Final Report

Stewart's Creek
Year 5 Monitoring Report

March 2019

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Table of Contents

List of Figures

List of Tables

1.0 INTRODUCTION/PURPOSE

This report summarizes the year 5 monitoring work completed in 2018 by Woods Hole Group at Stewart's Creek, marking the fifth year since the box culvert was constructed by the U.S. Army Corp of Engineers (USACE) in 2013. After restoring Stewart's Creek by replacing the dilapidated, undersized culvert with a larger box culvert, the Town of Barnstable (Town) was tasked with monitoring the restoration of Stewart's Creek for a five (5) year period. Woods Hole Group previously conducted monitoring in 2015, which was the first round of post-construction monitoring. The monitoring was focused on evaluating the performance of the Stewart's Creek project, and determining:

- What have been the effects of the project?
- What additional estuary response may occur?
- Has the project performed as expected?
- What complementary actions should be taken to enhance project performance?

In addressing these questions, the data collected in 2015 also advanced monitoring protocols in the operations and maintenance (O&M) plan. These data included tide and salinity measurements, vegetation surveys, sediment sampling and testing, benthic invertebrate sampling and sorting, and elevation surveys within the marsh system. The results of the monitoring, analysis, and recommendations were published in a 2016 Phase II Report.

In 2018, the Town is completing the 5-year monitoring program for Stewart's Creek to assess the status of the restoration. Monitoring data from 2018 and 2015 help to evaluate what additional restoration has taken place, and to assess whether the project is advancing the original project goals, primarily to restore estuarine habitat. Based on the results of the year 5 post-construction monitoring, the following general summary statements can be made:

- The culvert replacement project has restored tidal flow and salinity to the intertidal portion of Stewart's Creek marsh system; however, high tides do not inundate the marsh plain on a regular basis.

- Topographic survey data indicate limited localized erosion of the intertidal and subtidal areas occurred along with the establishment of a shallow flow channel; however, there remains a significant layer of fine (muddy) sediments throughout much of the system. There also is a flood shoal upstream from the culvert.

- A more rich and abundant estuarine benthic community established along with a more vibrant estuarine habitat for fish, birds, and other wildlife.

- Stands of invasive *Phragmites* have not been stunted or converted to native saltmarsh species since there is not inundation and penetration of salt water to the marsh plain even during high tides. Eradication/reduction of *Phragmites* will require active intervention addressed in a management plan being developed in parallel with this monitoring report.

- The overall goal of restoring estuary habitat advanced, but not to the level of stakeholder expectations for *Phragmites* retreat, colonization of native saltmarsh species, or flushing of fine (muddy) sediments.

This work was completed in cooperation with the Town of Barnstable Public Works Department Survey Team to obtain elevation data and with the Cape Cod Conservation District (CCCD) to obtain vegetation, pore water, and benthic samples. CCCD also completed an independent report detailing their work and analysis, which is found in Attachment B.

2.0 YEAR 5 POST-CONSTRUCTION FIELD DATA AND ANALYSIS

A year-5 post-construction monitoring survey was conducted in 2018 at Stewart's Creek (Figure 1) to provide data for comparison against the 2013 pre-construction monitoring data, as well as the prior year-2 (2015) post-construction monitoring. The monitoring effort included measurements/sampling of tides, salinity, vegetation, topography, and benthic communities. The monitoring also included sampling at the reference site, Hall's Creek shown in Figure 1, originally established by the USACE and located about a mile west of Stewart's Creek.

Figure 1. Overview of Stewart's Creek (outlined red) and the reference site Hall's Creek (outlined yellow).

2.1 TIDE AND SALINITY MONITORING

Historically, Stewart's Creek was an estuarine system, but since Ocean Avenue became a closed causeway in the 1880's, Stewart's Creek had very limited tidal action, and had mostly been a freshwater impoundment until 2013. As part of the year 2 (2015) post-construction monitoring, Woods Hole Group collected water surface elevation (tide), salinity, and temperature measurements at one (1) location outside of and three (3) locations within Stewart's Creek (Figure 2) to characterize the restored tidal regime throughout the system. The 2015 results showed that tidal action has been restored to the Creek where the water level fluctuated between 1 and 1.5 ft every tide cycle in the main basin (above the culvert), which dampens to 0.5 and 1 ft in the tidal creek upstream toward the golf course. At low tide, the main stem of the creek and basin are still flooded, but the eastern cove has gone dry; a trend also noted by the residents living there. of the tidal signal from Lewis Bay into Stewart's Creek.

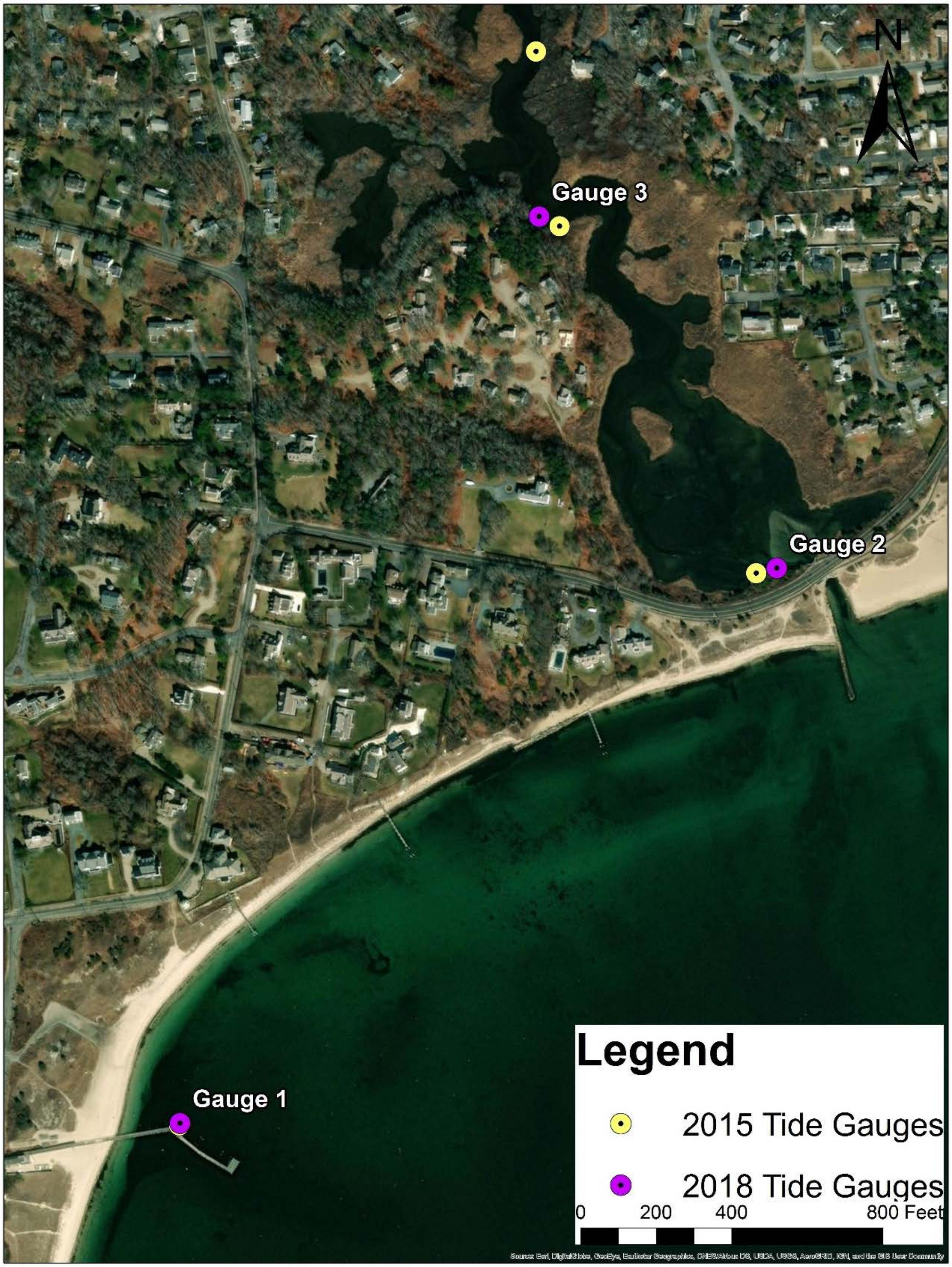

Figure 2. Tide, salinity, and temperature monitoring locations.

The restored tidal prism within Stewart's Creek, the volume of water exchanged between mean low water and mean high water, was reported to be approximately 429,000 ft^3 in the Phase II Report (2016). Salinity in Stewart's Creek also fluctuated between nearly salty ocean water to nearly fresh water on most tide cycles. These tide and salinity characteristics reflect those of an estuarine system; thus, one of the purposes of the project had been advanced. The 2015 measurements and analysis indicated that while tidal flow had been restored to a significant portion of the Creek, the box culvert still attenuated almost half

The Phase II Report (2016) showed the full tidal range from the Sound had not been fully restored to Stewart's Creek, nor was it expected. Tides in Lewis Bay typically fluctuated between 2 and 3 ft, with higher tides typically 0.5 ft higher and lower tides typically 1 ft lower than Stewart's Creek, respectively. The USACE pre-project analysis anticipated the new culvert would restore tidal action to Stewart's Creek. Their pre-project analysis predicted high tide elevations within Stewart's Creek to within 0.2 ft of the post-project measurements presented herein. Low tide elevations were anticipated to be approximately 0.7 ft lower. Thus, the actual tide levels measured within Stewart's Creek were fluctuating less than expected, but mostly at low tides (i.e., the pre-project USACE predictions suggested the tide level would fall lower at low tide). The difference may be due to uncertainty in the analysis, and also may be affected by accumulation of vegetation on the debris racks observed to limit drainage of water from the system at low tides. Overall, tidal activity has been restored to Stewart's Creek, but is attenuated compared to the Nantucket Sound/Lewis Bay tides.

For the 2018 (year 5) monitoring, water surface elevation (tide), salinity, and temperature field data were collected again to measure further changes to the Stewart's Creek tide or salinity regimes in the last three (3) years since the 2015 measurements. For the current monitoring program, instruments were deployed at one (1) location outside of and two (2) locations within Stewart's Creek (Figure 2), which are approximately at the same locations during the 2015 deployment. Gauge 1 (harbor) was deployed, with permission, off a piling at the Hyannis Port Yacht Club to capture the exterior forcing tides for Stewart's Creek from within Lewis Bay; this was the same location as in 2015. Gauge 2 (main basin) was deployed within the lower basin of Stewart's Creek in the tidal creek bed just upstream of the flood tidal pool to capture the tide signal that immediately enters the Stewart's Creek system; this location was located approximately 55 ft downstream of Gauge 2 in 2015. Gauge 3 (tidal creek) was deployed upstream in the tidal creek portion of Stewart's Creek adjacent to the Harbor Village Cottages to capture the tide that propagates up through the creek from the main basin; this location was slightly upstream of 2015. A tide gauge was not deployed at the 2015 upstream location for #4 during this round of monitoring since it was determined there was no significant difference in measurements between the two upstream gauges in 2015.

The instruments deployed were all In-Situ AquaTROLL 200s that incorporate pressure, conductivity, and temperature sensors to accurately calculate water depth, salinity, and temperature; these are the same model instruments that were deployed in 2015. The instruments were deployed from August 13 through September 12, 2018 for a period of 30 days, capturing a full lunar tide cycle (27.3 days). The instruments were synchronized with a universal clock and programmed to autonomously record a time-stamped data point every 6 minutes during the deployment period. The elevation of each instrument was surveyed by Woods Hole Group using a Trimble R8 RTK GPS to reference the water level records to a common vertical datum (NAVD88-ft). Upon recovery of the instruments, the data were downloaded, checked for accuracy, and processed with a 100% data return. The pressure data recorded by the AquaTROLLs was corrected for atmospheric pressure changes using a meteorological data record for the time period from the Barnstable Municipal Airport. The data provide direct insight into how the tide propagates from Nantucket Sound/Lewis Bay through the new Stewart's Creek culvert under Ocean Avenue, and within the Stewart's Creek system.

Figure 3 illustrates the time series of water surface elevation (top), salinity (2nd panel), and temperature (3rd panel) measured in Stewart's Creek along with rainfall (bottom) recorded at the Barnstable Municipal Airport (KHYA). Rainfall values taken from the meteorological data record for Barnstable Municipal Airport were added to identify precipitation events that could influence water levels in the creek. The top panel of Figure 3 shows the modulated neap and spring tidal cycle over the course of the month-long measurement period as the phase of the moon evolves. The plot also illustrates there is attenuation of the tide between Lewis Bay (black line) and Stewart's Creek (blue and red lines), but once the tide enters the system there is little dampening of the high tide between Gauges 2 and 3. The plot also demonstrates the alternating higher high and lower high tides that occur each day (known as the *diurnal inequality*). In addition, the salinity data shows salinity within Stewart's oscillates from salt water (32 ppt around high tides) to nearly fresh water (0 ppt around low tides) on every tidal cycle. This result indicates that even though tides have been restored to the system, there is still significant freshwater input to the system from runoff, groundwater, and/or upstream inputs.

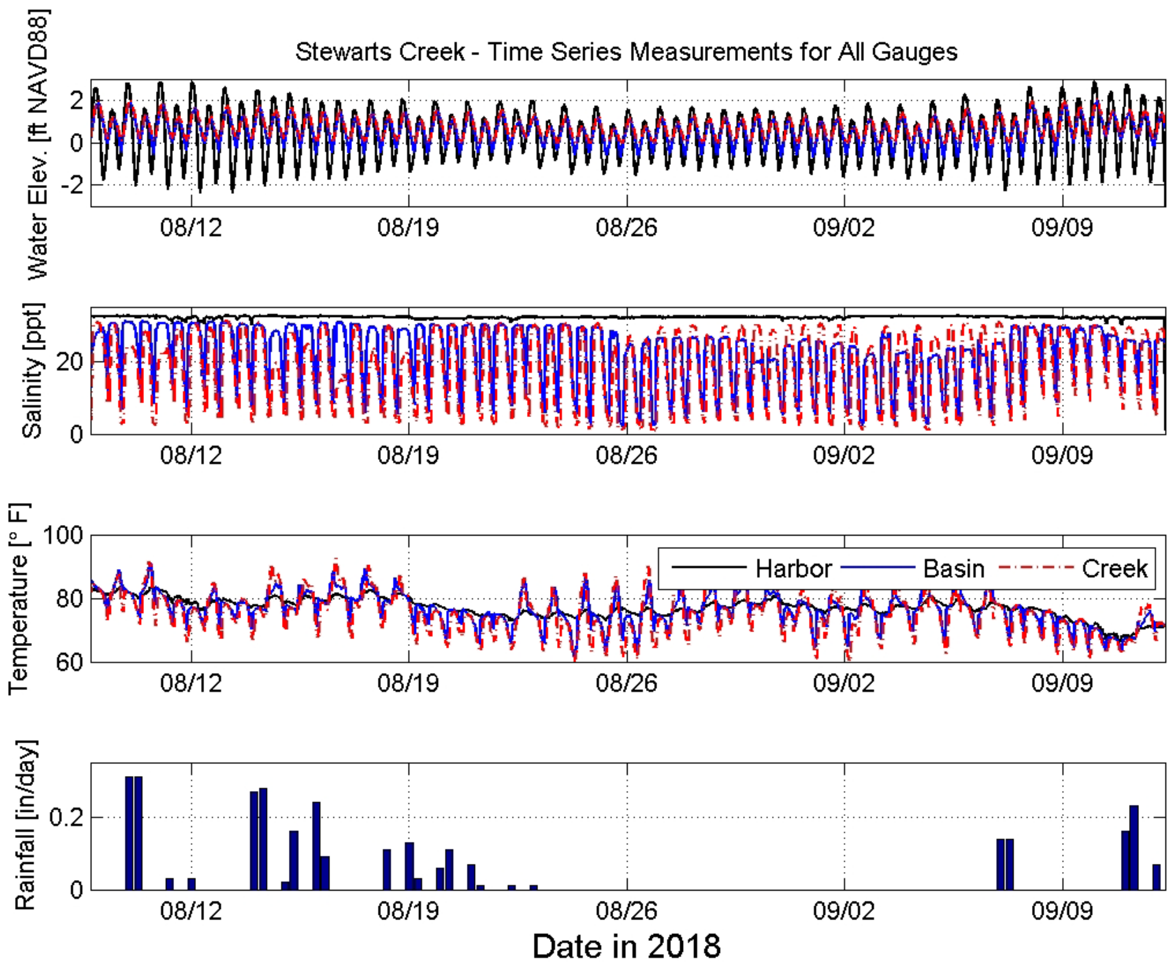

Figure 3. **Times series measurements showing water surface elevation (top), salinity (second), temperature (third), and rainfall (bottom) at the three monitoring locations at Stewart's Creek including Lewis Bay (black), main basin of Stewart's Creek (red), and tidal creek (blue).**

Greater insight into the tidal dynamics within the Stewart's Creek system is revealed through examination of the measured time series data over a shorter period of time. Figures 4 and 5 illustrate a 2-day sample zoom view of the water surface elevation and salinity time series data during a representative spring and neap tide, respectively. Figures 4 and 5 show that during both spring and neap tides there is significant attenuation of the high tide from Lewis Bay (black line) to Stewart's Creek (blue and red lines). There is a reduction of peak water surface elevation at high tides and a delay in the time high tide occurs (phase lag) within the system. Although the elevation of high tide matches well at the three locations within Stewart's Creek, the elevation of low tide increases within the system. Salinity oscillates from nearly saltwater, 30 ppt, to brackish or even freshwater conditions with each change of the tide. During Spring tides, the salinity at low tide remains brackish (5-15 ppt), an becomes nearly fresh during neap tides.

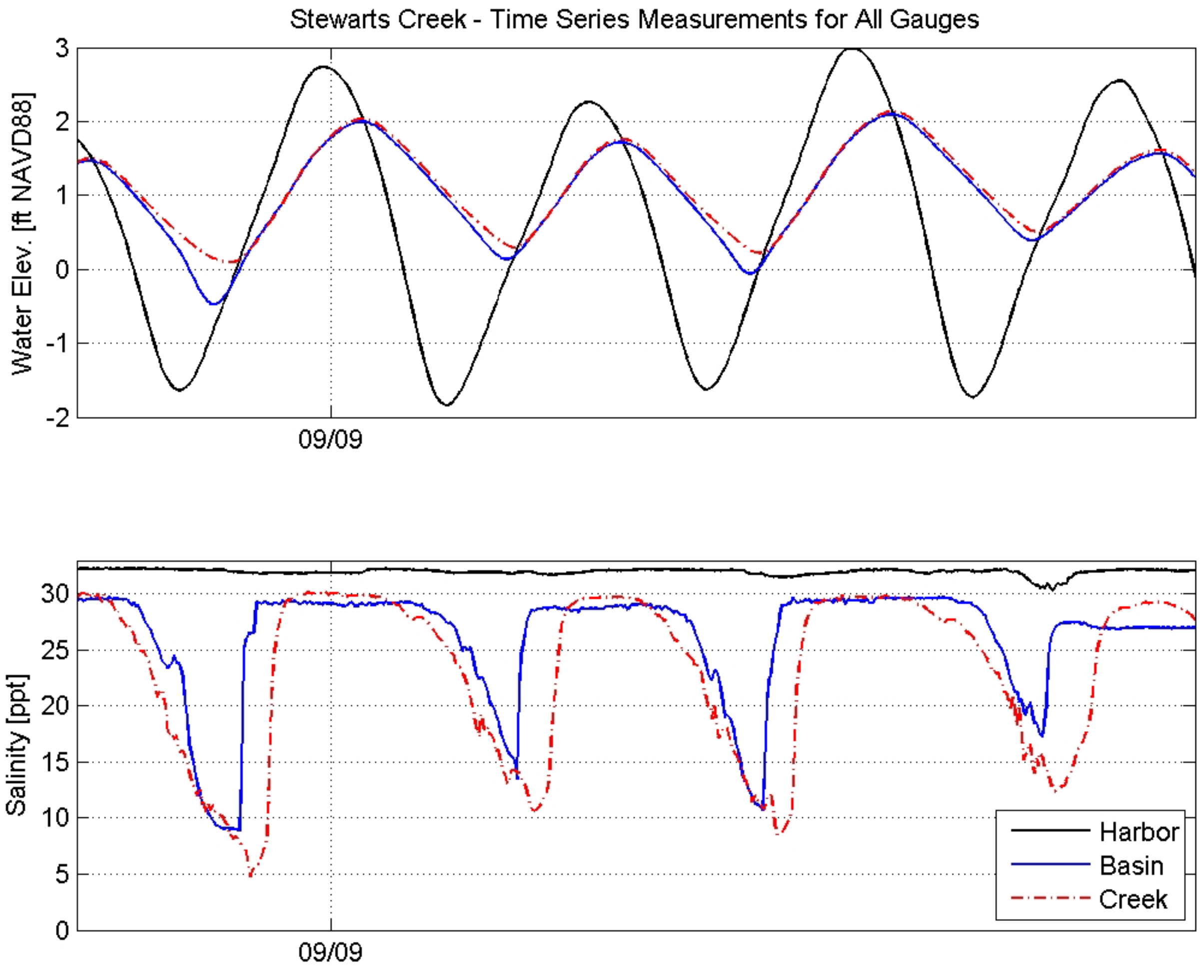

Figure 4. **Example of spring tide conditions for water surface elevation (top) and salinity (bottom) at Stewart's Creek.**

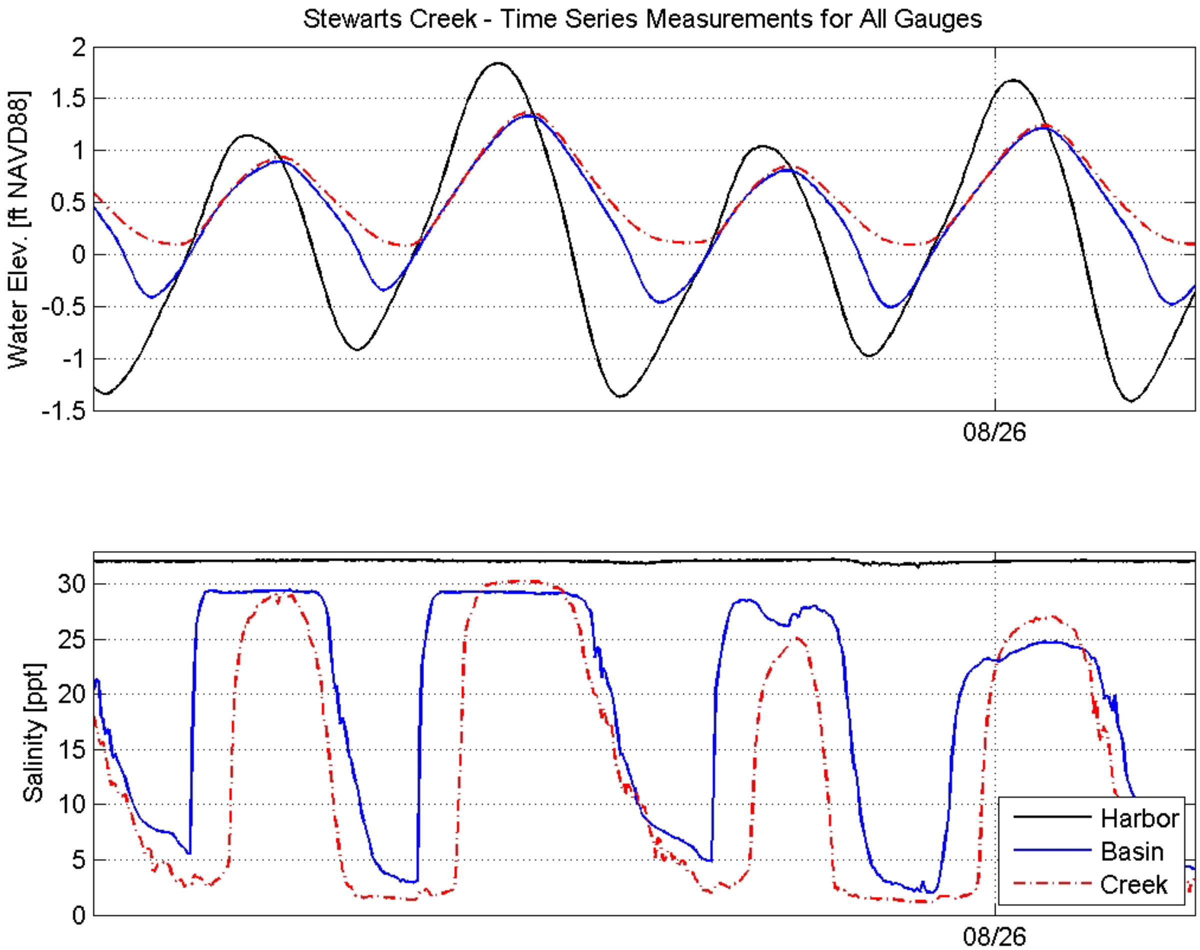

Figure 5. Example of neap tide conditions for water surface elevation (top) and salinity (bottom) at Stewart's Creek.

Tidal datums, referenced to NAVD88 feet, were calculated for each of the three (3) tide gauges to establish mean lower low water (MLLW), mean low water (MLW), mean tide level (MTL), mean high water (MHW), mean higher high water (MHHW), and the mean tide range (MR) as shown in Table 1. Results show the tidal mean tidal range (average difference between high tide and low tide) attenuates from 3.13 ft in Lewis Bay to 1.67 ft in the lower basin of Stewart's Creek, a ~47% reduction. This indicates that the large box culvert and bar screen are still a significant restriction to the system. Further upstream, the tide range is attenuated another 0.43 ft from the lower basin to the tidal creek, or 26% more reduction in the mean tide range.

Results from the current post-construction tidal survey were also compared to the prior 2015 post-construction monitoring to evaluate how the system has changed, if at all, in the last three (3) years. Results indicate the tidal range within Stewart's Creek increased by approximately 0.4 ft since 2015, rather significant considering the size of the culvert has not changed. High tides were approximately 0.1 foot higher and the lower tides were approximately 0.3 ft lower than recorded in 2015. Reasons for the higher high tides in Stewart's Creek appear to be related the higher high tides in Lewis Bay than previously measured in 2015 over a 30-day time period. It is possible the higher high tides could be related to the active storm season in the late summer and fall of 2018, where significant rain and wind activity could have created more runoff and/or elevated wind surge in Lewis Bay, respectively. The lower low tides could be related to the cleaning of the trash grate or because the location of the Main Basin gauge was 55 ft closer to culvert (downstream) with likely a lower creek bed elevation.

Table 1. Comparison of the 2015 and 2018 measured tidal datums (feet, NAVD88) in the Stewart's Creek.

Tidal Datum	Lewis Bay			Main Basin			Tidal Creek		
Ft-NAVD	2018	2015	Difference (Feet)	2018	2015	Difference (Feet)	2018	2015	Difference (Feet)
MHHW	1.97	1.86	0.11	1.37	1.25	0.13	1.47	1.37	0.10
MHW	1.71	1.66	0.05	1.21	1.12	0.08	1.30	1.24	0.06
MTL	0.15	0.12	0.03	0.37	0.47	-0.10	0.68	0.82	-0.14
MLW	-1.41	-1.42	0.01	-0.46	-0.18	-0.29	0.06	0.40	-0.34
MLLW	-1.56	-1.59	0.03	-0.55	-0.24	-0.31	0.03	0.38	-0.35
MR	3.13	3.09	0.04	1.67	1.30	0.37	1.24	0.84	0.41

2.2 ELEVATION DATA SETS

In 2016, Woods Hole Group constructed a three-dimensional topobathymetric map of Stewart's Creek using elevation data surveyed by the Town of Barnstable Department of Surveying and a 2014 USGS LIDAR data set for the area. The Survey Department had occupied similar cross section locations as those surveyed previously by USACE during the pre-construction monitoring (Cross Sections A, B, and C) as shown in Figure 6. The elevation data for Stewart's Creek included measurements of the marsh plain, creek bed, tidal flats, and control structures. Much of the Stewart's Creek shoreline and marsh is inaccessible due to tall, dense stands of *Phragmites* while much of the creek and basin itself is shallow with a bottom composed of black, silty find sediment limiting the ability of the survey to collect intertidal and subtidal elevation data. Therefore, survey data from the Town was supplemented with Light Detection and Ranging (LIDAR) data, which has a much more broad and dense data coverage for the area. LIDAR is a remote sensing method typically employed from a plane that uses light pulses (lasers) to measure ranges, converted to elevation data sets. Both the LIDAR and Town data sets were combined into a single topobathymetric data set referenced to NAVD88 (feet), where the Town data was used to ground truth and adjust the LIDAR data where necessary. The combined topobathymetric map from Figure 6 in the Phase II report (2016) is shown in Figure 6 below for reference. This map was used to evaluate flooding and inundation of the system compared to the pre-construction conditions.

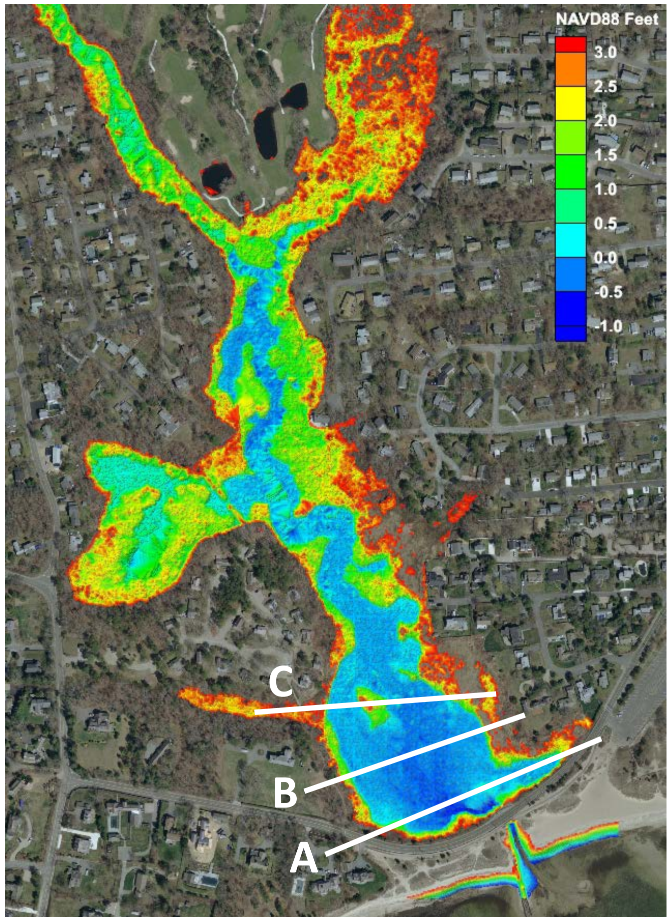

Figure 6. Composite map of LIDAR data and locations of Cross sections A, B, and C adjusted using Town Survey Data from the Phase II Report (2016).

Since there have not been any newer LIDAR data sets issued since the Phase II report was published in 2016, an updated topobathymetric map for Figure 6 could not be created for the year 5 monitoring. However, the Town reoccupied the survey cross sections originally established by the USACE to update the Stewart's Creek cross sections allowing for evaluation of how the system has accreted, eroded, or remained stable since the culvert was replaced. Figure 7 shows the elevation cross sections for cross sections A (lower basin), B (middle basin), and C (upper basin), shown in Figure 6, generated for three time periods including the USACE pre-construction survey (black), the 2015 post-construction survey (red), and 2018 post-construction survey (green). The figures indicate:

- Cross section A: This cross section is located upstream of the culvert inlet, and bisects the lower basin including the flood shoal. This area has been dynamic since the project was constructed, including net erosion in the central portion of the lower basin. A 1 foot deep channel has been established on the western side of the flood tide shoal located about 250 ft from western shoreline of Stewarts Creek since the culvert was installed.

- Cross section B: This cross section bisects the central portion of the main basin, and the bedform changes have been variable. From the pre-construction survey to the 2015 post-construction survey, a 0.5 – 1 ft thick layer of sediment eroded from this cross section. More recently, the 2018 survey of this cross section matches well with the 2015 survey; however, the data indicates there has been up to 0.5 ft of accretion and shoaling in the central portion of the basin since 2015. This is consistent with the observation of a flood tidal shoal forming.

- Cross section C: This cross section bisects the upper portion of the main basin and includes an island dominated by *Phragmites*. The 2015 post-construction survey showed two new channels, approximately 1-1.5 ft deep, formed on both sides of the island following replacement of the culvert. The 2018 survey of this cross section indicates that the while the western channel has been maintained, the channel to the east of the island has accreted and filled in. The field team observations support the measurements as they could not locate a channel east of the island during the benthic sampling.

To summarize, the cross-section elevation surveys indicate a layer of sediment has eroded from the intertidal and subtidal portions of the main basin of Stewart's Creek since the replacement of the culvert. A main flow channel has established along the southern and western portion of the main basin, following its historic flow path.

Another key aspect of the combined tide, salinity, and marsh elevation cross-section survey data is related to the marsh plain elevation where the *Phragmites* is growing compared to the high tide elevations. A comparison of the high tide elevations measured in Stewart's Creek (i.e., less than 1.5 ft NAVD) with the elevations where *Phragmites* is growing (i.e., generally higher than 2 ft and approaching 3 ft NAVD or more) reveals that MHW is still not reaching high enough to inundate the marsh plain at elevation with saltwater to naturally eradicate *Phragmites*. In fact, much of the marsh plain is elevated even above MHHW in Lewis Bay (~2 ft NAVD), meaning even if the full tidal range from Lewis Bay entered Stewart's Creek there would not be a significant increase in tidal inundation of the marsh plain where *Phragmites* is established. This has implications on *Phragmites* eradication and salt marsh restoration alternatives to be addressed under separate cover.

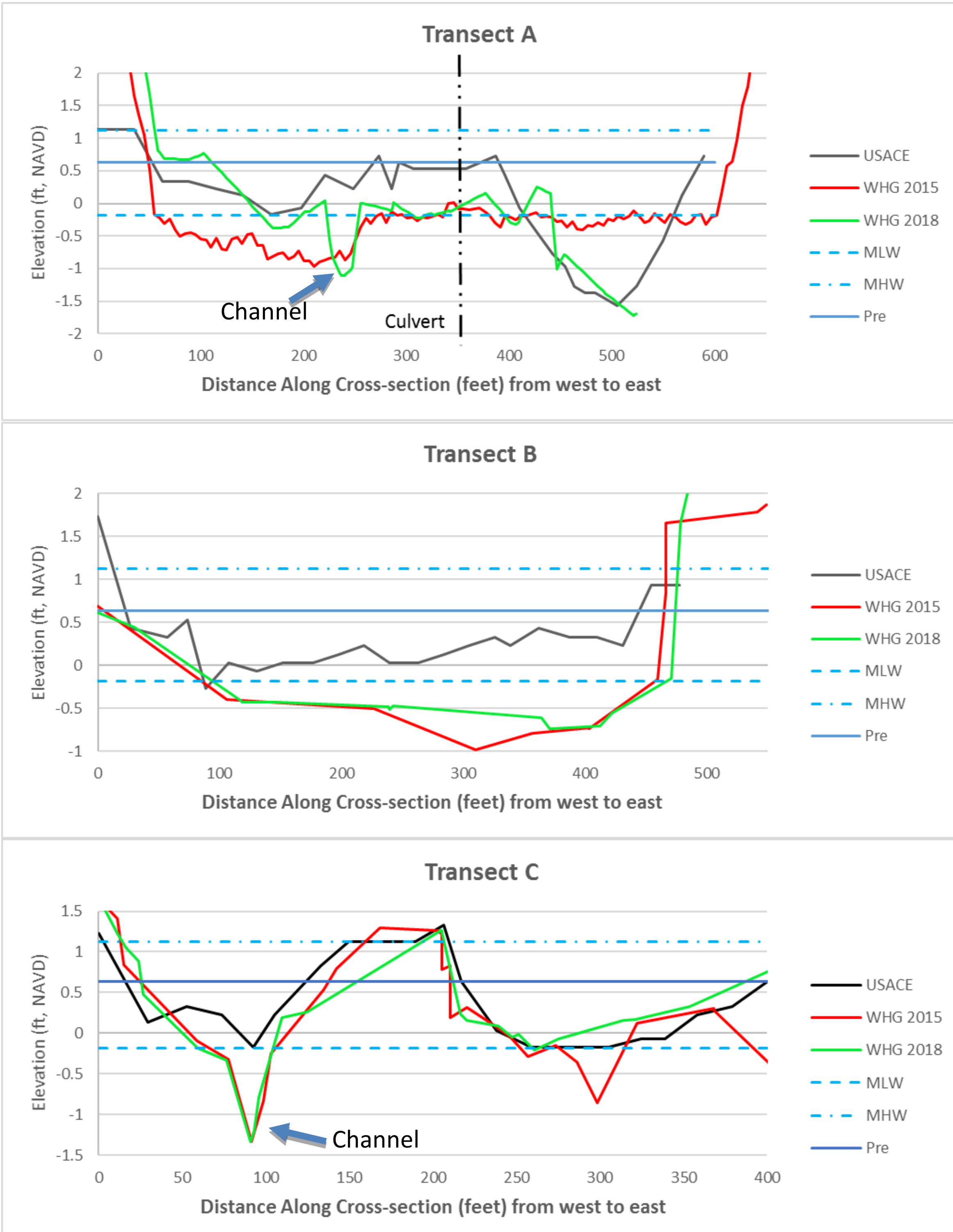

Figure 7. Cross section from lower (top), middle (middle), and upper (bottom) basin of Stewart's Creek.

2.3 BENTHIC SAMPLING

Benthic infaunal communities that reside in estuarine sediments are composed of a variety of small organisms including worms, clams, snails, crustaceans, and insects, and provide an indicator of wetland and subtidal conditions and health. As a part of the USACE pre-construction study of Stewart's Creek, the USACE collected benthic infaunal samples in 2002 to evaluate the benthic community abundance (number of individuals) and richness (number of species) in Stewarts Creek, which at the time was an impounded, degraded freshwater system due to a clogged, undersized culvert. As a part of this work, the USACE obtained four (4) subtidal sediment samples (blue triangles, Figure 8) from Stewart's Creek in 2002 from which benthic biota were separated and identified to establish a baseline for the existing benthic macrofauna communities prior to replacing the culvert. These pre-construction benthic samples indicated that only four (4) species inhabited the sediments and in small populations (15 total individuals), indicative of a degraded estuarine system.

As part of the Estuarine Restoration Act (ERA) grant application, the USACE and the Town established Hall's Creek as a reference site in 2010 to provide a restoration target and control site for the benthic macrofauna community restoration in Stewart's Creeks. The USACE also determined that additional, updated benthic samples from Stewart's Creek were not needed as the marsh was still in a degraded state. Hall's Creek was first sampled in 2010 by Sheldon Pratt of the University of Rhode Island (URI), on behalf of the USACE, who collected five (5) subtidal and five (5) intertidal benthic samples. The approximate 2010 benthic sampling locations are shown as blue triangles in Figure 9, and were estimated based on the Pre-Construction Monitoring Report figures; the sampler at the time did not record locations in the field, but rather estimated using Google Earth (*.kmz files were not available either). While the benthic samples collected in Stewart's Creek revealed low abundance and diversity in benthic infaunal species, Hall's Creek (Figure 9) harbored a more abundant and diversified benthic community indicative of a healthier estuarine environment. In this regard, Hall's Creek serves as a reference site by which the Stewart's Creek benthic population can be compared post-restoration target for estuary habitat restoration.

In 2015, Woods Hole Group subcontracted to Pratt to conduct post-construction (2 years after construction) benthic sampling and analysis at both Stewart's Creek and Hall's Creek. Five (5) intertidal and five (5) subtidal samples were collected from each water body as shown as yellow triangles in Figures 8 and 9, respectively; however, as with the 2010 event the sampler did not record the location of six samples in Stewarts Creek and no locations in Halls Creek so they are not shown but data are included in the analysis. The 2015 results shown in Table 2 indicate the abundance and richness of benthic infaunal community in Stewart's Creek increased significantly in the 2 years after restoring tidal flow to this previously perched, freshwater system. Opportunistic (stress tolerant) species, such as *capitella capitata* (annelida or ringed worms), dominated Stewart's Creek, which is expected given the high range of salinity and sediment characteristics. Based on relative densities, the intertidal benthic infauna did not remarkably differ between the Stewart's Creek and Hall's Creek and *C. capitata* was also the most abundant species at Hall's Creek, even though it has a natural tidal regime that had not been artificially altered during this time period. The 2015 monitoring indicated that by restoring higher quality salt water from Lewis Bay, the sub- and intertidal infauna populations of Stewart's Creek were recovering, although the composition still was not equivalent to that of Hall's Creek. It was concluded in the 2016 Phase II Report that more time (3-5 years typical) and suitable sediment substrate may be required to establish more diversity including higher level predator polychaetes (annelida), for instance.

In 2018, Woods Hole Group collected benthic samples at Stewart's Creek and Hall's Creek, which reflected the abundance and richness over 3-years since the last round of sampling in 2015, and over 5-years since the culvert was replaced. Benthic sampling was conducted at five (5) random stratified locations within the subtidal zone for each marsh system during a spring low tide on August 17, 2018; sample locations are indicated by purple triangles in Figures 8 and 9. Samples were collected using a 3-in diameter PVC coring tube plunged 4 inches into the substrate. Samples were then poured into Nalgene jars, placed on ice, and transported to a benthic laboratory, Normandeau Associates, where they were sieved through a 0.5-mm mesh size. All retained organisms were identified to the lowest practical taxon and counted. Table 2 summarizes the overall results of the 2018 sampling along with a comparison to historical results. A copy of the raw 2018 laboratory results are found in Attachment A.

The 2018 sampling results from Stewart's Creek indicate the species richness and abundance were similar to, but slightly lower than, the 2015 sampling. Although the total subtidal species richness and abundance in Stewart's Creek declined from 15 to 9 and 221 to 214, respectively, over the intervening 3-year time period, the differences are presumably attributable to natural variability, as well as differences in sampling precision, location, size, dates, natural variation, and/or laboratory methods (a different laboratory was used). The benthic community remains more diverse and abundant in Stewart's Creek compared to the pre-restoration condition. Species richness and abundance remained more robust in Hall's Creek in 2018 with 30 species and 276 organisms, respectively. This increase over 2015 is not attributed to changes in the ecosystem; thus, the natural variability also is a result of factors listed above. Hall's Creek is more of a broad sandy embayment than a restricted muddy tidal creek like Stewart's Creek, and, therefore, the composition should not be expected to be identical even after complete recovery to the best attainable condition. Overall, the benthic sampling results for Stewart's Creek show there was rapid recolonization by benthic organisms in the 2 years following culvert replacement, but recovery has plateaued as tidal and sediment conditions have not changed substantially in the subsequent 3 years.

Of note, the lab reported Nematoda, or round worms, were the most abundant animal with hundreds of individuals recorded from both Stewart's Creek and Hall's Creek, but were not reported during previous sampling rounds. The lab indicated nematodes are considered meiofauna often ignored in benthos data, but were reported in this case since they were so numerous. The abundance of Nematodes is considered a positive result for Stewart's Creek restoration in terms of the benthic community colonization.

Figure 8. Year 5 Benthic invertebrate sampling locations at Stewart's Creek.

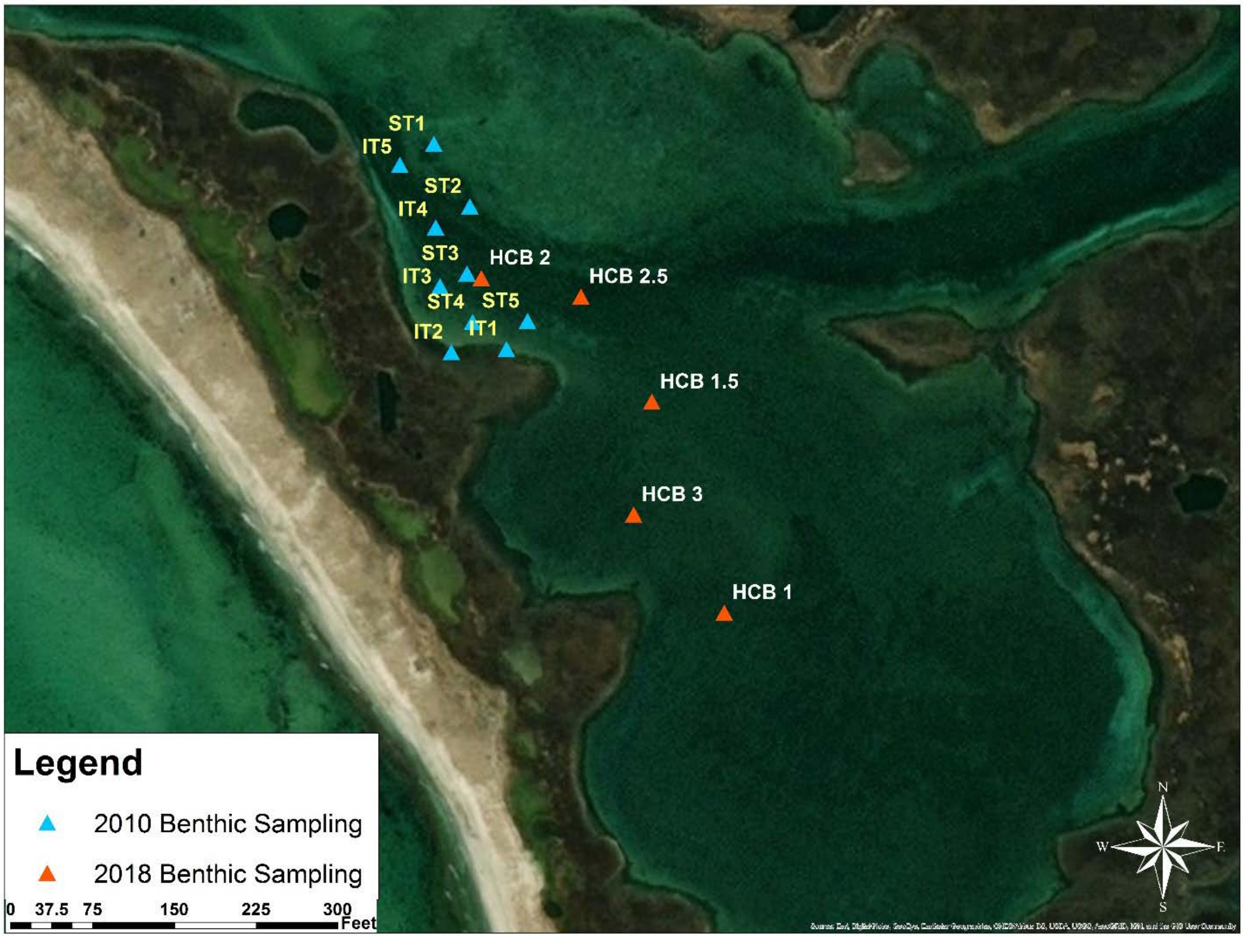

Figure 9. Year 5 Benthic invertebrate sampling locations at Hall's Creek (reference site).

Table 2. Composition of benthic infauna data from Stewart's Creek and Hall's Creek (reference site).

	HALL'S CREEK							STEWART'S CREEK				
Sample Date	10/2010		09/29/2015		10/10/2015		8/17/2018	09/12/2002	09/29/15		01/20/2016	8/17/2018
Benthic Sample Location	Subtidal[1]	Intertidal	Subtidal	Intertidal	Subtidal	Intertidal	Subtidal	Subtidal[2]	Subtidal	Intertidal	Subtidal	Subtidal
Number of Sample Locations	5	5	5	5	5	5	5	4	5	5	5	5
Percent Composition by Phylum												
PLATYHELMINTHES (flat worms)	17.3	12.4	0	0	17.5	12.5	0.7	0	0	0	1.2	0.5
ANNELIDA (ringed worms)	65.4	76.5	91.2	83.1	65.0	77.9	92.8	53.3	95.0	97.0	95.1	80.4
MOLLUSCA (Mollusks)	14.8	4.1	4.4	2.0	15.0	4.2	5.4	0	3.6	1.5	0	0
CRUSTACEA / Anthropoda (crustaceans)	2.5	7.1	4.4	14.9	2.5	5.4	1.1	0	1.4	1.5	2.5	19.2
INSECTA (insects)	0	0	0	0	0	0	0	46.7	0	0	1.2	0
Total No. of Species	16	19	17	17	15	19	30	4	15	10	11	9
Total No. of Individuals	81	170	155	99	80	159	276	15	221	66	81	214

1. URI Sampling.
2. U.S. Army Corp of Engineers sampling.

2.4 VEGETATION AND POREWATER SAMPLING

One of the primary goals of the Stewart's Creek culvert replacement project was to convert *Phragmites australis*-dominant marsh to *Spartina alterniflora*-dominant salt marsh. This goal was to be achieved by replacing the existing undersized culvert with a larger 6'x4' box culvert to reintroduce regular tidal flow to the existing marsh plain and create a more saline surface and porewater environment unsuitable for *Phragmites*. Project proponents intended for regular inundation of the marsh plain to help to eradicate dense stands of invasive *Phragmites* while allowing more desirable native species to re-colonize the marsh such as salt marsh cord grass, *Spartina alterniflora,* salt marsh hay, *Spartina patens,* and saltgrass, *Distichlis spicata*. As part of the Estuarine Restoration Act (ERA) grant application, the USACE and the Town developed a vegetation monitoring plan for the Stewart's Creek Restoration Project to gauge the success of the project goals from pre-construction to post-construction. In addition, vegetation monitoring was also conducted at the reference site, Hall's Creek, which is a typical New England saltmarsh dominated by *Spartina alterniflora* dominate the landscape that could be used as both a restoration target and a control site.

This vegetation monitoring protocol included establishing three (3) vegetation monitoring transects on the marsh plains of Stewart's Creek and Hall's Creek (Figures 10 and 11), and this monitoring protocol was documented in the Pre-Construction Monitoring Report (February 2013). During each round of vegetation monitoring at each site, approximately five (5) sampling stations were established along each of the three (3) transects, for a total of fifteen (15) individual sampling stations. Each sampling station was a composite sample of three (3) 0.25m plots for a total of 45 plots at each site. Within each plot, vegetation type (by percent cover), vegetation density (stems per m^2), height, and percentage of *Phragmites* or other vegetation stems in flower would be measured. In addition, shallow holes were dug at each station to measure the salinity of the porewater in the marsh plain.

The pre-construction vegetation monitoring in October 2010 revealed that Stewart's Creek is dominated by *Phragmites* with few other native salt marsh species present. Conversely, Hall's Creek vegetation monitoring found typical New England salt marsh species including cordgrass (*Spartina alterniflora*), salt hay (*Spartina patens*), Spike grass (*Distichlis spicata*) and saltwort (*Salicornia sp.*) with no *Phragmites* recorded. The porewater salinity in the marsh was measured at each vegetation station, which ranged from 31 – 33 ppt at Hall's Creek and 0 – 5 ppt at Stewart's Creek. The low porewater salinity at Stewart's Creek is major reason that *Phragmites* have been able to thrive here and not at Hall's Creek.

As a part of the year 2 post-construction monitoring in September 2015, Woods Hole Group partnered with CCCD to conduct the vegetation surveys along the three (3) established transects at Stewart's Creek and Hall's Creek. A total of fifteen (15) sampling stations were re-established along the three (3) transects (Figure 10), and, of the fifteen (15) sampling stations, fourteen (14) were found to be dominated by invasive *Phragmites*. Only one (1) station, located on the marsh edge closest to the Stewart's Creek culvert, recorded the presence of native salt marsh vegetation (*Spartina alterniflora* and *Spartina patens*, respectively). In contrast, no *Phragmites* were present at the Halls Creek reference site, which was still found to be dominated by typical salt marsh species, *Spartina alterniflora* and *S. patens*. The porewater salinity for the Stewart's Creek vegetation stations ranged from 0 to 8 ppt, indicating that even with restored tidal flow to the marsh, the saltwater was not significantly penetrating the marsh plain. The results of the year-2 vegetation monitoring (2015) showed there had been no measurable change in *Phragmites* at Stewart's Creek following construction of the culvert due to lack of inundation and penetration of the marsh plain by saltwater during regular tides.

During the year 5 post-construction monitoring in August 2018, the Woods Hole Group and CCCD project team re-established the fifteen (15) vegetation sampling stations along the three (3) transects at Stewart's Creek (Figure 10) and Hall's Creek (Figure 11). For detailed results of the most recent year 5 vegetation monitoring survey, refer to the CCCD Monitoring Report (Attachment B). Of the fifteen (15) sampling stations, fourteen (14) were found to be dominated by invasive *Phragmites*. Only one (1) station, the same station in 2015 located on the marsh edge closest to the Stewart's Creek culvert, recorded the presence of native salt marsh vegetation (*Spartina alterniflora* and *Spartina patens*, respectively). In contrast, *Phragmites* were still not present at Halls Creek, which was still dominated by typical salt marsh species. The porewater salinity measured from the Stewart's Creek vegetation stations ranged from 0 to 10 ppt, indicating that saltwater was not penetrating the marsh even 5 years following construction. Therefore, the year 5 post construction vegetation monitoring indicates that even with restored tidal flow, there has been no measurable decline in *Phragmites* at Stewart's Creek since the pre-construction monitoring, and that a decline may not be achievable given the current hydrodynamic and salinity regime in the Stewart's Creek marsh system on the established marsh plains.

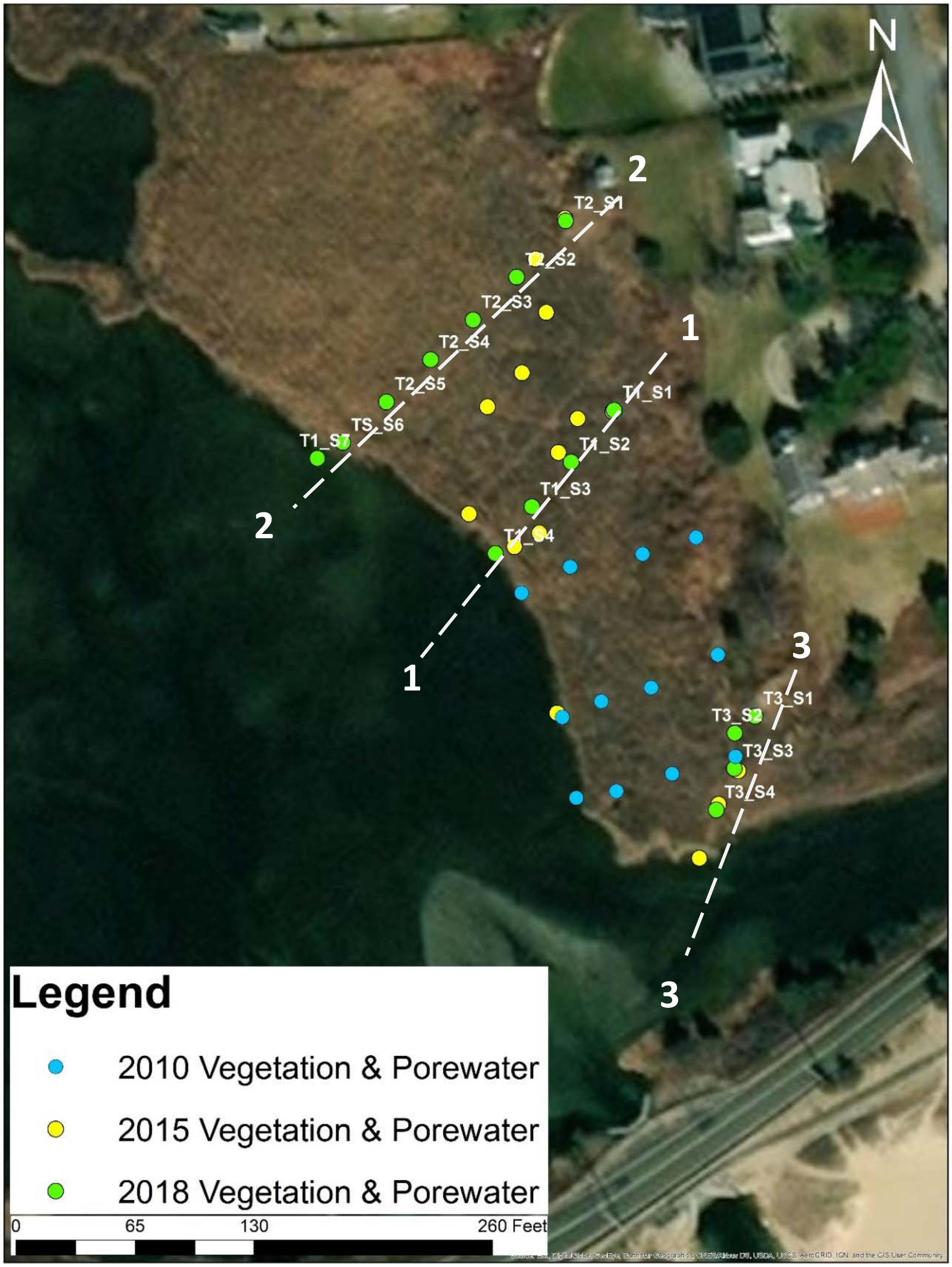

Figure 10. Year 5 Vegetation sampling locations along Transects 1, 2, & 3 at Stewart's Creek.

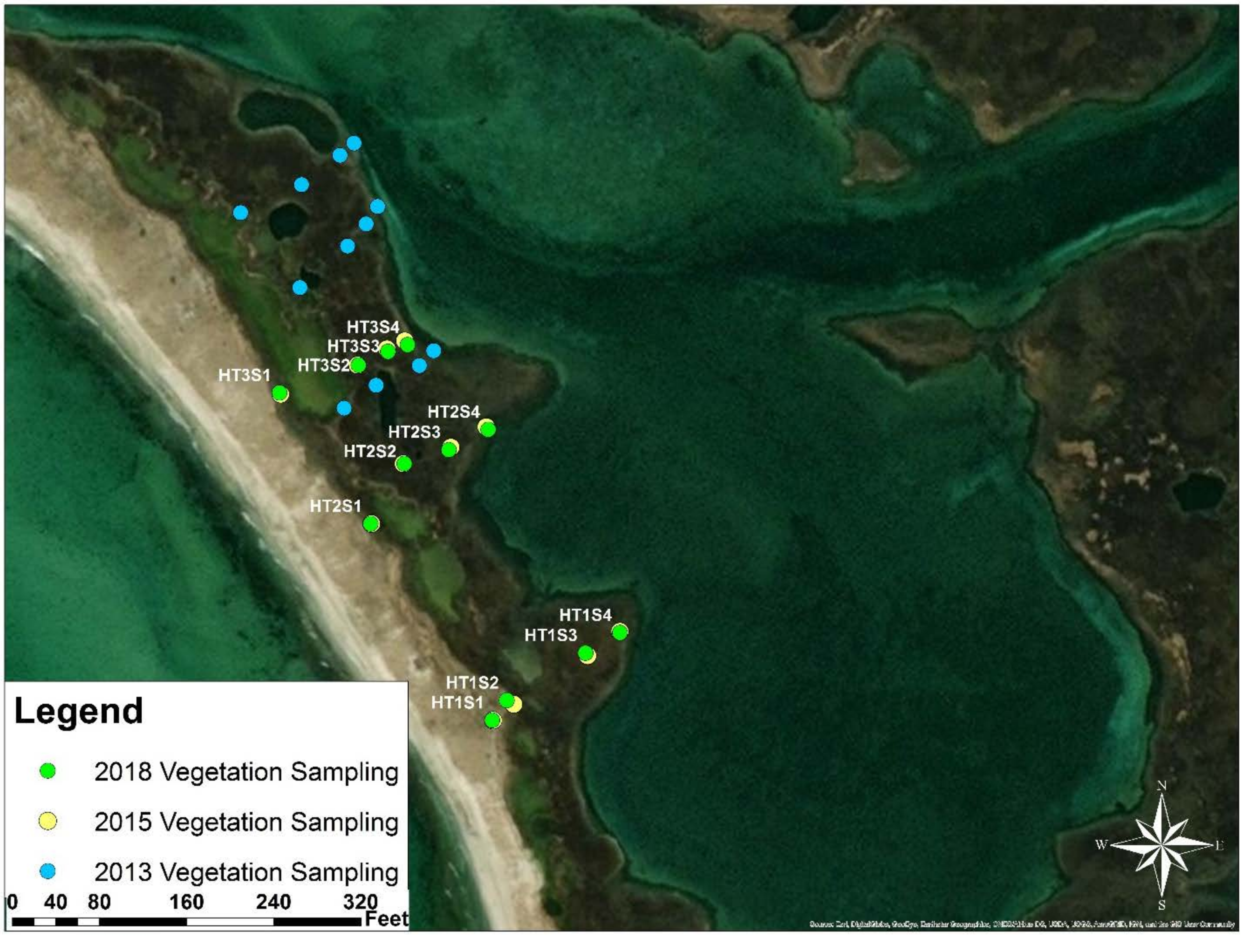

Figure 11. Year 5 vegetation sampling locations at Hall's Creek (reference site).

There are two potential reasons why *Phragmites* continues to dominate the marsh plain in Stewart's Creek. First, the recent 2018 measurements indicate the high tide has not increased significantly since 2015, and, therefore, is still not attaining a level where the tide would inundate the *Phragmites*-dominant marsh plain with salt water on a regular basis. Therefore, a primary mechanism for killing invasive *Phragmites* (saltwater inundation of the higher marsh plains) has not been established.

Second and related, the pore water salinity within the system has not increased following construction. Porewater sampling was conducted at each of the vegetation sampling locations in August 2018 using a YSI multiparameter sonde to evaluate whether porewater salinity had increased across the marsh plain. Although the tide and salinity measurements within the open water indicate a fluctuating saline and fresh water regime, the porewater within the marsh plain sediments remains fresh, consistent with the year-2 findings from 2015. This is likely because there is not regular tidal inundation. It is also possible the pore water remains fresh due to the location of ground water table in close proximity to the surface of the marsh plain, which elevated above the high tide benchmarks recorded by the tide gauges. As a result, *Phragmites* continues to thrive in the predominately fresh porewater which is not being consistently inundated with saltwater during high tide.

Additional factors limiting recolonization include a limited natural seed source within Stewart's Creek for native, salt marsh vegetation. Tidal currents may also preclude establishment of marsh vegetation in certain areas, such as the newly exposed mudflats, in the central portion of the system upstream from the culvert. While it can take 5-10 years for vegetation response to occur in restored systems, Stewart's Creek is now in the fifth year of restoration so there should be clear evidence of ongoing changes in vegetation composition. Reduction of the well-established *Phragmites* is hampered where the marsh plain has built (by way of sedimentation and accumulated detritus) above the high tide elevation (even above the Lewis Bay high tide elevation in certain *Phragmites* stands within Stewart's Creek). Future reduction of the *Phragmites* is unlikely without further intervention within the Stewart's Creek system. To facilitate the transition from *Phragmites*-dominant marsh to *Spartina*-dominant marsh, it is likely that a comprehensive invasive plant management (IMP) program will be required. A management plan is being developed to consider various alternatives for invasive treatment and native re-vegetation, including but not limited to: mowing and physical removal of invasive biomass; treatment of invasive vegetation with wetland-approved glyphosate-based herbicide; ditching to increase/decrease inundation of the marsh plain; excavation and/or regrading of marsh plain to increase/decrease inundation; and installation of native, salt marsh enhancement plantings.

3.0 SUMMARY AND CONCLUSIONS

With the Year 5 monitoring complete, the following general statements can be made about the state of the Stewart's Creek restoration:

- Hydrodynamic regime – Tidal action has been restored to the system as a result of the culvert installation. Prior to the culvert replacement, Stewart's Creek was a perched mostly freshwater system with little to no tidal flushing and degraded water quality. Following culvert replacement, the restored mean tidal range was measured to be 1.30 ft in 2015, which was lower than the USACE modeled tide range of 1.77 ft. In 2018, the mean tidal range increased to 1.67 with most of the gains related to lower low tides, likely resulting from cleaning debris from the screens. The location of the Main Basin gauge (#2) also was closer to culvert with a lower creek bed elevation; thereby resulting in a slightly lower low tide measurement due to the bottom slope. High tide elevations were measured to be within 0.1 ft 2018 and 2015, indicating the new culvert is functioning consistently at high tides.

- Marsh plain elevation – The marsh plain has been relatively stable. Margins where *Phragmites* is most densely colonized are above the restored high tide levels in Stewart's Creek; in fact higher than the high tide levels in Lewis Bay. There also is evidence of sediment accumulating in a flood shoal within Stewart's Creek in the main embayment near the culvert. It appears relatively stable since 2015 and has not been colonized by vegetation. While the elevation surveys for the main basin indicate a localized portion of the inter/sub-tidal flat in the main basin eroded following culvert replacement, there remains a substantial amount of fine (muddy) sediment throughout the system. In addition, a main flow channel has established along the southern and western portions of the main basin of Stewart's Creek, apparently following its historic pathway.

- Benthic and wildlife community – The benthic invertebrate community has increased in species richness and abundance since the culvert was installed. Notable changes resulted between the pre-project and post-project condition measured in 2015. Since 2015, there has been more stability. The 2018 sampling of benthic infauna indicated species richness and abundance is comparable to 2015, suggesting the quality of benthic habitat within Stewart's Creek has stabilized. Stewart's Creek is equilibrating in terms of benthic restoration, especially if no further restoration actions are taken. Of note, the field team observed many birds, small fish, and other intertidal animals while conducting the field survey. Residents confirm active fish, bird, and other wildlife in the system, a marked improvement from the pre-project condition.

- Vegetation Community - The vegetation surveys along the three established transects showed no meaningful retreat of *Phragmites*, which is still the dominant marsh plain species throughout the Stewart's Creek system. This is likely due to the fact that the high tides are not high enough to inundate the marsh plain with saltwater to stunt or kill *Phragmites*. The porewater sampling in the marsh indicated there is a freshwater lens providing an ample supply of freshwater.

Overall, results indicate species richness and abundance of the benthic community improved substantially in the 2 years following culvert replacement, and has remained relatively steady in Stewart's Creek since the last round of sampling in 2015. This advances the project objective to restore estuary habitat. However, a project objective for more diverse native salt marsh vegetation and *Phragmites* retreat has not yet been achieved as of 2018, nor is it expected to occur given prevailing conditions since the marsh plain is perched above the intertidal zone and has an available source of freshwater. Therefore, additional actions, such as physical removal and/or herbicide application will be required to reduce or eradicate the *Phragmites*. Lowering the marsh plain elevation to a level regularly inundated by tides along with installation of ditches to convey salt water flow may be effective as well. Although this type of wetland modification or marsh plain skimming has been practiced on the east coast, it is not common in this region and could be costly and subject to careful regulatory review. The marsh fringe and intertidal areas have not been colonized by *Spartina* species. Although it is possible colonization may occur naturally over the next 5 to 10 years, there may be a need to supplement the natural seed source in the system. Salt marsh seed set on the mud flats may also be inhibited by a combination of high ebb velocities across the relatively unstable soils on the flats. Establishing salt marsh vegetation on the shoals, if desired by the community, may require proactive seeding/plugging and perhaps use of fiber rolls or berms to restrict high velocity sheet flow over the intertidal areas.

Sediment management is another key future topic since there was a pre-project expectation that fine sediment could be exported from the system once flow channels were established in Stewart's Creek. This was expected to potentially create more open water. To date, there is no strong evidence of sediment export, and there is a flood tidal shoal formed upstream from the culvert. A layer of fine (muddy) sediment exists throughout the main basin and tidal creek adjacent to the flow channel established in the main basin. As in 2015, no evidence suggests this type of bedform change is expected to occur naturally given prevailing conditions.

With the Year 5 monitoring completed, the Town of Barnstable can now move forward with next steps to further the restoration of the marsh system while addressing local stakeholder concerns. The next steps will include a Master Planning Document including *Phragmites* eradication and sediment management components, expected to be complete by Summer 2019. The actual plan of action will depend upon priorities, public input, necessity for supplemental engineering/permitting, possible USACE participation, and availability of resources.

ATTACHMENT A. NORMANDEAU LABORATORY RESULTS

Stewart Creek and Halls Creek Benthic Sample Processing Results

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September 2018

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Table of Contents

Page

List of Tables

Page

1.0 Introduction

Normandeau Associates, Inc. (Normandeau), as a subcontractor to Woods Hole Group, Inc., was contracted to process benthic samples that were collected in the field on 17 August 2018 by Woods Hole Group in Stewart Creek (5 stations) and Halls Creek (5 stations), Barnstable Harbor, Barnstable, Massachusetts. Samples were collected using a 3”x 4” Core, preserved in 10% buffered formaldehyde in the field and delivered to Normandeau’s Bedford, NH office.

This report summarizes laboratory processing methods and presents the macroinvertebrate data from the samples. Laboratory processing methods and data handling procedures are described in Section 2.0. Quality control results for the laboratory sort and taxonomy are provided in Section 3.0. Results are presented in Section 4.0, Table 4.1.

2.0 Methods

2.1 Laboratory Methods

Soft-bottom macroinvertebrate samples were processed by Normandeau’s Bedford, NH laboratory following standard processing protocols. Upon arrival at the laboratory, all samples were gently rinsed with fresh water through a 0.5 mm mesh screen. To facilitate sorting, samples were elutriated to separate heavy and light materials and those with heterogeneously sized debris or organisms were washed through a series of graduated sieves down to a 0.5 mm mesh. Samples were sorted in their entirety. Macroinvertebrates were sorted from the debris into major taxonomic groups using a dissecting microscope and placed in vials with 70% ethanol for preservation. Specimen vials were distributed to taxonomists specializing in specific phyla. All organisms were identified to the lowest practical taxon (usually species) and enumerated, with the following exceptions: oligochaete annelids were identified to class, meiofaunal nematodes were identified to nematoda and other meiofauna (e.g., benthic copepods, ostracods) were not enumerated. Immature or damaged specimens that were missing the necessary diagnostic features for identification to the target taxonomic level were identified to the lowest practical taxon.

Quality control protocols were followed for both sorting and identification. At least the first three training samples undertaken by each new macroinvertebrate sample sorter were re-checked by the Quality Control Supervisor. The first sample sorted by each experienced macroinvertebrate sorter, considered a refresher sample, was also re-checked by the Quality Control Supervisor. At the discretion of the Quality Control Supervisor, additional samples could be checked prior to releasing any sorter from training. Regardless of experience level, a minimum of 10% of each sorter’s subsequent samples (one is each batch of ten samples) was randomly selected and subject to quality control. In addition, 10% of each taxonomist’s samples were re-identified. Any work found to be of insufficient quality resulted in re-checking samples in that batch of samples.

Identified specimens were inventoried and prepared for storage for one-year; all sorted samples were re-preserved and prepared for disposal, pending authorization by Woods Hole Group.

2.2 Data Handling

All data were entered into Excel, subjected to Quality Control in the form of a full inspection of the data to confirm accurate transcription and to remove any chance of error in the data.

3.0 Quality Control/Quality Assurance Results

One sample was rechecked during the refresher training phase of the sorting, with an additional 1 sample being resorted and determined to either pass or fail (Table 3-1). Both the Refresher (#HCB1 - 196419) and the randomly selected quality control sample (#SCB4 - 196428) passed (<10% difference between sorter and quality control check). The samples passed QC so further checking was not required.

Table 3-1. Number of samples rechecked for sorting accuracy.

Technician	QC	Total Samples	Results % Difference	P/F
1	Training* QC	1	1.9%	P
	Processing QC	1	7.8%	P

* Seasoned sorter requiring one initial sample checked.

Quality control was performed on the taxonomic processing (identification and enumeration of specimens) for one randomly selected sample and determined to either pass or fail (Table 3-2). The selected sample (#HCB1 - 196419) passed (<10% difference between sorter and quality control check and no further resolution was needed.

Table 3-2. Number of samples rechecked for taxonomy accuracy.

Technician	Processing QC	Results % Difference	P/F
1	1	0%	P
2	1	0%	P
3	1	0%	P

4.0 Laboratory Processing Results

A total of 36 macroinvertebrate taxa were identified; including nematodes, polychaetes, oligochaetes, molluscs, Cnidarians, Arthropods and Platyhelminthes. Results from the 10, 3”x 4” core samples collected in Stewarts and Halls Creeks, Barnstable Harbor, Barnstable, MA; are provided as raw counts in Table 4-1 and supplied separately in Excel format.

Table 4.1 Abundance (Number of Organisms per 3" x 4" core) of Benthic Macrofauna. Barnstable Harbor, Barnstable, MA. Stewart & Halls Creek, August 2018.

	Hall's Creek					Stewart's Creek					
Station	**HCB 1**	**HCB 1.5**	**HCB 2**	**HCB 2.5**	**HCB 3**	**SCB 1**	**SCB 2**	**SCB 3**	**SCB 4**	**SCB 5**	
Sample Date	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	
NAI SCNO	196419	196423	196420	196422	196421	196424	196425	196427	196428	196426	**Total**
Taxon	**Abundance**										
Nematoda											
Nematoda	39	27	254	455	252	398	126	209	25	4	1789
Annelida											
Polychaeta											
Hypereteone heteropoda	2		1	3	2					1	9
Microphthalmus sczelkowii			5								5
Oxydromus obscurus					1						1
Brania wellfleetensis				27	13						40
Streptosyllis verrilli				1							1
Nereididae						1					1
Neanthes arenaceodentata				8	16						24
Glycinde solitaria				1							1
Onuphis eremita			1		1						2
Leitoscoloplos fragilis	1		3		2						6
Polydora cornuta	2			1	1						4
Spiophanes bombyx					1						1
Streblospio benedicti	3	2	16	3	4	3	3		2	1	37
Marenzelleria viridis							13				13
Spiochaetopterus costarum oculatus					2						2
Capitella capitata	1		4		1	6		1		2	15
Heteromastus filiformis		3	2	15	4						24
Clymenella torquata				2	1						3
Pectinaria gouldii					1						1
Oligochata											
Oligochaeta	1	2	19	15	62		79	43	17		238

(continued)

Normandeau Associates, Inc.

Table 4-1. (Continued)

Station	Hall's Creek					Stewart's Creek					Total
	HCB 1	**HCB 1.5**	**HCB 2**	**HCB 2.5**	**HCB 3**	**SCB 1**	**SCB 2**	**SCB 3**	**SCB 4**	**SCB 5**	
Sample Date	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	8/17/2018	
NAI SCNO	196419	196423	196420	196422	196421	196424	196425	196427	196428	196426	**Total**
Taxon	**Abundance**										
Mollusca											
Gastropoda											
Haminoea solitaria	1		2	1							4
Acteocina canaliculata					1						1
Astyris lunata			3								3
Phronotis vibex				1	1						2
Bittiolum alternatum		1									1
Bivalvia											
Ameritella agilis					1						1
Gemma gemma				2							2
Limeola balthica					1						1
Cnidaria											
Actiniaria										1	1
Arthropoda											
Podocopida						2	2	11	7	6	28
Leptocheirus plumulosus							7	6			13
Ampelisca abdita	1										1
Leptocheliidae	1										1
Edotia triloba					1						1
Platyhelminthes		1		1			1				3
Total Abundance	52	36	310	536	369	410	231	270	51	15	2280

ATTACHMENT B. CAPE COD CONSERVATION DISTRICT REPORT

Stewarts Creek Restoration Annual Monitoring Study: Year-5 Results

Final Report

submitted

by

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to

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February 2018

Stewarts Creek Restoration Annual Monitoring Study: Year-5 (2018) Results

Background

In 2013, a road culvert under Ocean Ave. (Hyannis, MA) was enlarged to partially restore tidal exchange between Hyannis Harbor and Stewarts Creek (41.635476, -71.293078) **(Figure 1)**. The original culvert opening had restricted tidal flow to such a degree that it essentially impounded fresh water upstream from the road culvert, essentially lowering salinity and trapping nutrients. This change in hydrology and entrapment of nutrients (primarily nitrogen[1]) allowed the non-native, invasive *Phragmites australis* (common reed) to invade and eventually out-compete native salt marsh dominated by *Spartina alterniflora* (saltmarsh cordgrass). The impoundment also detrimentally impacted benthic and estuarine habitat. In fact, the road placement caused the entire ecosystem underwent a state change to a much less productive and species-rich ecosystem. To reverse the original shortsightedness of constructing a road across the mouth of the Stewarts Creek salt marsh, federal and state resource managers developed a plan to partially restore tidal exchange by widening the road culvert.[2]

As part of the post-project restoration effort required by the Army Corps of Engineers (USACE), a monitoring plan was developed to measure specific biological, structural, and physical attributes useful for determining if the restoration is on a trajectory toward full recovery (Rheinhardt 2013). Data on the measured attributes, described below, were to be collected annually for five years after construction (post-construction) and compared with an unaltered (reference)fringing salt marsh on Halls Creek, located about 1.5 miles west of Stewarts Creek (40.6282621, -70.366737). This report provides monitoring results of the Year-5 monitoring effort (2018). The Year-2 monitoring effort was conducted by Rheinhardt (2016), using the same data collection methods and in approximately the same locations. The Year-1, Year-3, and Year-4 monitoring efforts were never performed.

The USACE identified specific success criteria in their monitoring requirements, criteria they deemed would be useful in determining whether the restoration effort is on a successful restoration trajectory, with the Halls Creek reference site being the standard against which success is to be evaluated. Metrics for measuring success criteria (and comparing against the reference site) included data on the tidal prism (water level in the marsh at high and low tides during spring and neap tides), pore-water salinity at low spring and neap tides, composition of the fringing marsh vegetation, and the structure of *Phragmites australis* vegetation (cover, density, and maximum stem height). We supply those data (and additional data considered relevant)in this report and discuss whether, based on those data, if the fringing marshes in Stewarts Creek are on a successful restoration trajectory five years after the culvert opening was enlarged. Benthic species composition was also sampled in both creeks, but those data are provided in report by the Woods Hole Group (WHG) to which this report is attached. All field

[1] Nitrogen is the principal limiting nutrient in estuaries.
[2] The complete restoration of tidal flow, to pre-road conditions, was not considered to be economically feasible.

data from marsh sampling data are provided in the Appendix, including data not specifically required for monitoring.

Figure 1. Location of vegetation sample points in Stewarts and Halls Creeks. Stewarts (left panel), Halls (right panel), T#= transect number, and number = points. Each point had three vegetation plots associated with it.

As in 2015, three transects were established on marshes at both Stewarts Creek and Halls Creek (reference site). The 2018 transects started at about the same locations as transects sampled 2015 (within 1 m), but stations (points) along the transects were close, but not the same as points sampled in 2015. Nonetheless, both the 2015 and 2018 transects provide a detailed overview of the vegetation from the upper part of the marsh to the creek/marsh interface.

USACE defined five objectives (each with its own set of success criteria) for the Stewarts Creek Restoration project Objective 1 focused converting *Phragmites australis*-dominated marsh to *Spartina alterniflora*-dominated salt marsh. Objective 2 focused on restoring tidal flooding to the marsh, based on marsh elevations relative to mean high water. Objective 3 focused on restoring benthic habitat to Stewarts Creek. Objective 4 focused on restoring geomorphology of tidal creek (ratio of open water to marsh).[3] (5) Objective 5 focused on avoiding flooding of upland properties adjacent to the marsh due to restoration efforts. This monitoring report focuses only on Objective 1 (converting *Phragmites australis*-dominated marsh to *Spartina alterniflora*-dominated salt marsh) and the three criteria used to measure success in meeting this objective. Each success criterion is listed below, followed by methods (and metrics) used to measure the success criteria, data for the metrics, and whether the success criteria are being met at Year 5. I also discuss insights into whether the enhancement to tidal flow has been successful in setting the marsh on a successful trajectory toward the ecological target (salt marsh ecosystem), the practicality of various adaptive management strategies that could be adopted, and lessons learned.

Objective 1: Restore intertidal elevations and substrates (Spring high water to mean sea level) that allow salt marsh plants and associated animal communities to recolonize the marsh restoration site by increasing the abundance of salt marsh vegetation (e.g., *Spartina alterniflora, S. patens, Distichlis spicata, Juncus gerardii,* etc.) and eliminate most of the

[3] USACE did not define the targeted ratio.

Phragmites (a non-native invasive species). In other words, the objective of the culvert enlargement project is to convert the *Phragmites australis*-dominated marsh to an estuarine salt marsh dominated by *Spartina alterniflora*.

Success criterion A[4]: The area of the marsh flooded between once daily and two to eight times monthly is increased to within 75% of the plan requirements[5].

Methods used for measuring Success criterion A: At Stewarts Creek, we established 15 sample stations along three transects running from the upland edge to shoreline. We measured tide height at each station, relative to the marsh surface, at high and low tides during the neap and spring tidal phases. We also measured the thickness of *Phragmites* peat and elevation of the marsh surface at each station along the three transects. WHG measured the tidal prism in the Stewarts Creeks to determine the relationship between water level in the marsh and tide heights in Stewarts Creek and Hyannis Harbor. These data were used by WHG to determine if the area of surface water flooding is within 75% of plan requirements, whatever that is.

Results. Marsh surface elevations in Stewarts Creek gradually declined from stations nearest the upland to the creek edge (Figure 2). During two tidal phases in August, neap (8/17/18) and spring (8/24/18), none of the stations had water flooding the marsh surface, except during high neap tide for Stations S6 (+2.5 cm) and S7 (+9.3 cm) of Transect 2 **(Table 1)**. At spring high tide, water elevation was at the marsh surface (0.0 cm) at Station 7 of Transect 2 (**Table 2**). At stations nearest the upland border, water was 7.8–12.0 cm below the marsh surface during spring high tide and 2.0–6.3 cm below the marsh surface at high neap tide. Water level in stations nearest the marsh/creek interface seemed to respond most closely to tidal fluctuations in Stewarts Creek, but tides belowground in the marsh interior were more muted and lagged behind tides in the creek. Surprisingly, belowground water levels in the marsh near the upland border were higher at low tides than at high tides, possibly because (1) groundwater is being discharged to the surface of the marsh near the break in slope at the upland border and (2) tidal fluctuations in the marsh furthest from the creek (at the upland border) lag behind tidal fluctuations in the creek at the marsh/estuary interface.

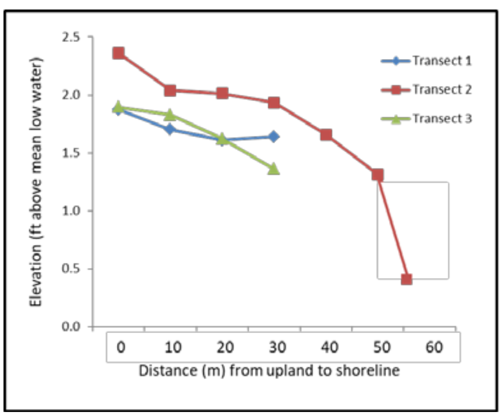

Figure 2. Marsh surface elevation at Stewarts Creek stations along the three transects.

[4] All success criteria are from those listed in the Pre-construction Monitoring Report (Rheinhardt 2013).

[5] Plan requirements were not clearly articulated.

Table 1. Salinities and water table elevations at neap tide on 08/17/18. Predicted high tide was at 0543; predicted low was at 1110. Actual high tide was at about 0845; low tide was at about 1315.

	High tide					Low tide				
		Surface (-7 cm)		At probe depth			Surface (-7 cm)		At probe depth	
Location[1]	Time	Water table elevation	Salinity	Probe depth (cm)	Salinity	Time	Water table elevation	Salinity	Probe depth (cm)	Salinity
T1S1	759	-2.0	1.0	26.6	1.4	1439	-5.0	1.2	27.5	1.3
T1S2	803	-3.0	3.2	24.0	3.4	1442	-6.5	3.4	23.3	3.4
T1S3	806	-4.5	3.6	31.5	5.8	1443	-4.8	3.8	34.0	9.1
T1S4	811	-9.0	10.7	24.7	11.6	1447	-12.3	10.6	21.5	11.7
T2S1	832	-4.0	0.2	34.8	0.2	1504	-8.0	0.2	32.5	0.2
T2S2	830	-4.0	0.3	34.8	0.3	1502	-4.8	0.3	34.8	0.3
T2S3	828	-4.3	0.4	34.8	0.4	1500	-5.0	0.4	34.8	0.4
T2S4	825	-2.8	2.8	34.8	4.1	1458	-4.0	2.7	34.8	3.2
T2S5	822	-4.0	6.2	34.8	6.3	1457	-6.0	6.7	34.8	6.3
T2S6	819	2.5	13.1	34.8	23.7	1454	-4.0	14.9	32.5	24.1
T2S7	815	9.3	29.4	25.5	26.3	1452	0.0	24.7	19.0	29.9
T3S1	841	-6.3	3.5	16.6	3.5	1509	-16.8	3.6	7.0	NA[2]
T3S2	843	-6.0	4.9	16	4.9	1511	-15.0	5.2	7.0	NA
T3S3	846	-0.8	9.4	24.3	9.7	1513	-14.5	10.2	16.3	10.3
T3S4	849	-10.0	29.7	13.2	27.2	1514	-23.0	23.3	7.0	NA

[1] T= Transect, followed by Transect #, S=Station, followed by Station #

[2] NA = probe depth was at surface (-7 cm) and so salinity is the same as surface salinity

Table 2. Salinities and water table elevations at spring tide on 08/24/18. Predicted high tide was at 1157; predicted low was at 0502.

	High tide					Low tide				
		Surface (-7 cm)		At probe depth			Surface (-7 cm)		At probe depth	
Location[1]	Time	Water table elevation	Salinity	Probe depth (cm)	Salinity	Time	Water table elevation	Salinity	Probe depth (cm)	Salinity
T1S1	1527	-7.8	0.82	28.5	0.85	1022	-6.75	0.77	27.8	0.93
T1S2	1530	-8.0	3.12	22.5	3.02	1025	-5.00	2.89	21.0	3.01
T1S3	1533	-17.0	1.54	34.7	1.49	1030	-3.50	11.55	34.8	1.55
T1S4	1535	-14.8	9.14	20.0	9.75	1034	-14.50	9.49	18.5	9.38
T2S1	1553	-9.0	0.19	ND[2]	0.20	1100	-6.50	0.19	25.5	0.19
T2S2	1551	-7.0	0.23	27.0	0.23	1057	-4.00	0.22	29.5	0.23
T2S3	1548	-6.5	0.24	30.5	0.26	1054	-6.25	0.24	34.8	0.33
T2S4	1543	-8.0	1.71	30.8	1.67	1049	-4.00	1.73	34.8	1.69
T2S5	1542	-8.0	5.08	34.8	4.88	1045	-4.00	4.94	34.8	5.15
T2S6	1540	-8.0	8.12	31.5	10.23	1042	-6.75	6.96	28.0	17.69
T2S7	1538	0.0	17.18	16.5	18.29	1038	-0.50	19.92	8.5	20.81
T3S1	1558	-12.0	2.18	NA	NA	1107	-14.00	2.16	7.0	NA[3]
T3S2	1600	-18.0	3.15	NA	NA	1110	-15.00	3.11	7.0	NA
T3S3	1602	-12.0	6.72	16.5	6.76	1112	-13.50	6.86	11.0	7.06
T3S4	1603	-20.5	27.79	20.0	NA	1115	-25.00	29.49[2]	3.0	NA

[1] T= Transect, followed by Transect #, S=Station, followed by Station #

[2] ND= no data

[3] NA = probe depth was at surface (-7 cm) and so salinity is the same as surface salinity

Furthermore, tidal fluctuations in Stewarts Creek lagged water level fluctuations predicted for Hyannis Harbor. For example, the August 17 low tide (neap tide) lagged by about two hours behind the predicted low for Hyannis Harbor, whereas the high tide lagged by about three hours behind the predicted high tide.

Water table elevation in the marsh for all transects was lower at low tide than high tide during the neap phase, which was expected. However, during the spring tidal phase, the water table elevation was higher (or only slightly lower) at low tide than at high tide. The only explanation for this unexpected result is that there is a long lag time in tidal fluctuations in the marsh relative the creek during the spring tidal phases, longer than the lag that occurs during the neap phase. That is, when the tide is high in the creek, water levels are still low in the marsh and vice versa. The amount of groundwater being discharged from uplands to the marsh likely complicates water table fluctuations even more.

Tidal flooding of the *Phragmites* marsh does not meet the success criteria for Objective 1 [i.e., area of the marsh flooded between once daily and two to eight times monthly is increased (relative to pre-restoration conditions) to within 75% of the plan requirements]. Only marsh stations located at or near (within 5 m) of the marsh/creek interface regularly floods at the surface[6]; the rest of the marsh surface never floods at high tide, except perhaps during storm surges[7]. Lack of regular flooding may be partially due to the thick layer of *Phragmites* peat (mostly rhizomes) that has raised the surface of the marsh as it has accumulated over the many years tidal flow has been restricted. The thickness of this *Phragmites* peat (depth to sand, silt, or saltmarsh peat) ranges from 31–51 cm (mean = 42 cm)[8]. There has been no change in the extent of surface flooding during high tides since the 2015 monitoring report.

Success criterion B: Soil water salinity is 20–33 ppt in portions of the marsh below the elevation of mean spring high tide.

Methods used for measuring Success criterion B: We measured water salinity with a YSI meter at low and high tides during the spring and neap tidal phases at each of fifteen stations along three transects in Stewarts Creek. We measured pore water salinity in holes we dug through the *Phragmites* peat to the original surface elevation and measured salinity both at the surface and at the bottom of the auger hole.

Results: Porewater salinity in the marsh interior never exceeded 20 ppt[9]; only the stations nearest the marsh/creek interface reached salinities above or near 20 ppt (**Tables 1 and 2**). Most porewater salinities values in the marsh interior were close to fresh (0.2–5 ppt). Only two stations at the ends of transects (at the marsh/creek boundary) showed surface porewater salinities >17 ppt (Stations T2S7 and T3S4) and only three stations showed porewater salinities >17 ppt at the bottom of the auger holes (Stations T2S6, T2S7, and T3S4).

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[6] Despite surface flooding at the marsh/creek interface, *Phragmites* dominated all plots except plot T3S4.
[7] We have no tide data for storm surges.
[8] Transect 3 Station 4 (creek edge) was not included because it was saltmarsh (only a few *Phragmites* stems).
[9] Salinity of pure seawater is about 23 ppt.

Porewater salinity does not meet Success criterion B (20–33 ppt required) for any portion of the marsh interior. However, the success criterion stipulates that the salinity criterion be met for portions of the marsh below mean spring high tide. Except at the marsh/creek interface (most shoreward stations), spring high tide does not flood the marsh surface, likely because *Phragmites* roots have raised the marsh surface by 31–51 cm[10]. There has been essentially no change in porewater salinities since the 2015 monitoring.

***Success criterion C*: The percent cover of salt marsh vegetation is higher (than under pre-restoration conditions) in areas flooded once daily to two to eight times monthly and is within 75% of reference condition.

Methods used for measuring Success criterion C: We quantitatively sampled the marsh vegetation at 15 stations in Stewarts Creek and 12 stations in Halls Creek to compare cover of native salt marsh vegetation with the amount of *Phragmites australis* cover. To do this, we sampled three 0.25 m^2 plots at each station, one near the location of the porewater hole (Plot 1) and two plots located about 5 m from Plot 1 (one on each side of Plot 1 parallel to shore). We estimated plant species cover into one the following cover classes and recorded the midpoint of the class (in parentheses): no cover (0%), trace (T, < 1%), 1-5% (3%), 5-25% (15%), 25-50% (37%), 50% (50%), 50-75% (62%), 75-95% (85%), 95-100 % (97%), ≥ 100% (100%). If the plot contained *Phragmites*, we counted the number of live *Phragmites* stems growing it and the number of those stems that were in flower or ready to flower. We also recorded the height of the tallest *Phragmites* stem.

Results: Halls Creek, the reference site, is a typical New England salt marsh. It is overwhelming dominated by *Spartina alterniflora* (89.2%), with lesser amounts of *Salicornia maritima* (6.4%) (**Table 3**). The shoreline of some plots was covered with wrack of brown algae (*Fucus vesiculosis*) and/or mats of decaying algae (*Ulva* sp. or filamentous algae). There was no *Phragmites* in any of the plots, but there was quite a bit of bare ground (mean = 24.7% cover). The vegetation in Halls Creek marsh has not changed since the 2015 sampling effort.

Only three of 45 plots sampled in Stewarts Creek supported any salt marsh vegetation (*Spartina alterniflora, S. patens,* and/or *Distichlis spicata*) and those plots were only at stations along the shoreline at the terminus of Transect 3, the transect closest to the inlet (culvert) **(Table 4)**. The other 42 plots were overwhelmingly dominated by *Phragmites* (54%) and secondarily by *Vitis labrusca* (8.5%) and *Hibiscus moscheutos* (7.6%). A few other freshwater wetland species co-dominated (>15%) in some plots, including *Impatiens capensis, Typha angustifolia, Persicaria hydropiperoides, Toxicodendron radicans, Celatrus orbiculata*, and *Ericthites hieraciifolius*. All these plant species are freshwater species (i.e., saltwater intolerant). In contrast, none of the freshwater species occurred at the Halls Creek reference site **(Table 3).**

[10] Essentially, the *Phragmites* is now perched above the original marsh surface, thus preventing tidal flooding at the surface.

Table 3. Vegetation in Halls Creek marsh (reference marsh). T= Trace (<1% cover), S = Station.

HALLS CREEK (08/10/18)	Transect 1				Transect 2				Transect 3			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Bare ground	20.7	24.3	3.0	69.7	30.7	-	6.3	34.0	42.0	5.7	6.3	54.0
Wrack (*Fucus vesiculosis*)	-	-	-	-	-	-	-	25.7	-	-	-	26.3
Wrack (filamentous algae)	-	-	-	-	-	-	-	0.7	-	-	-	-
Spartina alterniflora	-	97.0	85.0	29.7	69.0	93.0	93.0	10.7	49.7	81.3	93.0	22.3
Distichlis spicata	22.5	-	-	-	5.0	-	-	-	-	-	-	-
Salicornia maritima	38.2	0.7	6.3	-	T	T	T	-	0.7	5.0	0.7	-
Baccharis halimifolia	5.0	-	-	-	-	-	-	-	-	-	-	-
Limonium carolineanum	-	-	-	-	-	-	-	-	-	0.7	-	-
Suaeda linearis	T	-	-	-	-	-	-	-	-	-	-	-

Table 4. Vegetation in Stewarts Creek marsh. Salt marsh plant species highlighted in yellow. T= Trace (<1% cover), S = Station.

STEWARTS CREEK (08/24/18)	Transect 1				Transect 2							Transect 3			
	S1	S2	S3	S4	S1	S2	S3	S4	S5	S6	S7	S1	S2	S3	S4
Bare ground	2.0	29.7	29.0	-	-	29.0	-	6.3	5.7	30.7	77.3	-	T	22.3	13.7
Phrag detritus	57.3	60.7	99.0	100.0	100.0	66.7	100.0	89.0	82.3	61.7	32.5	100.0	99.0	73.5	12.5
Phragmites australis	54.0	58.0	73.3	61.3	45.7	70.7	73.7	77.3	45.7	54.0	29.7	61.7	61.3	45.3	22.3
Celantrus orbiculatus	-	-	-	-	15.0	-	-	-	-	-	-	-	-	-	-
Decodon verticillatus	15.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hybiscus moscheutos	2.0	-	37.0	-	-	-	-	5.0	25.7	-	-	-	T	40.8	-
Ilex verticillata	-	-	-	-	15.0	-	-	-	-	-	-	-	-	-	-
Impatiens capensis	0.8	-	-	-	-	62.0	-	-	-	-	-	-	-	-	-
Parthenocissus quiquefolia	-	-	-	-	26.0	-	-	-	-	-	-	5.0	12.3	-	-
Persicaria hydropiperoides	-	-	15.0	-	-	-	-	-	-	-	-	-	25.7	5.2	-
Toxicodendron radicans	-	-	-	-	15.0	61.3	-	-	-	-	-	-	-	-	-
Typha angustifolia	1.3	5.3	8.5	T	-	-	-	-	T	0.7	43.5	-	-	T	12.3
Vitis labrusca	26.0	2.0			73.5	-	-	-	-	-	-	12.3	-	-	-
Spartina alterniflora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	15.0
Spartina patens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44.7
Distichlis spicata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16.7
Smilax rotundifolia	-	-	-	-	-	-	-	-	-	-	-	16.7	-	-	-
Apios americana	-	-	-	-	-	-	-	-	-	-	-	T	-	-	-
Ericthites hieraciifolius	-	-	-	-	-	-	-	-	-	-	-	T	10.0	-	-
Frangulus alnus	-	-	-	-	-	-	-	-	-	-	-	T	-	-	-
Calystegia sepium	-	-	-	-	-	-	-	-	-	-	-	-	5.0	2.4	-
Morella pennsyvanica	-	-	-	-	-	-	-	-	-	-	-	-	5.0	-	-
Schoenoplectus pungens	-	-	-	-	-	-	-	-	-	-	-	T	-	-	-
Ptilimnium capillaceum	-	-	-	-	-	-	-	-	-	-	-	-	-	0.7	-
Atriplex sp. (prostrata or glabruscula)	-	-	-	-	-	-	-	-	-	-	-	-	-	T	-

Phragmites australis in the Stewarts Creek marsh is very dense, ranging from 3–24 stems/0.25m^2 plot (mean = 13). The *Phragmites* in plots were also tall, ranging from 1.25–3.8 m in height (mean = 2.94 m) (**Table 5).** Clearly, success Criterion C (vegetation recovery) has not been met.

However, the success criteria stipulates percent cover should increase in areas flooded once daily to two to eight times monthly, but only the most shoreward plots (marsh/creek interface) flood that frequently, likely because *Phragmites* roots have raised the marsh surface elevation, thus preventing surface flooding by tides.

Table 5. Characteristics of *Phragmites australis*, by plot, in Stewarts Creek. Plot names: T = transect, followed by transect #, S = Station, followed by Station #, and P = 0.25 m^2 plot, followed by Plot #. Sampling dates: Transects 1 and 2 (8/10/18) and Transect 3 (8/24/18).

Plot	%Cover	#Stems	#Stems in flower	Height (cm)
T1S1P1	62	13	10	230
T1S1P2	50	15	5	290
T1S1P3	50	14	7	290
T1S2P1	50	17	4	245
T1S2P2	62	17	10	305
T1S2P3	62	16	8	260
T1S3P1	50	16	10	305
T1S3P2	85	23	13	310
T1S3P3	85	24	15	270
T1S4P1	97	11	3	330
T1S4P3	37	12	9	310
T1S4P3	50	8	6	330
T2S1P1	15	9	5	350
T2S1P2	37	6	2	305
T2S1P3	85	14	2	380
T2S2P1	50	16	4	310
T2S2P2	62	18	7	320
T2S2P3	85	21	15	370
T2S3P1	97	15	12	360
T2S3P2	62	14	12	330
T2S3P3	62	7	7	380
T2S4P1	85	12	10	330
T2S4P3	62	22	21	320
T2S4P3	85	16	12	330
T2S5P1	50	12	10	305
T2S5P2	50	14	10	301
T2S5P3	37	13	12	300
T2S6P1	62	14	9	330
T2S6P2	85	17	16	330
T2S6P3	15	4	5	245
T2S7P1	15	12	4	310
T2S7P2	37	9	7	320
T2S7P3	37	6	1	280
T3S1P1	85	18	15	340
T3S1P2	15	4	4	250
T3S1P3	85	13	16	360
T3S2P1	37	13	12	290
T3S2P2	85	18	14	285
T3S2P3	62	26	20	280
T3S3P1	37	9	4	188
T3S3P2	37	12	8	245
T3S3P3	62	20	17	275
T3S4P1	15	4	3	125
T3S4P2	15	3	2	140
T3S4P3	37	5	1	185
Mean	55.3	13		294
SD	24.2	5.6		56
Range	15-97	3-24		125-380

Discussion

Five years after enlarging the culvert on Ocean Ave., none of the success criteria have been met for restoring the Stewart Creek *Phragmites* marsh to salt marsh. Stewarts Creek's marsh is still dominated exclusively by a robust and dense stand of *Phragmites australis*, except along a narrow strip of a small section of the shoreline. Although replacing the culvert and enhancing tidal exchange has improved tidal creek habitat,[11] the improved tidal exchange does not flood the marsh, except possibly during extreme storm events. Furthermore, the change in hydraulic regime has done nothing to counteract the long-term cumulative impact of the prior culvert, which trapped nutrients entering the estuary from upstream, from groundwater, and from surface runoff from fertilized yards and a golf course upstream. This nutrient enrichment has allowed *Phragmites* to invade and displace the original salt marsh and accumulate a high amount (0.5 m) of peat rhizome biomass over time. A freshwater lens of groundwater flows through the root zone of this raised fringing marsh. This groundwater input is substantial enough to maintain almost freshwater conditions in the root zone of the marsh, thus preventing inundation by salt water even though tidal regime has been partially restored to the estuary proper.

The *Phragmites* population along Stewarts Creek seems to have produced a substantial belowground rhizome system, enabling it to raise itself high above high tides of Stewarts Creek. The *Phragmites* stand is dense and robust, indicating that is successfully outcompeting potential competitors (Moore et al. 2012). In addition, the marsh sits atop a freshwater lens fed by groundwater from adjacent uplands. This groundwater is likely high in nitrogen, judging by the density of houses in the watershed and the intensity of fertilized of lawns upgradient from the marsh.

Fertilization of the *Phragmites* stand via groundwater and surface runoff over many decades may be somewhat responsible for the robustness of both above- and below-ground biomass (Myerson et al. 2002). However, wastewater from septic fields in the watershed has been leaching into the ground water for many decades, and even though much of the watershed has recently been sewered, there will likely be a several-decade time lag before nitrogen is flushed from the groundwater system. Given the current situation, it will be very difficult to eradicate *Phragmites* without mechanically removing its rhizomes and standing biomass, thereby reducing the marsh elevation by 0.3–0.5 m. Mechanical removal of *Phragmites* and its rhizomatous root system is the only way to insure tidal incursion across the marsh surface and into the root zone of marsh species. Excavation would both help prevent re-establishment of *Phragmites* and allow *Spartina* to establish in its place. However, until groundwater sources of nitrogen (septic and fertilizer) are eliminated or drastically reduced, *Phragmites* will likely eventually re-establish along the upland border even if it removed from the marsh proper.

It is perplexing that the USACE restoration has failed to meet its objective of flooding the marsh surface. USACE success criteria were based on meeting 75% of "Plan requirements", but plan

[11] See WHG report to which this report is attached.

requirements were not clearly articulated. Nonetheless, only 1 of 15 stations supported salt marsh, suggesting that perhaps less than 10% of the marsh is subjected to saturation by saline water. USACE designed the box culvert to accommodate a particular (chosen) tidal exchange, an exchange that the hydraulic model predicted would flood the marsh surface. Clearly, the marsh surface is not being flooded. This would suggest that either the hydraulic model was based on inaccurate data, the model was incorrectly calibrated, and/or the culvert was designed or constructed improperly.

The chosen model would have identified a particular opening (dimension) that was an optimal compromise between flooding the marsh and avoiding the flooding of private infrastructure. However, It is conceivable that the culvert dimension chosen by the model (or based on an iterative series of run models) identified culvert dimension properly, but that grating (**Figure 3**) on the upstream end of the culvert was added by project designers (or insisted upon by managers) as a safety precaution[12], but without considering its potential effect on tidal exchange. The grating has 13 bars (each 1.75”in diameter), which reduces the effective width of the culvert opening from 72” to 50” (producing a 31% narrower opening). The grating also collects wrack during ebb flows, which would further reduce the amount of potential tidal flushing. This constriction in the culvert opening (by the grate and wrack) would reduce the amount of tidal flushing that could potentially occur, likely enough to fail to meet flooding expectations (predictions). Tidal flushing could be improved by more frequently removing wrack that accumulates on the upstream side of the culvert opening, but the biggest improvement could be obtained by removing the grating altogether and using other infrastructure (outside the channel) to make it difficult for people to access the culvert opening from shore.

Figure 3. Wrack collecting on grates on the upstream side of the new culvert under Stewarts Creek during ebb flow.

[12] Presumably, the grate is there to prevent people who wade too closely to the culvert from getting sucked into it during strong ebb flows.

Adaptive Management

Restoring full tidal exchange might be sufficient to inundate the *Phragmites* marsh with salt water on a regular basis, but this strategy is likely not economically feasible. The first adaptive management option is to remove the grating blocking the culvert and use other means to deter people from accessing the culvert. Given the invasive nature of *Phragmites* (Uddin and Robinson 2018), any adaptive management approach that does not lower the marsh elevation relative to the current tide heights (poisoning, mowing, saltwater spraying) might only provide muted or temporary results until nitrogen input to the marsh is substantially reduced. Even if increased tidal flooding of the marsh successfully dilutes groundwater nitrogen concentration, *Phragmites* will continue to dominate the upland/wetland transition at the break in slope unless nitrogen input is reduced drastically where freshwater is discharged.

The only other option for eradicating *Phragmites* is to reduce the elevation of the marsh surface by removing the 0.5 m of *Phragmite*s peat that has accumulated there. To restore saltmarsh to the marsh proper (beyond the upland transition zone), the accumulated *Phragmites* peat would have to be excavated (with a backhoe or similar equipment) and removed from the site or chipped/pulverized and burned on site. However, care would have to be taken to prevent the heavy equipment from getting stuck in the soupy muck maintained by groundwater input. In addition, there may be only one practical access point and that is through private property. This option could be expensive and it might be a challenge to obtain regulatory permits and acquiring access rights through private property.

The intertidal portion of the project is still on a restoration trajectory and so it is possible that saltmarsh species will eventually naturally colonize portions of that area. Alternatively, *S. alterniflora* could be planted at appropriate elevations in the intertidal portion of the site and see if it survives and spreads to other areas.

Lessons Learned

A lot of effort was devoted to predicting the tidal elevation after enlarging the culvert. Apparently, the predictions were inaccurate. In addition, it appears that the groundwater discharge and the position (elevation) of the freshwater lens were not factored into the hydrologic models. Furthermore, the amount of nitrogen transported by groundwater was not considered.

Nitrogen concentration may influence the robustness of *Phragmite*s and its resiliency to eradication (Bertness et al. 2002, Myerson et al. 2002, Sciance et al. 2016, Uddin and Robinson 2018). The Stewarts Creek restoration attempt underscores the importance of accurately predicting post-project tides heights and in determining the amount of groundwater being discharged to fringing marshes identified for restoration. Furthermore, if *Phragmites* is to be eradicated, the effects of nitrogen concentration in groundwater input should also be considered. *Phragmites* established in the densities measured in this study is difficult to eradicate without raising salinity concentrations sufficiently, especially if nitrogen concentrations are high in freshwater inputs. If removing the grating system on the culvert does not successful in eradicating *Phragmites* from the marsh fringing Stewarts Creek, then extraordinary effort will be required to mechanically eradicate *Phragmites* and its peat biomass.

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Appendix

Table A1. Spring tide data for Stewarts Creek marsh.

SPRING (08/24/18) — HIGH TIDE

Location[1]	Time	Water Table elev	Surface salinity (-7 cm)	Conductivity at surface ms/cm	Conductivity at surface um/cm	pH at surface	Probe Depth (cm)	Salinity at probe depth	Conductivity at depth ms/cm	Conductivity at depth um/cm	pH at probe depth
T1S1	1527	-7.8	0.82	1.632	1,623	6.40	28.5	0.85	1.70	1,524	6.16
T1S2	1530	-8.0	3.12	5.735	5,488	6.09	22.5	3.02	5.60	5,207	6.12
T1S3	1533	-17.0	1.54	2.946	2,753	6.26	34.7	1.49	2.87	2,537	6.13
T1S4	1535	-14.8	9.14	15.95	14,905	6.2	20.0	9.75	16.52	15223	6.21
T2S1	1553	-9.0	0.19	0.406	362	6.67		0.20	0.43	372	6.68
T2S2	1551	-7.0	0.23	0.47	444	6.39	27.0	0.23	0.48	434	6.37
T2S3	1548	-6.5	0.24	0.497	448	6.49	30.5	0.26	0.46	491	6.35
T2S4	1543	-8.0	1.71	3.229	2,970	6.34	30.8	1.67	3.20	2,879	6.27
T2S5	1542	-8.0	5.08	9.07	8,616	6.37	34.8	4.88	8.73	7,895	6.33
T2S6	1540	-8.0	8.12	14.19	13,256	6.57	31.5	10.23	17.58	16,112	6.51
T2S7	1538	0.0	17.18	28.06	26,895	6.77	16.5	18.29	29.58	27,640	6.75
T3S1	1558	-12.0	2.18	4.093	3,725	6.55	NA[2]	NA	NA	NA	NA
T3S2	1600	-18.0	3.15	5.735	5,230	6.48	NA	NA	NA	NA	NA
T3S3	1602	-12.0	6.72	11.73	10,923	6.23	16.5	6.76	11.85	10978	6.19
T3S4	1603	-20.5	27.79	43.24	41,595	6.4	20.0	NA	NA	NA	NA

SPRING (08/24/18) — LOW TIDE

Location[1]	Time	Water Table elev	Surface salinity (-7 cm)	Conductivity at surface ms/cm	Conductivity at surface um/cm	pH at surface	Probe Depth	Salinity at probe depth	Conductivity at depth ms/cm	Conductivity at depth um/cm	pH at probe depth	Depth to Substrate (cm)	Substrate type
T1S1	1022	-6.75	0.77	1.532	1,349	6.28	27.8	0.93	1.835	1,620	6.04	49.0	silt/peat
T1S2	1025	-5.00	2.89	5.49	4,902	6.14	21.0	3.01	5.58	4,993	6.11	33.0	silt
T1S3	1030	-3.50	11.55	2.97	2,596	6.25	34.8	1.55	2.98	2,594	6.07	49.0	peat
T1S4	1034	-14.50	9.49	16.21	14,673	6.17	18.5	9.38	15.96	14,383	6.20	46.5	sand
T2S1	1100	-6.50	0.19	0.393	341	6.55	25.5	0.19	0.404	351	6.56	47.3	peat
T2S2	1057	-4.00	0.22	0.465	413	6.34	29.5	0.23	0.476	420	6.29	48.0	peat/silt
T2S3	1054	-6.25	0.24	0.493	437	6.31	34.8	0.33	0.679	599	6.07	51.0	peat/sand
T2S4	1049	-4.00	1.73	3.28	2,915	6.43	34.8	1.69	3.237	2,873	6.27	42.0	peat/silt
T2S5	1045	-4.00	4.94	8,875	7,947	6.55	34.8	5.15	9.185	8,274	6.34	45.5	peat/sand
T2S6	1042	-6.75	6.96	12.11	10,892	6.84	28.0	17.69	29.38	26,932	6.62	49.0	peat
T2S7	1038	-0.50	19.92	32.82	29,927	6.64	8.5	20.81	33.11	30,036	6.67	31.3	sand
T3S1	1107	-14.00	2.16	4.071	3,558	6.43	7.0	NA	NA	NA	NA	31.0	peat/c. sand
T3S2	1110	-15.00	3.11	5.74	5,160	6.45	7.0	NA	NA	NA	NA	31.0	peat/c. sand
T3S3	1112	-13.50	6.86	12.01	10,869	6.34	11.0	7.06	12.3	11,066	6.28	38.5	peat/c. sand
T3S4	1115	-25.00	29.49[3]	45.56	47,816	7.35	3.0	NA	NA	NA	NA	3.0	mud/sand

[1] T= Transect, followed by Transect #, S=Station, followed by Station #

[2] NA = probe depth was at surface (-7 cm) and so salinity is the same as surface salinity

[3] Not able to get YSI deep enough for reading. Took reading in creek.

Table A2. Neap tide data for Stewarts Creek marsh.

NEAP (08/17/18) Slack HT at 0848 — HIGH TIDE

Location[1]	Time	Water Table elev	Surface salinity (-7 cm)	Conductivity at surface ms/cm	Conductivity at surface um/cm	pH at surface	Probe Depth	Salinity at probe depth	Conductivity at depth ms/cm	Conductivity at depth um/cm	pH at probe depth
T1S1	759	-2.0	1.0	2.01	1,864	6.2	26.6	1.4	2.7	2,512	5.9
T1S2	803	-3.0	3.2	5.9	5,519	6.0	24	3.4	6.2	5,833	5.8
T1S3	806	-4.5	3.6	6.8	6,260	5.9	31.5	5.8	10.3	9,384	5.6
T1S4	811	-9.0	10.7	18.2	17,299	6.0	24.7	11.6	19.3	19,232	5.9
T2S1	832	-4.0	0.2	0.4	334	6.7	34.8	0.2	0.4	354	6.6
T2S2	830	-4.0	0.3	0.6	512	6.5	34.8	0.3	0.6	517	6.2
T2S3	828	-4.3	0.4	0.8	789	6.5	34.8	0.4	0.9	822	6.2
T2S4	825	-2.8	2.8	5.1	4,033	6.1	34.8	4.1	7.6	7,046	5.9
T2S5	822	-4.0	6.2	10.9	10,272	6.2	34.8	6.3	10.9	10	6.1
T2S6	819	2.5	13.1	21.7	20,857	6.5	34.8	23.7	36.9	35	6.3
T2S7	815	9.3	29.4	45.5	44,933	7.0	25.5	26.3	41.2	40,282	6.8
T3S1	841	-6.3	3.5	6.4	5,785	6.1	16.6	3.5	6.3	5,735	5.9
T3S2	843	-6.0	4.9	8.8	8,093	6.1	16	4.9	8.8	8,069	6.1
T3S3	846	-0.8	9.4	16.0	15,082	5.9	24.3	9.7	16.4	15,385	5.8
T3S4	849	-10.0	29.7	45.8	44,549	6.5	13.2	27.2	42.4	41,222	6.5

(Dead low tide was at 1315) — LOW TIDE

Location[1]	Time	Water Table elev	Surface salinity (-7 cm)	Conductivity at surface ms/cm	Conductivity at surface um/cm	pH at surface	Probe Depth (cm)	Salinity at probe depth	Conductivity at depth ms/cm	Conductivity at depth um/cm	pH at probe depth
T1S1	1439	-5.0	1.2	2.4	2,420	6.1	27.5	1.3	2.6	2,462	6.96
T1S2	1442	-6.5	3.4	6.2	6,215	6.0	23.3	3.4	6.3	6,090	5.95
T1S3	1443	-4.8	3.8	6.9	6,667	5.0	34.0	9.1	7.5	7,509	5.76
T1S4	1447	-12.3	10.6	18.0	17,455	6.0	21.5	11.7	9.7	18,763	6.02
T2S1	1504	-8.0	0.2	0.4	387	6.4	32.5	0.2	0.4	360	6.47
T2S2	1502	-4.8	0.3	0.6	540	6.2	34.8	0.3	0.5	495	6.14
T2S3	1500	-5.0	0.4	0.9	859	6.4	34.8	0.4	0.9	811	6.14
T2S4	1458	-4.0	2.7	5.3	5,117	6.1	34.8	3.2	6.0	5,527	6.01
T2S5	1457	-6.0	6.7	11.5	11,027	6.2	34.8	6.3	11.0	10,293	6.10
T2S6	1454	-4.0	14.9	24.9	24,296	6.5	32.5	24.1	38.0	35,999	6.27
T2S7	1452	0.0	24.7	38.3	40,508	6.7	19.0	29.9	40.7	40,608	6.64
T3S1	1509	-16.8	3.6	6.6	6,274	6.1	7.0	NA[2]	NA	NA	NA
T3S2	1511	-15.0	5.2	9.2	8,692	6.0	7.0	NA	NA	NA	na
T3S3	1513	-14.5	10.2	17.4	17,071	5.8	16.3	10.3	17.5	11,933	5.76
T3S4	1514	-23.0	23.3	37.0	37,731	6.4	7.0	NA	NA	NA	NA

[1] T= Transect, followed by Transect #, S=Station, followed by Station #

[2] NA = probe depth was at surface (-7 cm) and so salinity is the same as surface salinity

Table A3. Vegetation for Transect 1, Halls Creek marsh. T = Trace (<1% cover), S = Station, P = plot.

Transect 1	S1P1	S1P2	S1P3	S1	S2P1	S2P2	S2P3	S2	S3P1	S3P2	S3P3	S3	S4P1	S4P2	S4P3	S4
Bare ground	62.0	-	-	20.7	61.7	5.0	6.3	24.3	2.0	2.0	5.0	3.0	62.0	85.0	62.0	69.7
Wrack (*Fucus vesiculosis*)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Wrack (filamentous algae)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spartina alterniflora	-	-	-	-	97.0	97.0	97.0	97.0	85.0	85.0	85.0	85.0	37.0	15.0	37.0	29.7
Distichlis spicata	15.0	2.6	50.0	22.5	-	-	-	-	-	-	-	-	-	-	-	-
Salicornia maritima	2.5	62.0	50.0	38.2	T	T	2.0	2.0	15.0	2.0	2.0	6.3	-	-	-	-
Baccharis halimifolia	15.0	-	-	5.0	-	-	-	-	-	-	-	-	-	-	-	-
Limonium carolineanum	-	-	-	0.0	-	-	-	-	-	-	-	-	-	-	-	-
Suaeda linearis	T	T	-	T	-	-	-	-	-	-	-	-	-	-	-	-

Table A4. Vegetation for Transect 2, Halls Creek marsh. T = Trace (<1% cover), S = Station, P = plot.

Transect 2	S1P1	S1P2	S1P3	S1	S2P1	S2P2	S2P3	S2	S3P1	S3P2	S3P3	S3	S4P1	S4P2	S4P3	S4
Bare ground	62.0	15.0	15.0	30.7	-	-	-	-	2.0	15.0	2.0	6.3	85.0	15.0	2.0	34.0
Wrack (*Fucus vesiculosis*)	-	-	-	-	-	-	-	-	-	-	-	-	15.0	62.0	-	25.7
Wrack (filamentous algae)	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	-	0.7
Spartina alterniflora	37.0	85.0	85.0	69.0	97.0	85.0	97.0	93.0	97.0	85.0	-	60.7	15.0	15.0	2.0	10.7
Distichlis spicata	15.0	-	-	5.0	-	-	-	-	-	-	-	-	-	-	-	-
Salicornia maritima	-	T	T	T	T	T	T	T	T	T	T	T	-	-	-	-
Baccharis halimifolia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limonium carolineanum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Suaeda linearis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A5. Vegetation for Transect 3, Halls Creek marsh. T = Trace (<1% cover), S = Station, P = plot.

Transect 3	S1P1	S1P2	S1P3	S1	S2P1	S2P2	S2P3	S2	S3P1	S3P2	S3P3	S3	S4P1	S4P2	S4P3	S4
Bare ground	62.0	62.0	2.0	42.0	T	2.0	15.0	8.5	2.0	2.0	15.0	6.3	15.0	62.0	85.0	54.0
Wrack (*Fucus vesiculosis*)	-	-	-	-	-	-	-	-	-	-	-	-	62.0	15.0	2.0	26.3
Wrack (filamentous algae)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spartina alterniflora	15.0	37.0	97.0	49.7	62.0	97.0	85.0	81.3	97.0	97.0	85.0	93.0	15.0	37.0	15.0	22.3
Distichlis spicata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Salicornia maritima	2.0	T	-	1.0	15.0	T	T	15.0	T	T	2.0	2.0	-	-	-	-
Baccharis halimifolia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limonium carolineanum	-	-	-	-	T	-	2.0	1.0	-	-	-	-	-	-	-	-
Suaeda linearis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A6. Vegetation for Transect 1, Stewarts Creek marsh. T = Trace (<1% cover), S = Station, P = plot. Salt marsh species highlighted in yellow.

Transect 1	S1P1	S1P2	S1P3	S1	S2P1	S2P2	S2P3	S2	S3P1	S3P2	S3P3	S3	S4P1	S4P2	S4P3	S4
Bare ground	2.0	2.0	2.0	2.0	2.0	85.0	2.0	29.7	-	2.0	85.0	29.0	-	-	-	-
Phragmites australis	62.0	50.0	50.0	54.0	50.0	62.0	62.0	58.0	50.0	85.0	85.0	73.3	97.0	37.0	50.0	61.3
Phrag detritus	2.0	85.0	85.0	57.3	85.0	-	97.0	60.7	100.0	97.0	100.0	99.0	100.0	100.0	100.0	100.0
Celantrus orbiculatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Decodon verticillatus	-	15.0	-	5.0	-	-	-	-	-	-	-	-	-	-	-	-
Hybiscus moscheutos	-	-	2.0	0.7	-	-	-	-	-	-	37.0	12.3	-	-	-	-
Ilex verticillata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Impatiens capensis	2.0	-	T	0.8	-	-	-	-	-	-	-	-	-	-	-	-
Parthenocissus quiquefolia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Persicaria hydropiperoides	-	-	-	-	-	-	-	-	-	-	15.0	5.0	-	-	-	-
Toxicodendron radicans	-	-	-	-	-	-	-	-	-	-		-	-	-	-	-
Typha angustifolia	-	2.0	2.0	1.3	15.0	T	T	5.3		15.0	2.0	8.5	-	-	T	T
Vitis labrusca	37.0		15.0	26.0	2.0	-	-	0.7	-	-	-	-	-	-	-	
Spartina alterniflora				-				-				-			-	-
Spartina patens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Distichlis spicata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A7. Vegetation for Transect 2, Stewarts Creek marsh. T = Trace (<1% cover), S = Station, P = plot. Salt marsh species highlighted (yellow).

Transect 2	S1P1	S1P2	S1P3	S1	S2P1	S2P2	S2P3	S2	S3P1	S3P2	S3P3	S3	S4P1	S4P2	S4P3	S4
Bare ground	-	-	-		-	-	85.0	28.3	-	-	-	-	2.0	15.0	2.0	6.3
Phragmites australis	15.0	37.0	85.0	45.7	50.0	62.0	100.0	70.7	97.0	62.0	62.0	73.7	85.0	62.0	85.0	77.3
Phrag detritus	100.0	100.0	100.0	100.0	100.0	100.0	-	66.7	100.0	100.0	100.0	100.0	85.0	85.0	97.0	89.0
Celantrus orbiculatus	-	-	15.0	5.0	-	-	-	-	-	-	-	-	-	-	-	-
Decodon verticillatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hybiscus moscheutos	-	-	-	-	-	-	-	-	-	-	-	-	-	15.0	-	5.0
Ilex verticillata	15.0	-	15.0	10.0	-	-	-	-	-	-	-	-	-	-	-	-
Impatiens capensis		-	-	-			62.0	62.0	-	-	-	-	-	-	-	-
Parthenocissus quiquefolia	37.0	-	15.0	17.3	-	-	-	-	-	-	-	-	-	-	-	-
Persicaria hydropiperoides		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Toxicodendron radicans	15.0	-	-	5.0	62.0	37.0	85.0	61.3	-	-	-	-	-	-	-	-
Typha angustifolia		-	-	-	-	-	-	-	-	-	-	-	-	2.0	-	-
Vitis labrusca	62.0	85.0	-	49.0	-	-	-	-	-	-	-	-	-	-	-	-
Spartina alterniflora	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spartina patens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Distichlis spicata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table A7 (cont.)

Transect 2	S5P1	S5P2	S5P3	S5	S6P1	S6P2	S6P3	S6	S7P1	S7P2	S7P3	S7
Bare ground	-	15.0	2.0	5.7	15.0	15.0	62.0	30.7	97.0	85.0	50.0	77.3
Phragmites australis	50.0	50.0	37.0	45.7	62.0	85.0	15.0	54.0	15.0	37.0	37.0	29.7
Phrag detritus	100.0	62.0	85.0	82.3	85.0	85.0	15.0	61.7	T	15.0	50.0	32.5
Celantrus orbiculatus	-	-	-	-	-	-	-	-	-	-	-	-
Decodon verticillatus	-	-	-	-	-	-	-	-	-	-	-	-
Hybiscus moscheutos	62.0	-	15.0	25.7	-	-	-	-	-	-	-	-
Ilex verticillata	-	-	-	-	-	-	-	-	-	-	-	-
Impatiens capensis	-	-	-	-	-	-	-	-	-	-	-	-
Parthenocissus quiquefolia	-	-	-	-	-	-	-	-	-	-	-	-
Persicaria hydropiperoides	-	-	-	-	-	-	-	-	-	-	-	-
Toxicodendron radicans	-	-	-	-	-	-	-	-	-	-	-	-
Typha angustifolia	-	-	T	T	-	-	2.0	0.7	50.0	37.0		43.5
Vitis labrusca	-	-	-	-	-	-	-	-	-	-	-	-
Spartina alterniflora	-	-	-	-	-	-	-	-	-	-	-	-
Spartina patens	-	-	-	-	-	-	-	-	-	-	-	-
Distichlis spicata	-	-	-	-	-	-	-	-	-	-	-	-

Table A8. Vegetation for Transect 3, Stewarts Creek marsh. T = Trace (<1% cover), S = Station, P = plot. Salt marsh species highlighted in yellow.

Transect 3	S1P1	S1P2	S1P3	S1	S2P1	S2P2	S2P3	S2	S3P1	S3P2	S3P3	S3	S4P1	S4P2	S4P3	S4
Bare ground	-	-	-	-	T	-	-	T	15.0	37.0	15.0	22.3	2.0	2.0	37.0	13.7
Phragmites australis	85.0	15.0	85.0	61.7	37.0	85.0	62.0	61.3	37.0	37.0	62.0	45.3	15.0	15.0	37.0	22.3
Phrag detritus	100.0	100.0	100.0	100.0	97.0	100.0	100.0	99.0	85.0		62.0	73.5	-	37.0	0.5	12.5
Celantrus orbiculatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Decodon verticillatus	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-
Hybiscus moscheutos	-	-	-	-	T	-	-	T	37.0	85.0	T	40.8	-	-	-	-
Ilex verticillata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Impatiens capensis	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-
Parthenocissus quiquefolia	-	15.0	-	5.0	37.0	-	-	12.3	-	-	-	-	-	-	-	-
Persicaria hydropiperoides	-	-	-	-	-	62.0	15.0	25.7	15.0	-	0.5	5.2	-	-	-	-
Toxicodendron radicans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Typha angustifolia	-	-	-	-	-	-	-	-	T	-	-	T	-	-	37.0	12.3
Vitis labrusca	37.0	-	-	12.3	-	-	-	-	-	-	-	-	-	-	-	-
Spartina alterniflora	-	-	-	-	-	-	-	-	-	-	-	-	15.0	15.0	15.0	15.0
Spartina patens	-	-	-	-	-	-	-	-	-	-	-	-	97.0	37.0	-	44.7
Distichlis spicata	-	-	-	-	-	-	-	-	-	-	-	-	-	50.0	-	16.7
Smilax rotundifolia	-	50.0	-	16.7	-	-	-	-	-	-	-	-	-	-	-	-
Apios americana	-	T	-	T	-	-	-	-	-	-	-	-	-	-	-	-
Ericthites hieraciifolius	-	T	-	T	15.0	15.0	-	10.0	-	-	-	-	-	-	-	-
Frangulus alnus	-	T	-	T	-	-	-	-	-	-	-	-	-	-	-	-
Calystegia sepium	-	-	-	-	15.0	-	-	5.0	0.5	T	T	2.4	-	-	-	-
Morella pennsyvanica	-	-	-	-	15.0	-	-	5.0	-	-	-	-	-	-	-	-
Schoenoplectus pungens	T	T	-	T	-	-	-	-	-	-	-	-	-	-	-	-
Ptilimnium capillaceum	-	-	-	-	-	-	-	-	-	-	2.0	0.7	-	-	-	-
Atriplex sp. (prostrata or glabruscula)	-	-	-	-	-	-	-	-	-	-	T	T	-	-	-	-

Table A9. Surface salinity data at spring tide on 8/10/18. T = Transect, S = Station, P = Plot.

	HIGH TIDE				LOW TIDE			
Plot	Time	Salinity (at -4 cm)	Conductivity (Ms/cm)	pH	Time	Salinity (at -4 cm)	Conductivity (Ms/cm)	pH
T1S1P1	1136	4.3	7.5	NA	1700	3.4	6.2	5.93
T1S2P1	1144	6.8	12.0	NA	1701	5.8	10.4	5.89
T1S3P1	1149	11.5	19.3	NA	1702	9.1	15.5	5.9
T1S4P1	1151	13.3	22.1	NA	1706	14.3	23.6	6.21
T2S1P1	1203	0.2	0.4	NA	1722	0.2	0.5	6.45
T2S2P1	1201	1.3	2.5	NA	1720	1.1	2.2	5.99
T2S3P1	1200	1.8	3.3	NA	1720	1.7	3.2	6.09
T2S4P1	1158	6.3	11.0	NA	1718	5.9	10.4	5.99
T2S5P1	1157	9.2	15.6	NA	1715	9.2	15.7	6.3
T2S6P1	1156	16.4	26.8	NA	1714	14.3	23.5	6.44
T2S7P1	1155	27.4	42.9	NA	1712	17.2	28.5	6.78
T3S1P1	1208	7.9	7.9	NA	1650	4.8	8.7	5.68
T3S2P1	1209	16.5	16.5	NA	1652	16.9	27.8	5.91
T3S3P1	1210	15.1	15.1	NA	1654	14.7	24.2	5.73
T3S4P1	1210	28.5	28.5	NA	1657	27.9	43.3	6.27