight plots in the upland transition zone. Monitoring was only conducted post-restoration and there was no representative reference marsh at this site. See Appendix A for a map of the plots in the restored marsh area at Mill River.

There were no significant differences in vegetation types in the study area's low marsh zone over the monitoring timeframe (2010-2023). However, in Mill River's high marsh zone, *Spartina alterniflora* cover significantly increased ($p<0.01$; 12% to 48%, n=14), while high marsh species significantly decreased ($p<0.01$; 73% to 24%, n=14). Additionally, the area of unvegetated "other" significantly increased ($p=0.03$; 8% to 25%, n=14). In the upland transition zone, the abundance of high marsh species ($p=0.05$; 1% to 22%, n=8) and other halophytes ($p=0.01$; 1% to 33%, n=8) significantly increased, while the cover of *Phragmites* significantly decreased ($p<0.01$; 37% to 3%, n=8). The cover of unvegetated "other" also significantly decreased ($p<0.01$; 60% to 23%, n=8).

During the 2023 site visit, SSCW staff noted water ponding with *Salicornia* on the landward end of transect 1 (Image F13), bank die-back and erosion (Image F14), and substantial amounts of wrack and debris deposited on the marsh platform (Image F15). Additional notes from the 2023 site visit are provided in Appendix E.

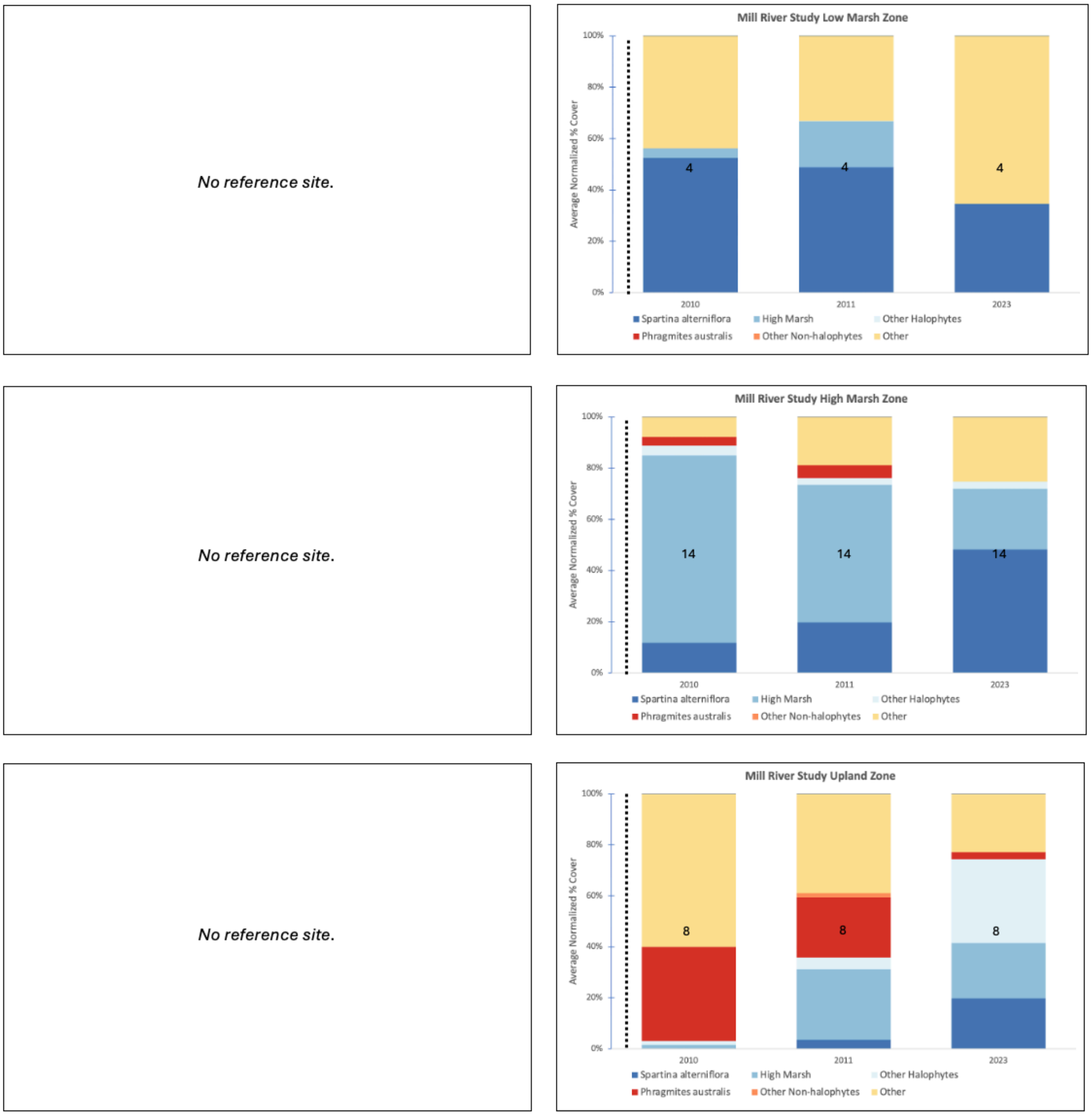

Figure 5: Average normalized percent cover for five dominant plant community types across three marsh zones within study area of Mill River, Gloucester, MA. Note, this evaluation area did not have a corresponding reference site. “Other” represents unvegetated area, such as bare sediment, wrack, standing water, and/or dead vegetation. Column numbers represent plot sample size. The vertical dotted line indicates when tidal restriction restoration occurred.

Newman Road, Newbury

Newman Road's reference marsh (left) and study marsh (right). June 2023.

In the first year of monitoring at Newman Road, the most prevalent plant community type in the reference marsh was the high marsh zone (n=5; Table 3), followed by the low marsh zone (n=3) and the upland transition zone (n=1). The study marsh was dominated by high marsh plots (n=18; Table 3) and low marsh plots (n=16), with zero plots in the upland zone. See Appendix A for a map of the plots in the restored marsh area at Newman Road.

There were no significant differences between the high marsh zones of the reference marsh and study marsh in the first year of monitoring (2010). However, the abundance of high marsh species was significantly higher in the low marsh zone of the study marsh in 2010 ($p=0.04$; Reference=0%, n=3; Study=3%, n=16). In 2023, following restoration, the high marsh zone of each evaluation area remained stable, with no significant differences in vegetation types between the reference and study marshes. In the low marsh zone (2023), the reference marsh had significantly more *Spartina alterniflora* ($p=0.01$; Reference=90%, n=3; Study=59%, n=16) and significantly less unvegetated "other" ($p=0.01$; Reference=7%, n=3; Study=31%, n=16).

Throughout the monitoring timeframe (2010-2023), the reference marsh remained stable, with no significant differences in vegetation type. While there were no significant differences in the low marsh zone of the study marsh in this timeframe, the abundance of *Spartina alterniflora* significantly increased ($p<0.01$; 21 to 51%, n=18) in the high marsh zone, while the abundance of high marsh species significantly decreased ($p<0.01$; 69% to 34%, n=18). During the 2023 site visit, SSCW staff noted that there was ponding towards the tree line (Image F16) and the deep creek banks were slumping in the study marsh (F17). Additional notes from the 2023 site visit are provided in Appendix E.

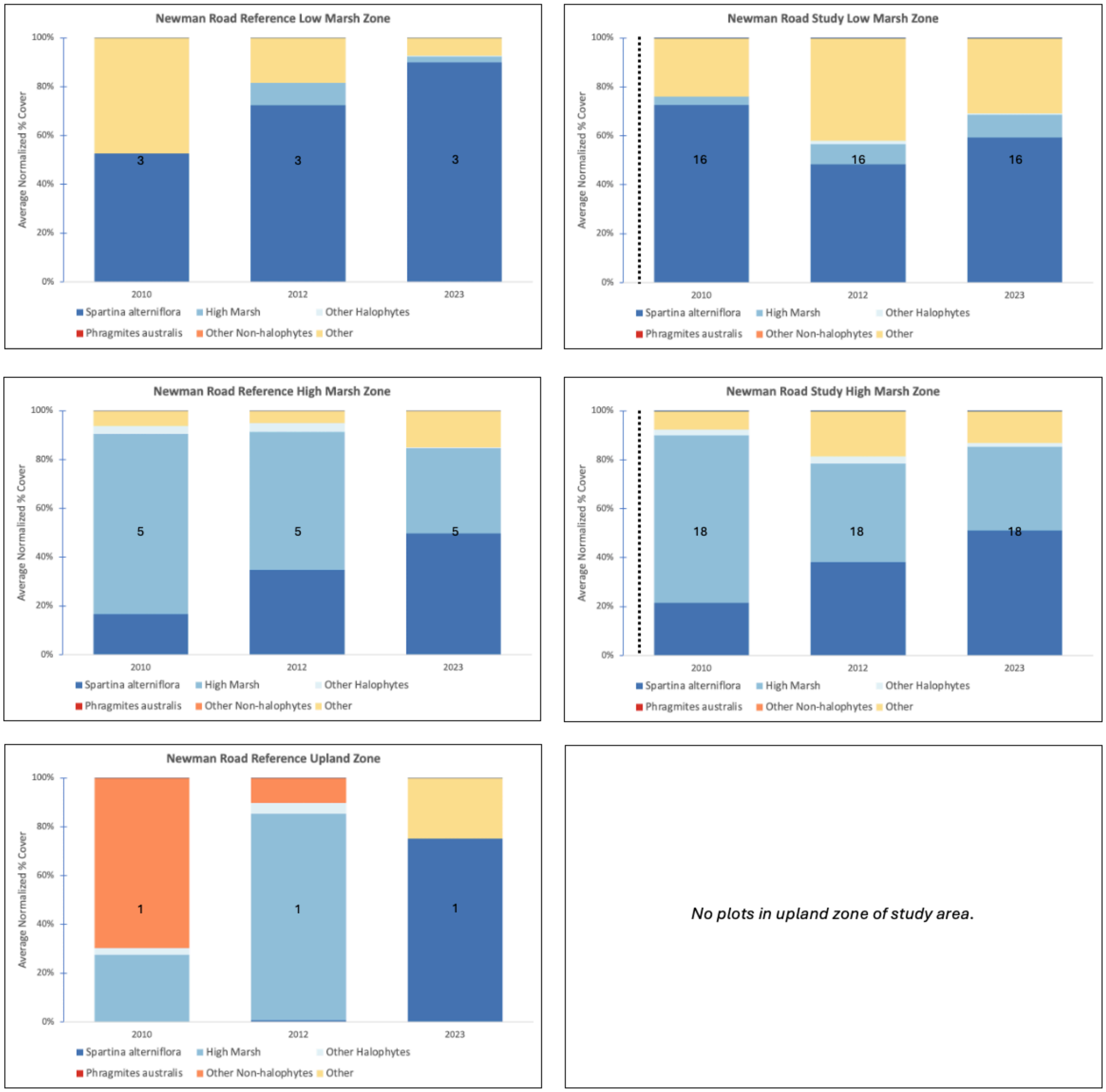

Figure 6: Average normalized percent cover for five dominant plant community types across three marsh zones within the reference and study areas of Newman Road, Newbury, MA. “Other” represents unvegetated area, such as bare sediment, wrack, standing water, and/or dead vegetation. Column numbers represent plot sample size. The vertical dotted line indicates when tidal restriction restoration occurred.

All Site Summary

A summary of results ($p < 0.2$ and $p \leq 0.05$) from the two-sample t-test analyses of all sites is provided in Table 4. Clear trends were apparent for the percent cover of *Spartina alterniflora* and high marsh species, but general trends were not observed for the other vegetation community types.

The percent cover of *S. alterniflora* increased in the high marsh zones at two of the four reference marshes (Little Neck and Newman Road) and four of the five study marshes (Eastern Point, Little Neck, Mill River, and Newman Road). Additionally, *S. alterniflora* increased in one upland transition zone of the Mill River study marsh. The abundance of *S. alterniflora* remained unchanged in the low marsh zones of all evaluation sites, though showed an increasing trend at Conomo Point the reference marsh. There were no decreases in *S. alterniflora* observed at any site.

In contrast, the percent cover of high marsh species (*Spartina patens, Distichlis spicata,* and *Juncus gerardii*) decreased in the high marsh of all sites. High marsh species declined in the high marsh zones of three of four reference marshes (Conomo Point, Little Neck, and Newman Road) and four of five study marshes (Conomo Point, Eastern Point, Mill River, and Newman Road). Percent cover of high marsh species increased in the low marsh zones of one reference marsh (Little Neck) and one study marsh (Little Neck), as well as in the upland transition zone of one study marsh (Mill River).

Changes in the percent cover of other halophytes, *Phragmites australis*, and unvegetated “other” (bare sediment, wrack, dead vegetation) varied across evaluation areas and did not demonstrate a clear general trend. The abundance of other halophytes increased in the high marsh zone of the Eastern Point study marsh, as well as the Conomo Point reference and study marshes, but decreased in the high marsh zones of Good Harbor and Little Neck reference marshes. Other halophytes also increased in the upland transition zone of the Mill River study marsh and the low marsh zone of the Conomo Point reference marsh.

Phragmites cover decreased in the upland transition zone and the high marsh zone of Mill River’s study marsh, while increasing in abundance in the high marsh zone of Conomo Point’s study marsh. Unvegetated “other” increased in the high marsh zones of Conomo Point’s reference marsh and Mill River’s study marsh, while decreasing in abundance in the high marsh zones of Eastern Point and Little Neck study marshes. Unvegetated areas also decreased in the low marsh zone of Newman Road’s reference marsh, as well as the upland transition zone of Mill River’s study marsh.

Table 4: Summarized results from t-test analyses of marsh vegetation percent cover, comparing first monitoring year to 2023 by marsh zone. Double arrows represent a significant ($p \leq 0.05$) increase or decrease, while single arrows represent an increasing or decreasing trend ($p < 0.2$). Horizontal dashed lines indicate no change, NP = community type is "not present," and NA = results "not available" if sample size was < 3.

Marsh	Site	Zone	*Spartina alterniflora*	High Marsh Species	Other Halophytes	*Phragmites australis*	Other Non-Halophytes	Other
Conomo Point	Reference	Low Marsh	↑	---	↑↑	NP	NP	↓↓
Conomo Point	Reference	High Marsh	---	↓↓	↑	NP	NP	↑
Conomo Point	Reference	Upland	NA	NA	NA	NA	NA	NA
Conomo Point	Study	Low Marsh	NP	NP	NP	NP	NP	NP
Conomo Point	Study	High Marsh	---	↓↓	↑	↑	NP	---
Conomo Point	Study	Upland	NA	NA	NA	NA	NA	NA
Eastern Point	Study	Low Marsh	NP	NP	NP	NP	NP	NP
Eastern Point	Study	High Marsh	↑↑	↓↓	↑↑	NP	↓	↓
Eastern Point	Study	Upland	NA	NA	NA	NA	NA	NA
Good Harbor	Reference	Low Marsh	NA	NA	NA	NA	NA	NA
Good Harbor	Reference	High Marsh	---	---	↓↓	NP	---	---
Good Harbor	Reference	Upland	NP	NP	NP	NP	NP	NP
Little Neck	Reference	Low Marsh	---	↑	---	NP	NP	---
Little Neck	Reference	High Marsh	↑↑	↓↓	↓↓	NP	NP	---
Little Neck	Reference	Upland	NP	NP	NP	NP	NP	NP
Little Neck	Study	Low Marsh	---	↑↑	---	NP	NP	↓↓
Little Neck	Study	High Marsh	↑↑	---	---	---	NP	↓↓
Little Neck	Study	Upland	NA	NA	NA	NA	NA	NA
Mill River	Study	Low Marsh	---	---	NP	NP	NP	---

Mill River	Study	High Marsh	↑↑	↓↓	---	↓	NP	↑↑
Mill River	Study	Upland	↑	↑↑	↑↑	↓↓	NP	↓↓
Newman Road	Reference	Low Marsh	---	---	---	NP	NP	↓
Newman Road	Reference	High Marsh	↑	↓	---	NP	NP	---
Newman Road	Reference	Upland	NA	NA	NA	NA	NA	NA
Newman Road	Study	Low Marsh	---	---	---	NP	NP	---
Newman Road	Study	High Marsh	↑↑	↓↓	---	NP	NP	---
Newman Road	Study	Upland	NP	NP	NP	NP	NP	NP

DISCUSSION

Overall Conclusions

The overall trend across sites showed an increase in *Spartina alterniflora* cover in the high marsh and a decrease in the abundance of high marsh species (*Spartina patens, Distichlis spicata,* and *Juncus gerardii)* in the high marsh zone. The cover of *S. alterniflora* increased in the high marsh zones of 50% of the reference marshes and 80% of the study marshes, while high marsh species declined in 75% of the reference marshes and 80% of the study marshes.

S. patens typically outcompetes *S. alterniflora* in the high marsh, driving *S. alterniflora* to lower elevations (Bertness 1991). However, *S. alterniflora* is well-adapted to anoxic conditions, surviving extended periods of tidal inundation in the low marsh daily (Teal & Kanwisher 1966). Since *S. patens* is unable to tolerate conditions typical of the low marsh (Gleason & Zieman 1981), areas that experience frequent flooding are often dominated by *S. alterniflora*. The observed decrease in the abundance of *S. patens*, and other high marsh species, and increase in *S. alterniflora* in the high marsh indicates more frequent flooding by salt water. Since this trend has impacted reference marshes, as well as restored marshes, the cause of these shifts in vegetation composition in the high marsh may be attributed to sea level rise associated with climate change.

Several studies of New England marshes' response to more frequent flooding from sea level rise support our findings. Donnolly and Bertness (2002) found that the landward migration of *S. alterniflora* into higher marsh elevations dominated by *S. patens, D. spicata,* and *J. gerardii* coincided with accelerating rates of sea level rise. A study of Rhode Island marshes by Raposa et al. (2017) documented the decline of *S. patens* during periods of accelerated sea level rise, as well as its replacement by *S. alterniflora* in the high marsh.

Historically, marshes have kept pace with sea level rise with vertical accretion matching or exceeding the rate of sea level rise. The National Oceanic and Atmospheric Administration predicts that the rate of sea level rise in the Boston, MA area will accelerate in the years ahead to 2.94 mm/year (NOAA 2023). A recent study of the Great Marsh (North Shore, MA) predicted that the entire high marsh platform will be converted to low marsh by 2070 under moderate sea level rise scenarios (FitzGerald et al. 2021). Restoration of tidally restricted marshes was a necessary step in creating hydrology typical of an unaltered marsh to prevent total loss of marsh area; however, ongoing monitoring is necessary to determine how the marsh is responding to sea level rise and to determine whether further management actions may be necessary in the future.

Conclusions by Site

This section provides a discussion of site-specific trends, conclusions, and recommendations for future monitoring efforts based on the analyses. Table 5 displays the years of pre- and post-restoration vegetation monitoring for each marsh, as well as the total amount of time that had elapsed between restoration and the final survey in 2023 (grey cells). The extent of monitoring time ranges from 14 to 24 years across all six sites. The varied timeframes should be considered while interpreting the results of the vegetation surveys. Bolded “pre” and “post” that are denoted with a double asterisk indicate the survey years that were utilized in statistical t-test analyses.

Table 5: List of pre- and post-restoration vegetation monitoring completed for each site by year. "Pre" denotes vegetation monitoring that occurred prior to tidal restoration, while "Post" denotes monitoring that occurred after tidal restoration at the study and reference marshes. Bold text with a double asterisk indicates the first and last year of monitoring data that were used for statistical t-test analyses. Cells highlighted in grey visualize the years that elapsed between when restoration occurred and the final year of vegetation monitoring included in analysis.

Year	Conomo Point	Eastern Point	Good Harbor (reference)	Little Neck	Mill River	Newman Road
1999	**Pre****					
2000	Pre			Pre*		
2001	Post	**Pre****	**Pre****	**Pre****		
2002		Pre	Pre	Post		
2003		Pre	Pre	Post		
2004		Post	Post	Post		
2005		Post	Post	Post		
2006						
2007	Post*	Post		Post		Pre*
2008		Post				
2009						
2010		Post			**Post****	**Post****
2011		Post			Post	Post
2012			Post			
2013	Post*				Post*	
2014						
2015			Post			
2016						
2017						
2018						
2019						
2020						
2021						
2022			Post			
2023	**Post****	**Post****	**Post****	**Post****	**Post****	**Post****
No. Years Elapsed	**23**	**20**	**20**	**22**	**14**	**14**

*Data were inaccessible and not included in analysis.
**The first and last year of monitoring data that were used for statistical t-test analyses

Conomo Point, Essex

With any tidal restoration effort, the goal is to restore the natural flow of salt water to a restricted marsh to create an environment that promotes native salt marsh vegetation. Following restoration of the Conomo Point culvert, the abundance of non-halophytic *Phragmites* showed an increasing trend in the study area's high marsh zone. *Phragmites* was not recorded in the high marsh in 1999 and 2000, prior to restoration; however, in 2001, immediately following restoration, *Phragmites* covered about 20% of the high marsh zone, which persisted into the final year of monitoring in 2023. Although the small plot sample size prevented statistical comparisons in the upland transition zone, *Phragmites* showed an increasing trend there, as well.

Like the high marsh zone, *Phragmites* was not recorded in the upland zone before restoration (1999) but following restoration 100% of upland area was *Phragmites* in both 2001 and in 2023. Field observations in 2023 noted large ponding of water towards the north end of the study area (farthest from the culvert) (Image F1). A 1999 report (Kooken et al. 1999) of the Conomo Point study area did not mention this standing pool of water. In fact, the report stated that salinity measurements could not be taken at northern points along the creek, as the water had dried up in response to the collapsed culvert. The report also noted that, contrary to what was expected, the salinity was higher in the study area due to increased evaporation of water. This may explain the reemergence of *Phragmites* after the culvert was replaced. Additional information on porewater salinity is provided in Appendix D.

Field observations of the reference marsh in 2023 noted a striking increase in muddy die-back zones in the high marsh platform (Image F2). Analysis of the high marsh data supports this observation. Bare mud ("other") and other halophytes, most notably *Salicornia europaea,* showed an increasing trend in the high marsh that coincided with a significant decline in high marsh species (Image F5). *Salicornia spp.* is an opportunistic species that can thrive in high saline conditions and is a frequent colonizer of disturbed areas. These trends are not only consistent with more frequent inundation by salt water, but also ponding of water in the high marsh, causing wide-spread die-back of high marsh vegetation. The upland zone of the reference marsh abruptly transitions to a steep, forested hill, which could impede future migration of the high marsh zone. Further investigations should monitor the extent of saturated die-back areas as sea levels continue to impact this marsh system.

Eastern Point and Good Harbor, Gloucester

Before restoration, the Eastern Point marsh had been almost completely restricted from tidal flow by a small, paved road that enclosed the salt marsh. Although a culvert was installed under the road, it had become completely blocked by sediment and cobble from 1993 to 2003 (Warren et al. 2003). At this time, the marsh's porewater salinity ranged from 11-17ppt, while the channel water was nearly fresh, at 3ppt (Warren et al. 2003). The marsh was dominated by high marsh species (*Distichlis spicata, Juncus gerardii,* and *Spartina patens*) in the high marsh zone and non-halophytes in the upland zone, with no low marsh zone (*Spartina alterniflora*). A new culvert was then constructed to reconnect the marsh with natural tidal flow. The study marsh at Eastern Point has responded well to restoration. Bare mud ("other") decreased, while other halophytes have significantly increased in the high marsh zone in response to the increased flow of salt water. *Salicornia spp.* and *Suaeda linearis* represent the majority of those other halophytes. These species were not present in the marsh before restoration but appeared immediately following restored tidal flow. *Spartina alterniflora* follows this same pattern in the high marsh area, indicating a distinct influx of salt water. Although the upland zone plot sample size was too low to compare statistically, there was a substantial decrease in other non-halophytes after restoration. *Spartina pectinata* and *Lythrum salicaria* (invasive purple loosestrife), along with other non-halophytes, made up about 40-75% of the upland zone before restoration and were virtually nonexistent in the upland area immediately following restoration, which persisted to the final year of monitoring. This can very likely be attributed to the restored tidal flow, as these species are intolerant to frequent inundation by salt water.

In 2003 there was a distinct increase in abiotic "other" in both the high marsh zone and, more apparently, in the upland zone of the Eastern Point study marsh. Although early surveys did not specify if the "other" was mud, wrack, water, etc., this increase can most likely be attributed to the deposition of cobble and sand from ocean waves overtopping the cobble dune that separates the marsh from Massachusetts Bay (Image F7). Field observations in 2023 noted that the downstream side of the culvert looked to be partially restricted by clumps of peat and *S. alterniflora* (Image F6). It's unclear for how long the marsh peat had blocked the culvert channel and, as our study did not measure the hydrology of the area, if this blockage restricts tidal flow.

The high marsh zone of the Good Harbor reference marsh remained relatively stable throughout the 23 years of monitoring, despite the overall trends observed at the other monitored reference marshes. There was, however, a significant decrease in other halophytes in the high marsh, namely *Glaux maritima, Agropyron pungens, and Atriplex* *patula*, which have lower tolerances to flooding and/or salinity. This could represent the first signal of the impacts from sea level rise, particularly since observations in 2023 noted an area of marsh-collapse within the high marsh platform (Image F8).

Although the low marsh zone plot sample size was too small to compare statistically, the bank exhibited large swings in plant composition throughout the monitoring period. In 2001, the creek bank was composed almost entirely of *S. alterniflora*. Three years later, it was composed almost entirely of high marsh species. Most recent observations have noted large areas of *Suaeda linearis,* which is often an early colonizer of disturbed areas (Image F10). The bank edge is a dynamic area, so further investigations are necessary to elucidate the exact cause(s) of these shifts, such as flooding, bank edge erosion, deposition of wrack, or interactions with range-expanding species. Like the Conomo Point reference marsh, Good Harbor's upland border is defined by a steep slope. The Good Harbor beach parking area could inhibit future marsh migration or be redesigned to accommodate marsh migration.

Little Neck, Ipswich

The study area at Little Neck was inundated by freshwater following the culvert collapse in 2000, which caused a die-back of native salt marsh vegetation and areas of "open, muddy ground" (Carlisle et al. 2002). Following restoration, succession of the low marsh zone is quite evident. Once the tidal restriction was removed, the areas of bare mud were colonized by *Salicornia europaea* between 2002-2005, followed by succession to high marsh species between 2007-2023. This increase in high marsh species is reflected in the reference site's low marsh zone, which also exhibited an increasing trend of high marsh species in the low marsh zone. The high marsh zone saw similar changes, with significant decreases in mud and increases in *S. alterniflora* abundance, while high marsh species remained stable. By the final monitoring year there were no apparent differences between the high marsh zones of the reference and study marshes, indicating that the restoration led to salt marsh recovery.

Although the study area's upland plot sample size was too small to run statistical analysis, the abundance of *Phragmites* gradually decreased by about half from 2001 to 2007 and was replaced by high marsh species. However, data from 2023 shows that *Phragmites* has encroached, on average, 16 feet into the marsh from where it was reported in 2001. Due to the established sampling protocol and limited accessibility, plots well-within the *Phragmites* stand were not sampled in 2023 that may have been sampled in 2001 (and categorized as "upland"). Therefore, the same plots that were categorized as "upland" in

2001 were not sampled in 2023, which is why 2023 is not represented on the upland zone graph. The apparent encroachment of *Phragmites* should be investigated further. However, overall, the Little Neck study marsh has responded well to tidal restoration.

The low marsh zone of the reference site remained relatively stable, with the exception of the increasing trend in high marsh species in the low marsh. Little Neck was the only monitored location to show this change and was likely a result of the presence of *Iva frutescens*, commonly referred to as the "high tide bush," along the creek edge indicating this area of the marsh likely had a higher elevation despite being in the low marsh zone (Image F12). Otherwise, the high marsh zone of the reference area seems to be experiencing the same shifts that may be attributed to sea level rise as the other marshes, with *S. alterniflora* expanding into the high marsh area, replacing high marsh species and other halophytes.

Mill River, Gloucester

Although no pre-restoration monitoring data were available for Mill River's study area, observations before the opening of the tide gate report that freshwater was retained in Mill River's pond, to the point that houses lining the pond flooded during rainstorms. This environment would have favored non-halophytic plants, such as *Phragmites australis*. Our analysis follows the gradual opening of the tide gate, which restored a more natural flow of saltwater to the area.

Throughout the 14-year span of monitoring data, *Spartina alterniflora* increased in the high marsh and showed an increasing trend in the upland zone. High marsh species, however, decreased in the high marsh and increased in the upland zone, demonstrating an inland migration of low marsh and high marsh vegetation. *Phragmites* retreated, as well, decreasing in abundance in both the high marsh and upland zones. In 2010, the first report of *Phragmites* along all five transects occurred at 60ft, on average, while in 2023, the first report, on average, was at 185ft, which demonstrates an average landward retreat of 125 feet. These clear shifts in vegetation indicate that the slow opening of the tide gate was successful at restoring a more typical salt marsh environment. Further landward migration, however, may be impeded by the sloping hills that border the marsh.

The increasing amount of "other" in the high marsh and decreasing amount of "other" in the upland zone supports observations from the 2023 field survey. "Other" is most frequently noted as bare (mud) in these two areas. A large, wet die-back area was evident in the high marsh platform of transect 1, in particular (Image F13). This area remained saturated at low tide and supported thick algal mats and bacterial films. Although the saturated, muddy area extended into what would have been categorized as upland zone (*Phragmites*) in year 1 of analysis, *Salicornia europaea* had colonized this bare die-back area, contributing significantly to the increase in other halophytes in the upland zone. Further investigations should monitor the extent of saturated die-back areas of the marsh bank (Image F14) and platform as sea levels continue to encroach landward.

Newman Road, Newbury

Pre-restoration monitoring data were not available for this report. Therefore, the Newman Road study site was only assessed for the earliest available survey year, 2010, which is a year after culvert restoration. Plant composition in the high marsh zones of the study and reference areas were similar in 2010 and in 2023. Both sites experienced *Spartina alterniflora* overtaking high marsh species in the high marsh zone, consistent with possible sea level rise. Much of the study area's "other" represents large, standing pools of water towards the upland border (Image F16). Although these areas have remained stable over time, further studies should investigate the development or enlargement of these pools using aerial imagery over time, as well as their potential expansion in the future.

Lessons Learned and Recommendations

1. *GPS locate or physically mark individual marsh plots to ensure exact plot locations are monitored year to year.*

   Transects always began at the bank edge (0 ft). Individual plots were located by measuring along the transect at corresponding distances, from the bank to the upland edge. Based on this monitoring protocol, any erosion of the creek bank would lead to a different starting point than the previous monitoring year, shifting all plots along the transect incrementally landward. Shifting plots could, in theory, keep pace with any changes to the bank edge due to sea level rise. This could cause researchers to miss shifts in plant assemblages by sampling a slightly more landward plot each year. We recommend GPS locating each plot to ensure the same location is monitored each year. If the cost of this equipment is prohibitive, permanent stakes, marking the beginning and end of each transect, could be a viable alternative.

2. *Survey additional plots in the low marsh and upland transition by reducing distance between plots in these zones.*

   Based on existing protocol, plots were established either 30 feet or 60 feet from one another. Even at the smallest interval (30 feet), generally only one plot may be sampled in the low marsh, potentially missing changes to this dynamic zone. In our analysis, one-third of low marsh zones and 56% of upland zones could not be compared statistically, as the plot sample size was too small to run statistical analyses ($n < 3$). Monitoring additional plots in these narrow areas of the marsh would allow researchers to observe changes in greater detail and provide more accurate comparisons year to year. We recommend establishing plots at 5 ft, 10 ft, and 20 ft in the low marsh to provide additional information about any potential changes to this area. Researchers would be welcome to sample any additional randomized plots in the low marsh if they felt it necessary. We recommend additional randomized sampling in the upland zone, as well.

3. *Ensure that random selection of established transects maintains statistically independent and interspersed plot replicates.*

   Protocols from *A Volunteer's Handbook for Monitoring New England Salt Marshes* (Carlisle et al., 2002) utilized a random number generator to assign the start of each transect within each 100-foot section at each evaluation site. While all of the transects were assigned randomly, the starting points of at least two pairs of transects were very close to one another (7-10 feet), which could potentially compromise the independence of each transect's plots. While we recommend the continued use of the random number generator in selecting transect starting points, we advise that if two transects fall within 20 feet of one another, that the random number be regenerated to ensure that each transect is independent of one another.

4. *Utilize discrete "other" categories, such as bare, standing water, wrack, etc. for future marsh monitoring.*

   While SSCW researchers used discrete categories to define abiotic "other" cover as bare, water, wrack, and/or dead vegetation in 2023, earlier protocol combined all abiotic "other" and often did not make note of what that "other" was. Increasing areas of mud or standing water are particularly important to differentiate while assessing the health of the marsh. Thus, we recommend setting a protocol for more specific "other" classifications.

5. *Track large-scale changes in marsh vegetation by utilizing additional analysis techniques and exploring emerging monitoring methods*.

   Since the analysis protocol requires exact plots are analyzed year to year, important marsh-wide changes may be missed by disregarding plots if they do not have a corresponding location in another monitoring year. In addition to traditional transect/plot methods, we recommend utilizing additional analysis techniques that take a more wholistic view of the marsh to capture large-scale changes. We also encourage researchers to explore the use of different or emerging monitoring techniques, such as measuring marsh elevation changes and utilizing drones or aerial imagery to map marsh-wide changes, such as die-back zones and pool formation/expansion.

6. *Utilize continuous water loggers to collect more accurate changes in salinity.*

   The salinity results presented in Appendix D are representative of the available data, which varied in collection methods, timing, sample size, and environmental conditions. Therefore, accurate comparisons in salinity before and after tidal restoration were difficult to make. Due to the inherent dynamic nature of estuarine salinity, continuous water monitoring loggers would provide more consistent and accurate information.

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

Transects and plots were located and measured using Google Earth. These maps provide a general location of the survey area for each monitored marsh. They were not located by exact GPS coordinates, so their accuracy may vary.

Conomo Point, Essex, MA

Figure A1: Vegetation plots at Conomo Point salt marsh restoration site in Essex, MA. Transects labeled “R” represent the reference marsh, while transects labeled “S” represent the study marsh. The yellow X represents the location of the former tidal restriction.

Eastern Point, Gloucester, MA

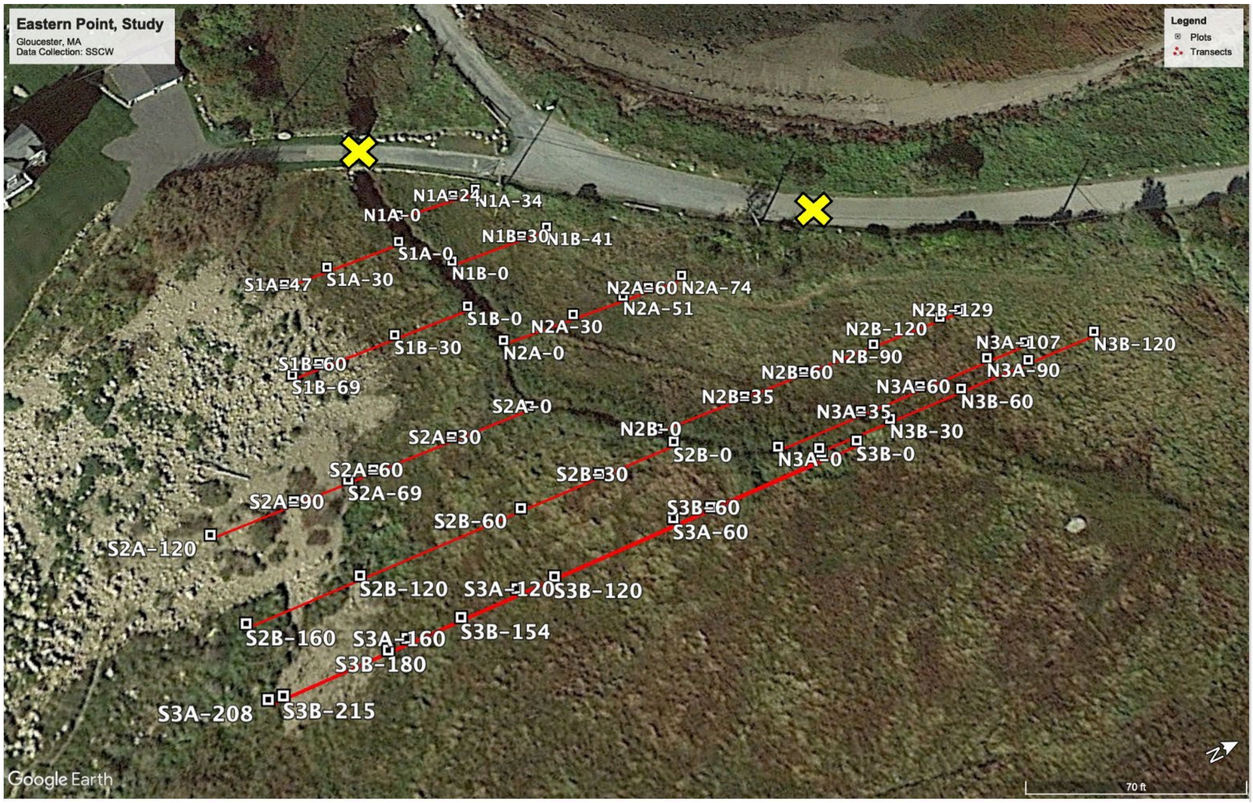

Figure A2: Vegetation plots at Eastern Point salt marsh restoration site in Gloucester, MA. Transects labeled “S” represent the original study marsh, while the “N” represents the north side of the study marsh that was added in 2005. The yellow Xs represent the locations of the former tidal restrictions.

Good Harbor, Gloucester, MA

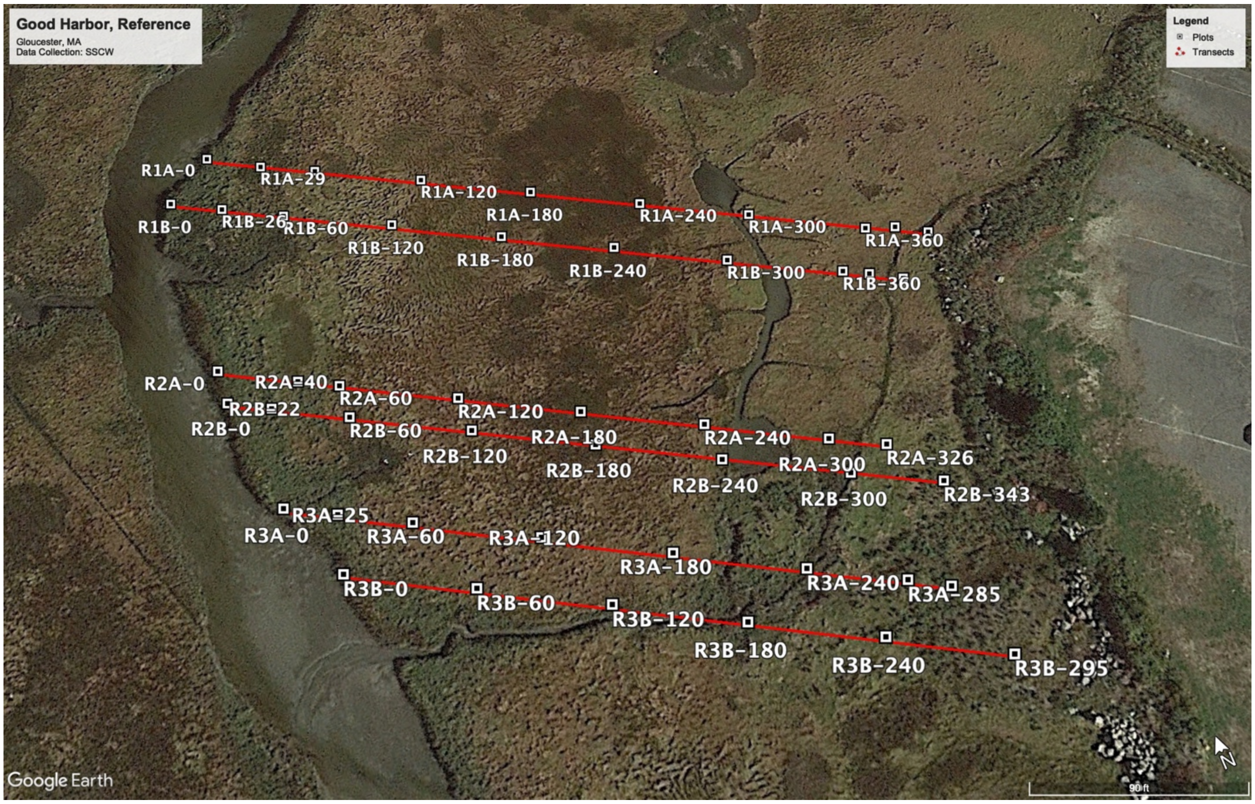

Figure A3: Vegetation plots at Good Harbor salt marsh reference site in Gloucester, MA. Transects labeled “R” represent the reference marsh to the Eastern Point study area.

Little Neck, Ipswich, MA

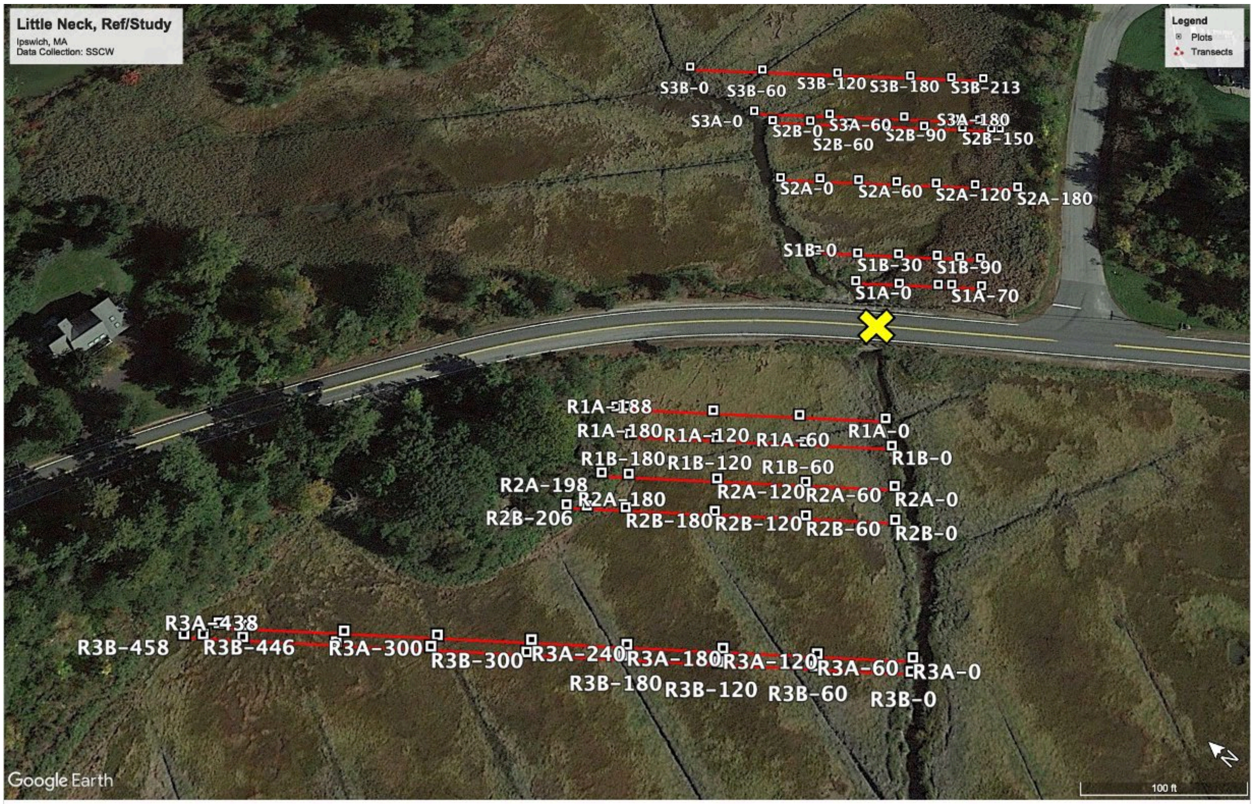

Figure A4: Vegetation plots at Little Neck salt marsh restoration site in Ipswich, MA. Transects labeled “R” represent the reference marsh, while transects labeled “S” represent the study marsh. The yellow X represents the location of the former tidal restriction.

Mill River, Gloucester, MA

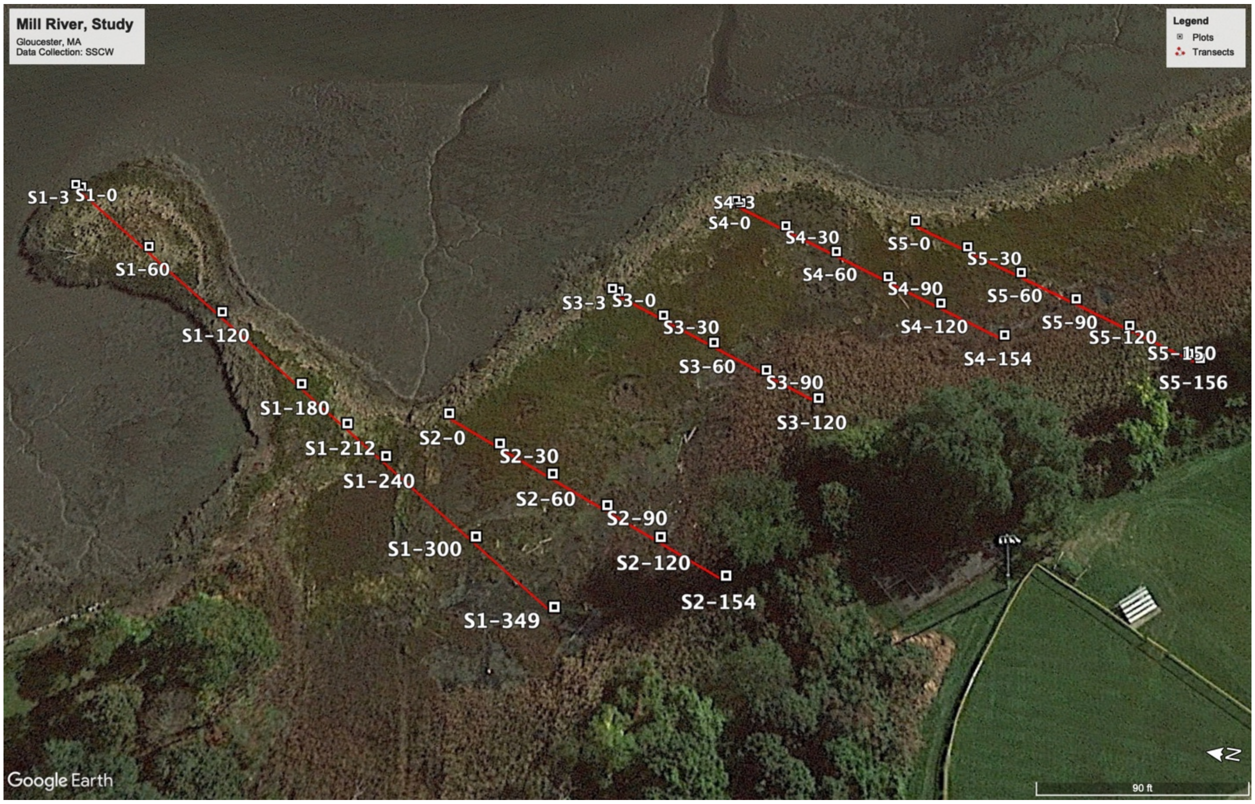

Figure A5: Vegetation plots at Mill River salt marsh restoration site in Gloucester, MA. Transects labeled “S” represent the study marsh. Mill River did not have a corresponding reference marsh. The former tidal restriction was a tide gate north of the marsh area.

Newman Road, Newbury, MA

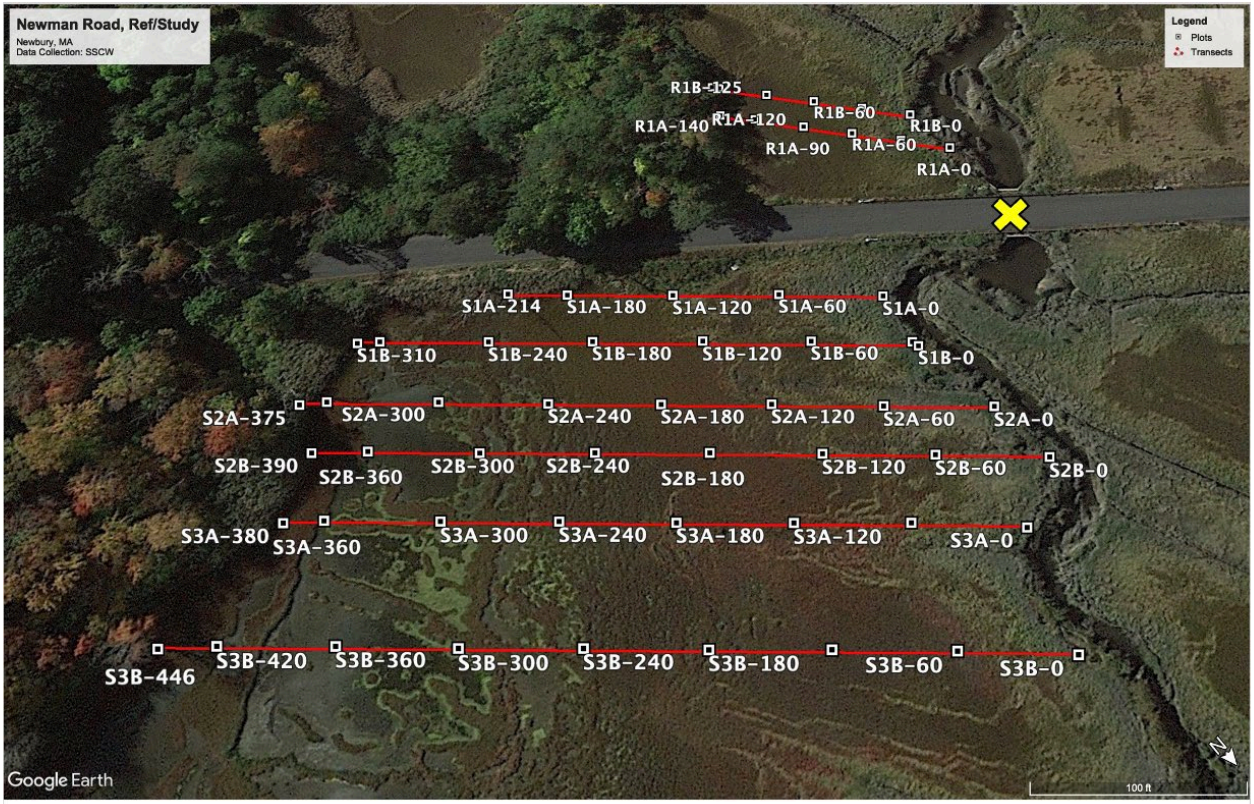

Figure A6: Vegetation plots at Newman Road salt marsh restoration site in Newbury, MA. Transects labeled “R” represent the reference marsh, while transects labeled “S” represent the study marsh. The yellow X represents the location of the former tidal restriction.

APPENDIX B: Master Species List

Species Name	Type	Conomo Point	Eastern Point	Good Harbor	Little Neck	Mill River	Newman Road
Achillea millefolium	non-halophyte	X	X				
Agalinis maritima	halophyte		X	X	X		
Agropyron pungens	halophyte	X	X	X	X		
Agropyron repens	halophyte		X			X	
Agrostis alba	non-halophyte						X
Agrostis stolonifera	non-halophyte		X	X			X
Amaranthus cannabinus	non-halophyte						X
Ambrosia artemisiifolia	non-halophyte		X	X			
Anagallis arvensis	non-halophyte		X				
Artemisia vulgaris	non-halophyte		X				
Atriplex patula	halophyte	X	X	X	X	X	X
Atriplex sp.	halophyte		X				
Bolboschoenus robustus	non-halophyte	X		X			X
Calystegia sepium	non-halophyte	X	X	X			
Celastrus orbiculatus	non-halophyte	X	X				
Celastrus scandens	non-halophyte			X			
Chamaecyparis thyoides	non-halophyte	X					
Chenopodium rubrum	non-halophyte			X			
Convolvulus sepium	non-halophyte		X				
Cruciferae	non-halophyte		X	X			
Daucus carota	non-halophyte		X				
Distichlis sp.	halophyte	X					
Distichlis spicata	halophyte	X	X	X	X	X	X
Eleocharis rostellata	non-halophyte	X					
Festuca rubra	non-halophyte	X			X		
Galium tinctorium	non-halophyte		X				
Glaux maritima	halophyte			X	X		
Hierochloe odorata	non-halophyte		X				
Impatiens capensis	non-halophyte		X				
Iva frutescens	halophyte	X	X	X	X		X
Juncus balticus	halophyte	X					
Juncus gerardii	halophyte	X	X	X	X	X	X
Limonium nashii	halophyte		X	X	X	X	
Linaria vulgaris	non-halophyte			X			
Lythrum lineare	non-halophyte				X		
Lythrum salicaria	non-halophyte		X				X
Myrica gale	non-halophyte			X			
Myrica pensylvanica	non-halophyte			X	X		
Oxalis stricta	non-halophyte			X			

Panicum virgatum	halophyte	X		X			
Parthenocissus quinquefolia	non-halophyte		X				X
Persicaria arifolia	non-halophyte	X					
Phragmites australis	non-halophyte	X	X	X	X	X	X
Plantago maritima	halophyte			X	X		
Pluchea odorata	halophyte				X	X	
Polygonum punctatum	non-halophyte		X				
Polygonum sp.	non-halophyte		X				
Potentilla anserina	non-halophyte						X
Ptilimnium capillaceum	non-halophyte		X				
Puccinellia maritima	halophyte		X	X			
Ranunculus cymbalaria	halophyte		X				
Rhus hirta	non-halophyte			X			
Rosa multiflora	non-halophyte	X					
Rosa palustris	non-halophyte	X					
Rosa rugosa	non-halophyte		X				
Rubus sp.	non-halophyte			X			
Rumex crispus	non-halophyte		X				
Salicornia europaea	halophyte	X	X	X	X	X	X
Salicornia sp.	halophyte			X	X		
Salicornia virginica	halophyte		X	X	X		
Schoenoplectus americanus	non-halophyte						X
Schoenoplectus pungens	non-halophyte	X			X		X
Setaria geniculata	non-halophyte	X					
Solidago sempervirens	halophyte	X	X	X	X	X	X
Spartina alterniflora	halophyte	X	X	X	X	X	X
Spartina patens	halophyte	X	X	X	X	X	X
Spartina pectinata	non-halophyte	X	X		X		
Spergularia marina	halophyte			X			
Suaeda linearis	halophyte	X	X	X	X	X	
Symphyotrichum sp.	halophyte				X		
Symphyotrichum tenuifolium	halophyte				X		
Teucrium canadense	non-halophyte		X				
Thelypteris thelypteroides	non-halophyte	X					
Toxicodendron radicans	non-halophyte	X	X	X	X		X
Triglochin maritimum	halophyte			X	X		
Triglochin striata	halophyte				X		
Typha angustifolia	non-halophyte						X
Upland grass	non-halophyte		X		X		X
Upland weed	non-halophyte		X				
Total number of species per site		**29**	**43**	**35**	**29**	**12**	**21**

Table B1: Master species list showing the marsh plant species and total number of species identified at each of the six marshes throughout the entire monitoring timeframe. Plants that were identified to the genus level were considered distinct from other identified species within that genus. While "unknown" species were not included in analysis, unidentified plants that indicated the zone in which it was found, such as "upland weed," were utilized in analysis.

APPENDIX C: Annual Species Richness

Overall Species Richness Discussion

General trends for annual species richness show a decline in non-halophytes in both the reference and study marshes, consistent with more frequent inundation by salt water (Fig. C1). All reference marshes (Conomo Point, Good Harbor, Little Neck, and Newman Road) showed an overall decline in the total number of non-halophytic species since monitoring began. Three out of five study marshes (Conomo Point, Eastern Point, and Newman Road) showed the same decreasing trend. Both the Little Neck and Mill River study marshes started with only one non-halophytic species and remained low, between 1-2 non-halophytic species, over the course of marsh monitoring. A general trend was not evident for halophytic species, though it's worth noting that all reference marshes had a higher species richness, and therefore a more diverse assemblage of halophytes, than their corresponding study marsh.

Species Richness Discussion by Site

Conomo Point, Essex

In 1999, the 7 species of non-halophytic plants that were reported in the Conomo Point study marsh included: *Eleocharis rostellata, Persicaria arifolia, Rosa multiflora, Schoenoplectus pungens, Spartina pectinata, Thelypteris thelypteroides, and Toxicodendron radicans*. In 2023, this number had dropped to just one species of non-halophyte, *Phragmites australis*. As mentioned in the Discussion, *Phragmites* was not present in the Conomo Point study marsh before culvert restoration, but after restoration it seems to have outcompeted other non-halophytes at the marsh edge.

While the number of halophytes has remained relatively stable over the monitoring period, the Conomo Point reference marsh had a consistently higher diversity of halophytic plants.

In 2023, *Agropyron pungens, Atriplex patula, Solidago sempervirens,* and *Suaeda linearis* were present in the reference marsh but absent in the study marsh.

Eastern Point and Good Harbor, Gloucester

Between 7-14 non-halophytic plants were present in the Eastern Point study marsh before restoration (2001-2003). This number sharply dropped to 3 non-halophytic species in 2004, following culvert restoration. Between 2004-2011 the number of non-halophytic plants remained stable, ranging from 0-3 species and including: *Agrostis stolonifera, Calystegia sepium, Convolvulus sepium, Phragmites australis, Spartina pectinata,* and *Toxicodendron radicans*. In 2023, the number of non-halophytes increased to 10 species (*Artemisia vulgaris, Calystegia sepium, Celastrus orbiculatus, Parthenocissus quinquefolia, Phragmites australis, Rosa rugosa, Spartina pectinata, Toxicodendron radicans*, "Upland grass," and "Upland weed"). Most of these species were reported in the "north" study area along the roadside where they receive enough freshwater runoff from the road to persist along the border of the marsh.

Following restoration of the Eastern Point culvert, halophytes displayed more diversity, increasing from 5 to 11 species. *Iva frutescens, Limonium nashii, Salicornia europaea, Spartina alterniflora,* and *Suaeda linearis* were recorded in the years following restoration but were not present in the preceding years (2001-2003). *Suaeda*, in particular, was observed in high abundance immediately following restoration. *Suaeda* is an early colonizer of disturbed areas and would have thrived in these conditions as the marsh changed drastically after the influx of salt water.

Halophyte diversity remained stable in the Good Harbor reference marsh (12-14 unique species), while no non-halophytes were recorded since 2004. The absence of non-halophytic plants could coincide with increasing sea level, as the transects end at the distinct transition from marsh to parking lot edge.

Little Neck, Ipswich

The number of non-halophytic species was low, with just one species before restoration of the Little Neck study area, and remained low through the final year of marsh monitoring. The number of halophytes also remained quite stable throughout the monitoring period, ranging in number from 9-11 species over the course of 22 years. While the diversity of halophytes in the Little Neck reference marsh also remained quite stable, it was typically more diverse than the study area with 12-16 unique species throughout the monitoring period.

Mill River, Gloucester

Phragmites was present in the Mill River study marsh throughout the monitoring period. Halophyte diversity declined since the opening of the tide gate, from 9 to 5 species. Halophytic species that were present for the first two years of monitoring but were not recorded during the final year of monitoring, included: *Atriplex patula, Limonium nashii, Solidago sempervirens,* and *Suaeda linearis*.

Newman Road, Newbury

The number of non-halophytic species in the Newman Road study area initially increased from 3 to 7 from 2010 to 2011, following culvert restoration, and then declined to 1 species in 2023. The only non-halophyte recorded in 2023 was *Phragmites*. The diversity of halophytes remained stable, at 7 species, in the Newman Road study marsh throughout the 14 years of monitoring.

In the Newman Road reference marsh, the abundance of non-halophytic species declined from two in 2010 to zero species in 2023. Several new halophytic species emerged in the reference marsh since 2010: *Iva frutescens, Juncus gerardii,* and *Salicornia europaea*.

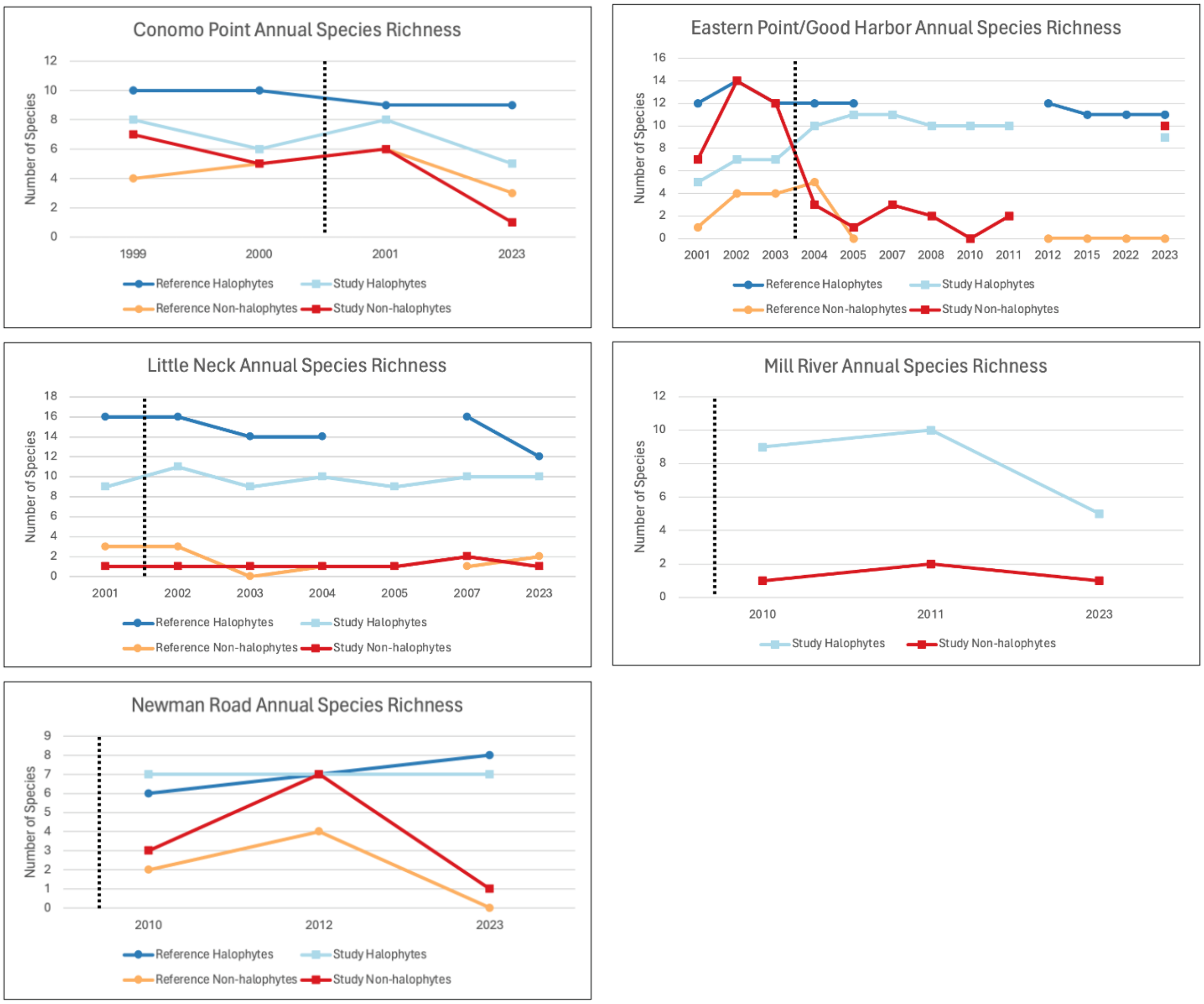

Figure C1: Annual species richness of marsh vegetation for the Reference and Study sites at each of the five monitored marshes. Good Harbor represents the Reference site for Eastern Point (Study). The dotted line indicates the approximate time of tidal restriction restoration. Analysis includes all marsh plots.

APPENDIX D: Salinity Monitoring Results

Overall Porewater Salinity Discussion

Following tidal restoration, an increase in salinity would be expected in the upstream ("study") marsh as a more natural tidal flow is restored. Therefore, we would expect the salinity in a successfully restored marsh to approach, if not equal, the salinity of the reference marsh.

The porewater salinity of three study sites (Eastern Point, Little Neck, and Newman Road) increased immediately following restoration (Fig. D1). These three sites experienced an average porewater salinity increase of 11ppt in the monitoring year directly following restoration. For three sites (Eastern Point, Little Neck, and Newman Road), the porewater salinity was typically higher in the reference marsh throughout the entire monitoring period. Throughout the monitoring timeframe, the reference marshes' porewater salinity was, on average, 7.2ppt higher than the study marsh. Conomo Point's study marsh, however, had a slightly higher salinity than its reference site. This coincides with the 1999 report that noted the study site had a higher salinity due to increased evaporation and reduced tidal flow (Kooken et al., 1999). Mill River did not have a representative reference site, so comparisons were not possible.

Salinity is intrinsically dependent on the tide and weather conditions on the day of sampling. Porewater salinity varied considerably over the monitoring timeframe, so overall conclusions must consider environmental conditions at the time of monitoring. The focus of the 2023 monitoring surveys was vegetation. Therefore, one salinity sample was collected at the midpoint of each vegetation transect for each evaluation area (i.e., typically 6 salinity measurements per evaluation area). Earlier surveys that focused solely on salinity sampled multiple areas up to five different days over the study season. Sample sizes for each evaluation site ranged from 2 to 52 unique samples per monitoring year. Additionally, during some monitoring years, salinity was taken but not vegetation data, so exact comparisons are difficult. Throughout the monitoring timeframe, two different methods were utilized to collect salinity: extracting porewater 1. from a permanent salinity well and 2. With a sipper. The following salinity results are representative of the available data, but considering the variation in collection methods, timing, sample size, and environmental conditions, these salinity results should only be used to supplement vegetation data and not to inform the overall success of tidal restoration. Due to the dynamic nature of salinity, continuous water monitoring loggers would provide more consistent and accurate information.

Figure D1: Average summer porewater salinity in the reference and study sites within each of the five monitored salt marshes. Good Harbor represents the reference site for Eastern Point (study). Salinity at the reference marshes was not sampled in 2007 and 2010. The dotted line indicates the time of tidal restoration.

APPENDIX E: Site background and observation notes

Reconnaissance Methods

In June 2023, Salem Sound Coastwatch staff revisited six salt marsh restoration sites that had been previously monitored, some as early as 1999, to inform salt marsh monitoring in August/September 2023. In preparation for each visit, SSCW staff reviewed maps, site information, and transect locations. At each site, SSCW took photos, noted species present (vegetation, avian, and invertebrate), located transects that were either marked physically with flagging tape or via GPS, and took note of existing salinity wells. General evaluations, such as the condition of the marsh and the culverts were also noted.

Observation Notes

Conomo Point, Essex, MA

Conomo Point Road salt marsh study site is in Essex, Massachusetts (Ipswich U.S.G.S. topographic map, 1:25,000). The study marsh is approximately one and a half acres surrounded by white cedars. Its culvert was replaced in October 2000. SSCW conducted baseline pre-restoration monitoring of nektons, water chemistry, macroinvertebrates, birds, and vegetation from 1999 through 2001. In 2007, post-restoration monitoring was completed for nektons, water chemistry, and vegetation.

On June 21, 2023, Salem Sound Coastwatch staff completed a reconnaissance of the marsh to visually assess the current condition from the road. Photos of the marsh and access to it were taken. SSCW would like to discuss with DER the continuation of monitoring this site. This site might be good to use drone flyover to monitor.

<u>Reference and Study</u>

- Unable to step into the marsh because of thick patches of poison ivy and multiflora rose along the road edge.
- Reference area photo (CP-ESX-20230621_115203.jpg) shows the lack of access from the road because of dense vegetation and shows scouring or dieback near the tree line.
- The upstream study area is fed by a small creek (CP-ESX-20230621_115459.jpg) with entrance restricted because of poison ivy
- Visual confirmation of degradation in the study area of the marsh was seen (CP-ESX-20230621_120325.jpg), for example, patchiness in vegetation, large mud flats, and thick multiflora rose and *Phragmites* at roadside.

- On the left side of the marsh, visual confirmation of *Phragmites* stands throughout.

Eastern Point, Gloucester, MA

The Gloucester study site is on the tip of Eastern Point, Gloucester, MA, next to a Coast Guard Station and Eastern Point Lighthouse (Gloucester U.S.G.S. topographic map, 1:25,000). The site is part of a Massachusetts Audubon Society sanctuary, which encompasses approximately 53 acres. The salt marsh is approximately 5 acres in size and separated from a cove of Gloucester Harbor by a narrow, paved road, the end of Eastern Point Boulevard. The salt marsh is bounded by this road on the west, a freshwater marsh (approx. 2.5 acres) to the north, the driveway to the Coast Guard house to the south, and a rock barrier beach on the easterly ocean side.

The No-Name Storm of 1993 blocked tidal flow into the marsh when it filled the culvert with cobbles. The marsh became severely degraded. During the three summers of 2001-2003, SSCW and its volunteers collected pre-restoration baseline data for the Eastern Point salt marsh. In response to the degradation, Massachusetts Audubon Society, NOAA Community-based Restoration Program, Massachusetts Wetlands Restoration Program, and several supporting agencies, local government and businesses combined efforts to install a new box culvert and driveway culvert in November 2003. A small channel between the two culverts was opened to connect the salt marsh to tidal flow from the harbor. Post-restoration monitoring results in 2004, 2005, and 2007 showed that the Eastern Point salt marsh degradation had stopped. Tidal inundation was restored; although at normal high tides, tidal flow still measures within the "significantly restricted" category (51-70%) (tidal range: 2005=50.65%; 2004=51.63%). It took approximately five hours of incoming tide before water began flowing through the harbor side culvert into the salt marsh. High tide waters flow into the marsh for an hour to an hour and half. Thirty to twenty minutes after high tide, the water begins flowing back out of the salt marsh. This means the salt marsh receives salt water for an hour or two every twelve-hour tidal cycle. The marsh may not become inundated on neap tides, but there is extensive inundation on spring tides. This may be the best-case scenario for this salt marsh since it is separated from the harbor by elevation and a road.

SSCW has conducted baseline pre-restoration monitoring from 2001 through 2003 and post-restoration in 2004 and 2005 for tidal influence, birds, nektons, water chemistry, vegetation, and macroinvertebrates. In 2007, nektons, water chemistry, vegetation, and macroinvertebrates were sampled.

On June 15, 2023, Salem Sound Coastwatch staff completed a reconnaissance of the marsh to visually assess the current condition and review transect and quadrat locations in preparation for vegetation monitoring in FY24. The transects were located at the creek edge, marked, and GPS located. Photos of various aspects of the marsh were taken.

The channel that provides tidal flow between the marsh and the harbor needs to be investigated. Photos were taken to show the thick growth of *Spartina alterniflora* and sedimentation.

East Side of Marsh

- Cobble barrier beach has moved into the marsh.
- Foot traffic for fishing has created a path from the driveway to the ocean along the edge of the marsh.
- *Phragmites* appears to have receded since 2007, but this will need to be verified by vegetation monitoring
- Ditches at 46’, 88’, 141’ (pool) 196’, 252’.
- SSCW salinity wells were found at 252’ and at 263’. Mass Audubon wells are also in the marsh.

North Side of Marsh (closest to the road)

- SSCW began monitoring the north side after restoration of the culvert, November 2005. Previously, the area was mostly poison ivy and *Rosa rugosa*.
- Marsh platform stable with low marsh, *Spartina alterniflora,* at the creek edge and *Distichlis spicata* and *Spartina patens* away from the creek edge. Some patches of *Juncus gerardii* were found.
- The original culvert that was clogged is free of cobbles, but it is not clear if ocean water is entering this way now.
- Ditch at 101’ and 235’

Good Harbor, Gloucester, MA

The Gloucester reference site is located behind Good Harbor Beach, Gloucester, MA off Route 127A (Gloucester U.S.G.S. topographic map, 1:25,000). A tidal stream flushes this marsh and exits to the Atlantic Ocean at the southeastern end of Good Harbor Beach. Route 127A loops around the marsh west to north. Good Harbor Beach is located to the east of Route 127A, and a residential area is south of the marsh. Downstream of the sampled area, a small pedestrian bridge crosses the tidal creek but does not inhibit tidal flow. A berm on the eastern edge of the salt marsh offers some protection from the beach parking lot. The wetland evaluation area comprises a small part of the larger salt marsh system.

On June 22, 2023, Salem Sound Coastwatch staff were joined by DER staff to complete a reconnaissance of the marsh to visually assess the current condition and review transect and quadrat locations in preparation for vegetation monitoring in FY24. The transects were located at the water’s edge and wells were located. Photos of various aspects of the marsh were taken.

- Marsh has evidence of erosion close to the creek and had areas of die back on the bank edge (GH-GLO-20230622_101305.jpg).
- In comparison to past evaluation, it is evident that the creek/ditches have widened (GH-GLO-20230622_103656.jpg).
- Multiple rebar stakes have been lost, which are used as spatial markers to measure Saratoga Creek erosion (GH-GLO-20230622_100413.jpg).
- In general, marsh continues to have a diversity of salt marsh species with low, high, and border zones, including *Distichlis spicata, Spartina patens, Juncus gerardii,* and short and tall forms of *Spartina alterniflora, Suaeda linearis, Plantago maritima, Limonium nashii,* and *Iva frutescens*.
- Located two wells; one on transect 3B where there has always been pooling and black algal mats (mosquitoes); extent seemed smaller but will evaluate in the fall (GH-GLO-20230622_104804.jpg)
- Wrack on top of the *Iva frutescens* (high tide bush) at the border edge of the marsh, also saw the top branch dieback seen in other marsh; probably from the cold snap last winter (2023, minus 20°F).
- *Salicornia* found throughout the marsh where there had been a vegetation disturbance.
- Sentential rock for photo-documentation at border where we enter the marsh (GH-GLO-20230622_111038.jpg)
- Examined the "Rising Sea" monitoring that SSCW is conducting at the pools/panne complex (GH-GLO-20230622_094718.jpg) and the raised mound (GH-GLO-20230622_095029.jpg)

Little Neck, Ipswich, MA

The Little Neck Road salt marsh site is located on Great Neck in Ipswich, Massachusetts (Ipswich U.S.G.S. topographic map, 1:25,000). This extensive marsh system is fed by Neck Creek and located in a low-density residential coastal area. Little Neck Road, a two-lane paved road, separates the study site from the larger reference marsh to the southwest. The study marsh is surrounded by topographically elevated areas on three sides and is approximately 6-acres in size, significantly smaller than the 100-acre reference marsh. The reference site was selected to be the North Shore reference for vegetation because it represents "best obtainable" conditions for the same type of wetland. Data collected at the reference site may be used for baseline comparisons with North Shore salt marsh study sites.

SSCW and its volunteers began collecting data at both these sites in 1999. At that time, the Little Neck Road culvert was in disrepair. It eventually collapsed in 2001 and was replaced in June of that year but not until fresh water inundated the marsh for most of the spring. Therefore, vegetation continued to be impacted by fresh water in the 2001 growing season.

SSCW conducted baseline pre-restoration monitoring from 1999 through 2001 and post-restoration in 2002 and 2003 for tidal influence, birds, macroinvertebrates, nektons, water chemistry, and vegetation. In 2004 and 2005, only vegetation was sampled. In 2007, nektons, water chemistry, and vegetation were monitored at the study and reference sites.

On June 21, 2023, Salem Sound Coastwatch staff completed a reconnaissance of the marsh to visually assess the current condition and review transect and quadrat locations in preparation for vegetation monitoring in FY24. The transects were located at the water's edge, marked, and GPS located. Photos of various aspects of the marsh were taken.

Reference – Downstream (LN-IPS-20230621_110616.jpg)

- Scouring by the culvert with Salicornia in the dieback
- Wrack on roadside and against the tree line (LN-IPS-20230621_111813.jpg)

Study - Upstream

- Saw mink at culvert (LN-IPS-20230621_103920.jpg)
- Marked the beginning of each transect and had tape follow the creek
- Near road and on elevated sections, *Iva frutescens* with die-off of top branches
- Three large ditches across the marsh, some difficult to cross over; looks like the largest one had recently been dug or edged. (LN-IPS-20230621_110543.jpg)
- Small pools; short form *Spartina alterniflora*.
- Mid-marsh vegetation a mix of *Distichlis spicata, Spartina patens,* and short form *Spartina alterniflora* on the high marsh platform; occasional *Juncus gerardii*
- *Limonium nashii (*sea lavender) present (LN-IPS-20230621_111313.jpg)
- Salinity wells present throughout the marsh, along with multiple PVC pipe markers

Mill River, Gloucester, MA

The Gloucester Mill River follows in a northerly direction into the Annisquam River, which flows into Ipswich Bay. The portion of the Mill River southeast of Washington Street (Rt. 127) has been "ponded" 1677. A tide gate installed in 1989 during the re-construction of Washington Street created a severe tidal restriction impounding the Mill River. Properties around the pond experienced flooding.

The resulting Mill Pond wetland system was freshwater dominated, had extensive stands of Phragmites australis, obstructed ditches, and accumulations of fine sediment extending from Washington Street to north of Dr. Osman Babson Road. Downstream of the Washington Street Bridge, the Mill and Annisquam Rivers are open to shellfish harvesting. Upstream, the Mill River flows from the Babson Reservoir, which provides the City of Gloucester drinking water.

Beginning in April 2004, the Washington Street tide gate was left in an open position to restore partial tidal flow to approximately 30 acres and improve ecological conditions within Mill Pond, now referred to as Mill River. In 2011, the tide gate system was modified with the addition of two more tide gates.

On June 15, 2023, Salem Sound Coastwatch staff completed a reconnaissance of the marsh to visually assess the current condition and review transect and quadrat locations in preparation for vegetation monitoring in FY24. The transects were located at the water's edge, marked, and GPS located. Photos of various aspects of the marsh were taken.

- Entered the marsh through the property of Lois Barstow, as we had in the past. When asked about any changes, she said there was more flooding (not of their home) but was not sure if it had to do with the tide gate openings or climate change. Woodcock had been nesting in the *Phragmites*.
- Need to come 2 hours before low tide to safely access the marsh
- Very buggy, mosquitoes, and hot. Recommend coming when it is cooler and windy
- The peninsula has changed: erosion at river edge (MR-GLO-20230615_145430.jpg); *Phragmites* retreated to 305' (MR-GLO-20230615_145444.jpg). There is a lot of pooling and *Salicornia* at the landward edge (MR-GLO-20230615_145857.jpg).
- Transects T2-T5 marked at river edge with orange flagging pins.
- Large areas of *Phragmites* wrack on the marsh
- A lot of trash on the marsh platform and in the *Phragmites,* in desperate need of cleanup.
- Multiple horseshoe crabs, both dead and molts, were found on site.
- Excessive bank erosion (slump), as well as multiple crab burrows (green crabs?)
- Looks like some kind of monitoring platform might be in the marsh (MR-GLO-20230615_151721.jpg). Should discuss marsh with Conservation Agent.

Newman Road, Newbury, MA

Newman Road crosses a tidal creek and restricts tidal flow to approximately 40 acres of degraded upstream salt marsh. Located in Newbury, Massachusetts, the site can be located on the Newburyport U.S.G.S. topographic map, 1:25,000. This extensive marsh system is fed by a tributary of Little River and located in a low-density residential area. A Wetland Restoration Priority Site, marsh restoration was in the permitting and funding phase when SSCW began monitoring. Replacement of the existing, undersized 4-foot diameter pipe culvert was permitted to restore tidal hydrology to upstream habitats. SSCW 2007 monitoring of nektons, water chemistry and macroinvertebrates provided baseline *pre-restoration data. The property is owned by The Trustees for Reservations:* old-town-hill-trailmap.pdf (thetrustees.org)

On June 21, 2023, Salem Sound Coastwatch staff completed a reconnaissance of the marsh to visually assess the current condition and review transect and quadrat locations in preparation for vegetation monitoring in FY24. The transects were located at the water's edge and GPS located. Photos of various aspects of the marsh were taken. Both sides of Newman Road were monitored, downstream, the "reference," and upstream, the "study."

Reference – Downstream (NR-NEW-20230621_090242.jpg)

- Road edge vegetation: *Juncus gerardii, Iva frutescens, Solidago sempervirens*
- Lush, thick, tall *Spartina alterniflora* at the creek edge
- *Distichlis spicata* and *Spartina patens* away from the creek edge.
- Small pool with Salicornia and short form *Spartina alterniflora*

Study - Upstream

- Creek bank erosion, creek is deep, bank edges are slumping (NR-NBY-20230621_092420.jpg)
- Appears that there might have been some ditch filling; talk to The Trustees of Reservations to learn what they are doing with this section of their marsh;
- Met TTOR bird monitor who reported seeing 5 salt marsh sparrows; we flushed out one from the creek bank tall *Spartina alterniflora*.
- Very wet at the back of the marsh, with a lot of holes throughout, tricky walking. Pooling towards the tree line, with a large buildup of bacteria present and mosquitoes; mainly short form *Spartina alterniflora* (NR-NBY-20230621_100543.jpg)
- Mid-marsh vegetation a mix of *Distichlis spicata, Spartina patens,* and short form *Spartina alterniflora* on the high marsh platform; occasional *Juncus gerardii* (NR-NBY-20230621_093743.jpg)
- Found one dead fiddler crab and mud snails

APPENDIX F: Photodocumentation

Conomo Point, Essex


Image F1: Pool of standing water in study marsh


Image F2: Muddy die-back areas in reference marsh


Image F3: Expanding creek width at reference marsh


Image F4: Clear and unobstructed culvert at reference marsh

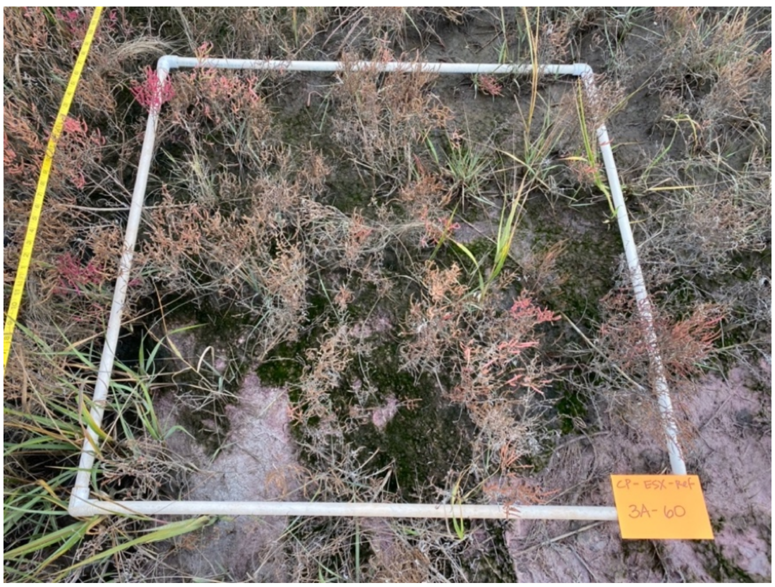

Image F5: Increasing *Salicornia* and mud on high marsh

Eastern Point, Gloucester

Image F6: Blocked culvert leading to restored marsh

Image F7: Cobble on restored marsh from storms

Good Harbor, Gloucester

Image F8: Marsh platform collapse at Good Harbor reference marsh

Image F9: Rebar stake that was once on marsh platform, located in creek

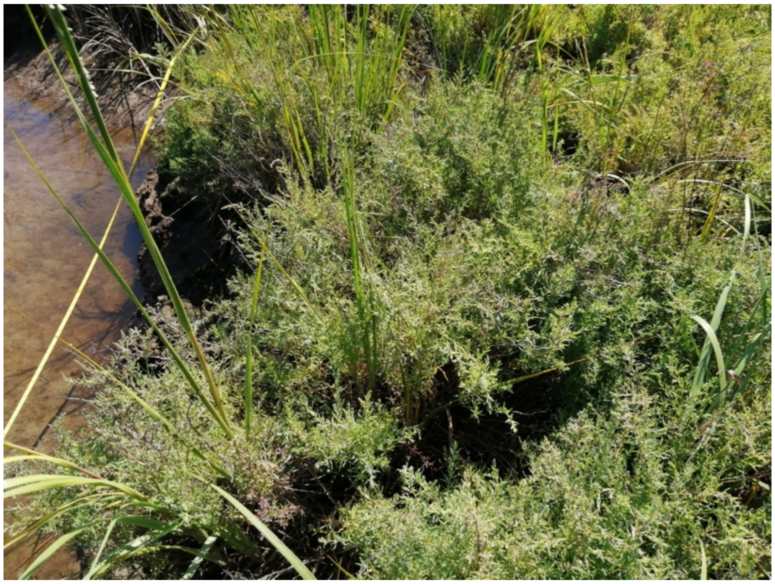

Image F10: *Suaeda linearis* along creek bank

Little Neck, Ipswich

Image F11: Little Neck culvert

Image F12: *Iva frutescens* along bank edge in study area

Mill River, Gloucester

Image F13: Ponding in high marsh

Image F14: Erosion and die-back of marsh edge

Image F15: Excessive wrack and debris on Mill River marsh

Newman Road, Newbury

Image F16: Ponding of water in Newman Road study area

Image F17: Slumping of creek bank at Newman Road study site