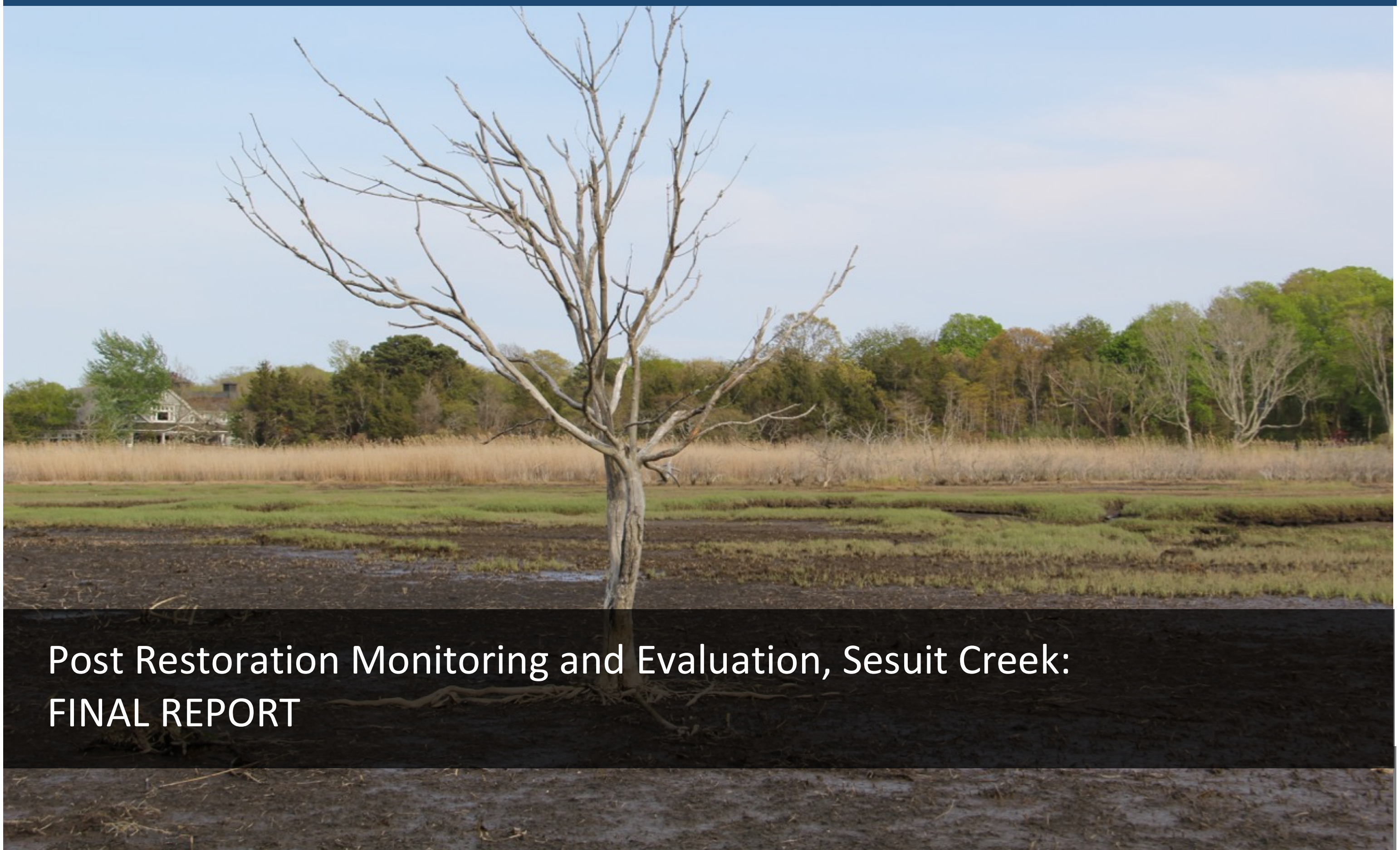

Post Restoration Monitoring and Evaluation, Sesuit Creek: FINAL REPORT

Prepared for:

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Task 1.0 – Project Review/Kick-off Meeting

1.1 Our team reviewed available background materials to prepare for 2016 field work, including project history and current conditions provided by DER, as well as reports, data sets and notes from Louis Berger Group and the University of New Hampshire. These documents were used to lead the first Project Team Meeting (Task 1.2) as well as to help design project approach and make best use of existing data. Review of these materials will also help the Project Team facilitate comparison over time, a critical step in subsequent deliverables we will be reporting on in 2017.

1.2 Led by APCC, we had a Project Team meeting to review the deliverables from Task 1.1. The purpose of this meeting was to clarify project tasks, resolve any questions or concerns, resolve issues related to site access, and reach agreement on project protocols, sampling methods, parameters and schedule. The meeting led to a draft Scope of Work, including specific requirements of field sampling, techniques and related methods needed to address DER's main concerns for the site.

Figure 1: Overview of restoration area showing native marsh, bare mud flats, and Phragmites-dominated areas. Even at this scale, the lower elevation portions of the restoration area are visibly noticeable.

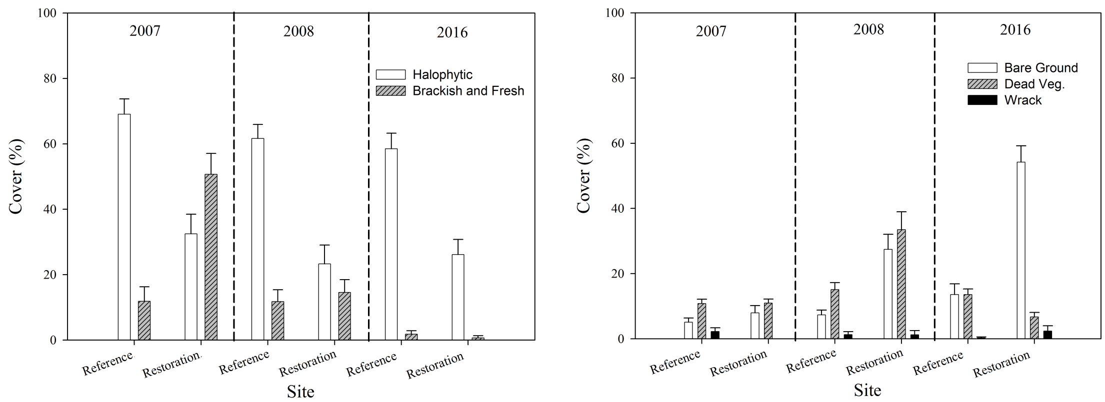
Task 2.0 – Field Data Collection

2.1 Our team reviewed the locations of historic vegetation transects prior to conducting 2016 field visits. During the site visit, we attempted to relocate those locations using GPS coordinates. We found that some markers were still present on the landward end of the transect, but many of the creek edge plot markers appeared missing or lost to erosion of the creek bank. In the interest of time, we abandoned efforts to relocate the exact position of the original transect marker posts during the first site visit since our primary goal at the time was to establish sediment elevation plots.

Figure 2: Orthophoto showing vegetation transect and photo station plots (orange circles) and sediment elevation plots (white triangles). At each point illustrated, at least one elevation data point was recorded and major habitat noted (Image source: October 2016 GoogleEarth™).

During the summer site visit, we resumed the search for the original transect posts. In the end, we confirmed that our 2016 sampling transects correspond well with their historic path. However, the seaward edge of several transects is now more landward of the original. The result of this change is that the fixed distance plots along some transects would be shifted landward in some cases, and potentially hindering direct comparison of plot-wise data from historic to present. Overall this shift is not expected to significantly impact data analysis, but it should be noted and discussed in the discussion of results.

2.2 Vegetation and Photographic Monitoring Tasks were conducted over two days in August 2016 when vegetation had reached maximum biomass. Vegetation plots ($0.5m^2$) were assessed at fixed intervals along each transect (see Figure 2). Prior to any disturbance, each plot was labeled and photographed from a fixed height of 1.6m and the elevation of the marsh surface at the plot center determined using RTK GPS. Plot photos can be found in Appendix A, while the complete plot-wise list of elevations is contained in Appendix B. After photographing and documenting plot elevation, species richness and presence/absence of invasive species (including average stand height) were documented and percent cover of each species visually estimated. Vegetation results from 2007, 2008, and 2016 are summarized in several ways to illustrate plant community changes over time as well as to illustrate increases in unvegetated portions of the marsh by documenting percent of plots that are bare mud or wrack (Figures 3 and 4).

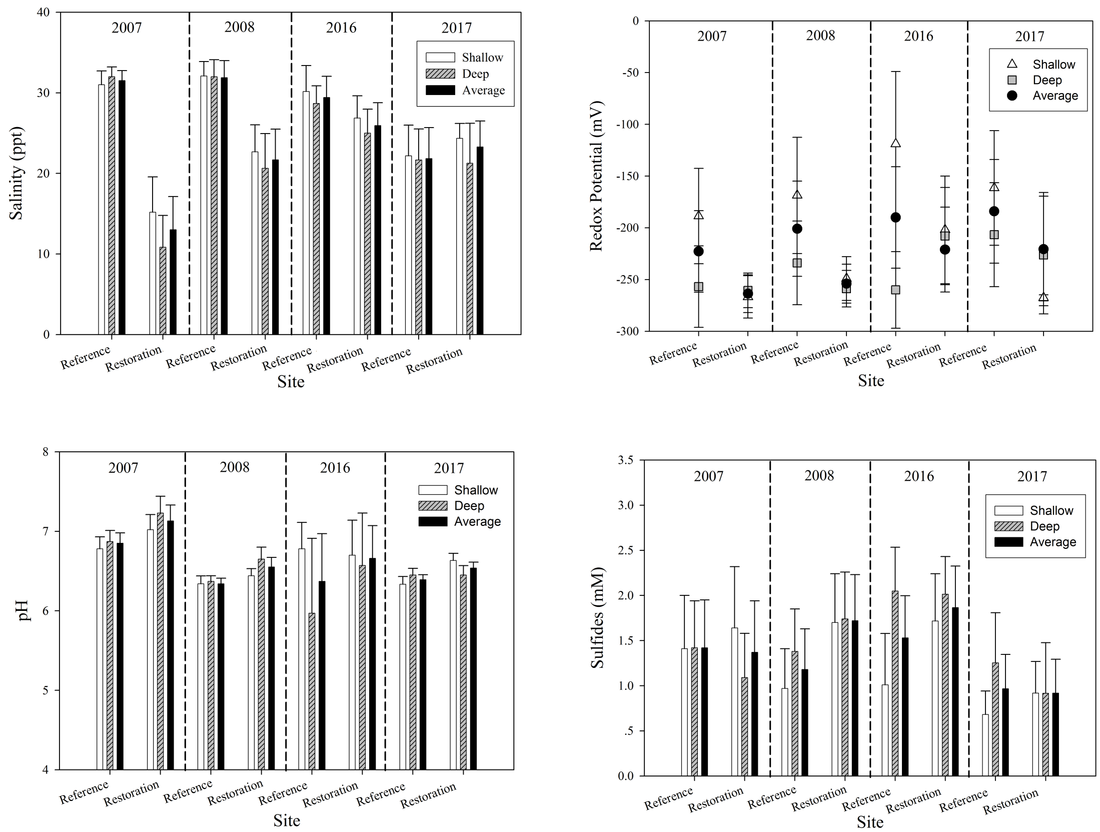


Figures 3 and 4: Comparison of percent cover for halophytes vs brackish-fresh species by observation year (left) and the change in unvegetated area over same time period (right).

In terms of overall plant community response, evidence of change can be interpreted several ways. Since a central goal of the restoration work was to deter *Phragmites* (a brackish-fresh species), the vegetation data support the achievement of this goal (Figure 3). Percent cover of brackish-fresh species declined dramatically in the restoration site over time and that decrease was statistically significant from year to year. However, the percent cover of halophytes, while variable, did not change significantly over the same period. This trend is immediately obvious in the field and is associated with the rise of barren, often eroded mudflat areas (Figure 4). It appears that halophytes have not recolonized formerly brackish-fresh dominated areas of the marsh, despite evidence that pore water conditions have developed to now support halophytic communities (Section 2.3). The factors that likely influence this pattern are discussed in detail in Section 4.0.

2.3 Pore Water Chemistry monitoring was conducted in late summer 2016 and again in June of 2017. In both cases, pore water parameters included salinity, redox potential, pH and sulfides. Pore water was sampled at two depths (5-10cm and 40-60cm). Figures 5-8 report results at each depth and the average of the two for all parameters (Note: the 2017 data are from early season). Salinity values show a clear increase as the restoration condition approaches that of the reference by 2016, but appear slightly decreased in the early summer of 2017 (Figure 5). Given its early season and there has been excessive rain, these values reflect the expected conditions. Other parameters are not as clear, although redox potential suggests a similar trend where the reduction of prolonged flooding resulted in less anaerobic conditions over time (Figure 6) but that does not align that well with the sulfide data. Its was surprising to see that as redox potential trended towards a more oxidized state, sulfide data showed higher accumulations over time – until 2017 when sulfide levels fell noticeably (Figure 7). The 2017 decrease is well correlated to the reduced salinity of the early growing season, as heavy rains both decrease salinity and increase flushing of sulfides from the sediment. Sulfide concentrations are also typically lower in the early season, having not had time to accumulate when compared to mid or late summer values.

Redox and sulfides are highly variable and as a result, we can only really discuss the trends and since none of these differences are statistically significant. The pH data reveal a significant decrease from 2007 to 2008, but the 2016 and 2017 data do not reveal any trends, significant or otherwise (Figure 8). Because pore water sampling stations where situated broadly throughout the site and not paired with each vegetation plot, it is not possible to formally compare vegetation presence/absence with specific pore water results. But we can show that the pore water stations situated in the barren mudflat areas are somewhat different that of vegetated areas in the restoration or reference area. Even so, there is no evidence that pore water conditions are predictively unsuitable for plant survival in these areas. While each parameter contributes to the goal of the restoration project, restoration of hydrology and the related increase in tidal influence and salinity were central to the project. Figures 5 and 6, in particular, suggest that goal was largely achieved and suitable conditions to support a halophytic plant community presently exist. So, if the pore water conditions themselves do not limit plant survival, the bigger limiting factor may be how these conditions play out new colonization of bare areas and seed germination – both of which are influenced by elevation and hydrology as discussed in Section 4.



Figures 5 – 8. Clockwise from top left salinity, redox potential, sulfides and pH by depth and site over time.

Task 3.0 – Establishment of Marker Horizons to Evaluate Marsh Accretion

3.1 In mid-May 2016, our Team established marker horizons to evaluate marsh accretion in the restored marsh area (Figure 9). We established three feldspar marker horizons (comprising three replicates each) along a linear gradient from creek to upland within both the restoration and reference areas (18 markers total) using the protocol defined by Lynch et al. (2015). Each marker horizon measured 0.25 m^2 with corners marked by PVC pipe. The creek edge horizons were situated ~5 m from the main tidal creek. The additional horizons were situated at ~10 and 50m distances landward of the creek. Each marker horizon was survey located in the field (see Task 4).

In June of 2017, the marsh surface was cut with a serrated blade to exhume a plug of vegetated and sediment from which we could determine the potential accretion of sediment above the marker horizon. In 17 of 20 plots, we clearly observed the feldspar layer and were able to quantify fine-scale accretion using a micrometer (Figure 10). Accretion rates varied widely, but in general, there was a linear relationship between accretion and distance from the main creek. The greatest accumulation of sediment was found in the plots closest to the creek, and the least amount of accretion occurred in unvegetated areas. In the three cases where the feldspar layer was not found, it was not possible to accurately determine whether the feldspar was washed away, or if the area was subject to erosion (taking feldspar and underlying layers of sediment). It should be noted each of these three cases each occurred in unvegetated muflats within the restoration area. Accretion was clearly documented in 100% of the reference marsh plots regardless of distance from the creek.

Figure 9. Establishing feldspar marker horizons in restoration and reference marsh areas (left) and; location of feldspar marker horizons with elevations shown in meters (right). Note that ALL the restoration plots are well under 1m in elevation at the marsh surface, while only low marsh/creek bank plots in the reference marsh follow this pattern. Essentially, the entire restoration area appears to exist at a 'low marsh' elevation – and thus its plant community should reflect that condition.

Figure 10. Examples of sediment accretion in low marsh creek bank (left) and high marsh (right) marker horizon plots.

<u>Task 4.0 – Bio-Benchmark Ground Survey</u>

4.1 We initiated a Bio-Benchmark ground survey within both the restoration and reference marsh areas using a survey grade GPS-RTK (Figure 11). The survey included the elevation of all feldspar marker horizons the location each vegetation plot, noting the major vegetation community (*see Figure 2*). In addition, photos of the existing plant community at each sediment elevation site were recorded (Figure 12).

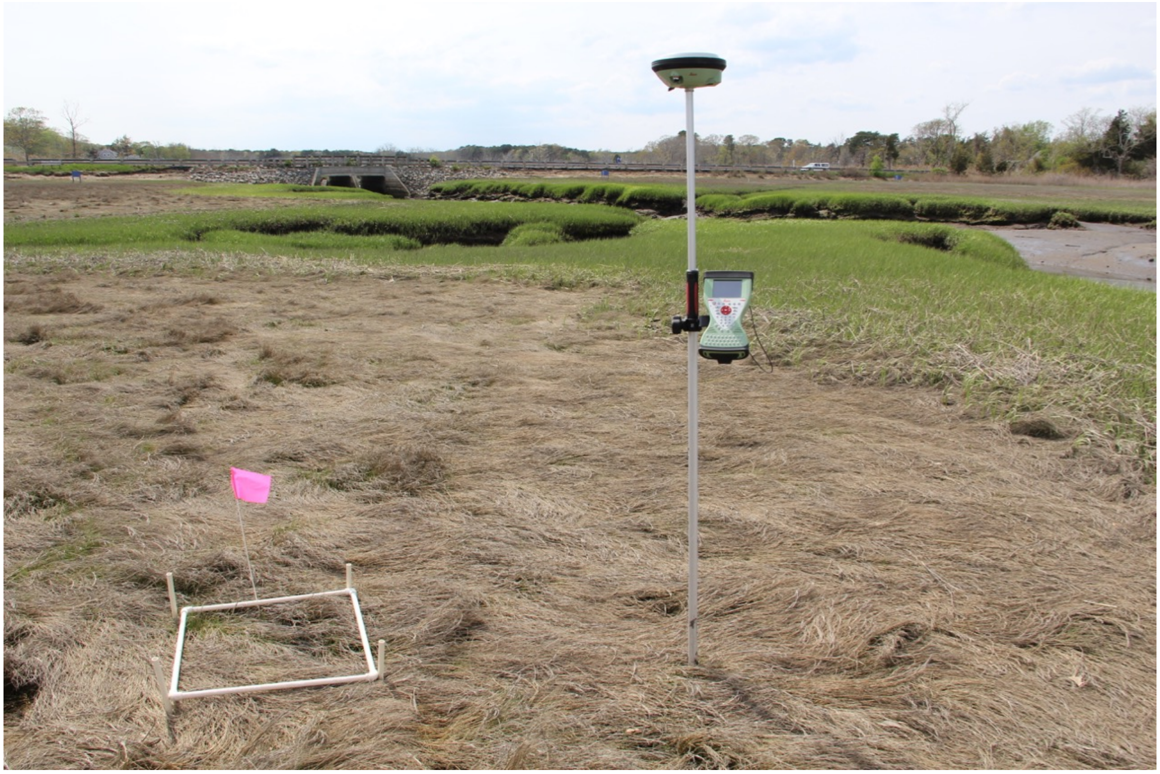


Figure 11. Survey-grade Real Time Kinematic (RTK) GPS was used to document elevation (±2cm) at critical locations throughout the marsh.

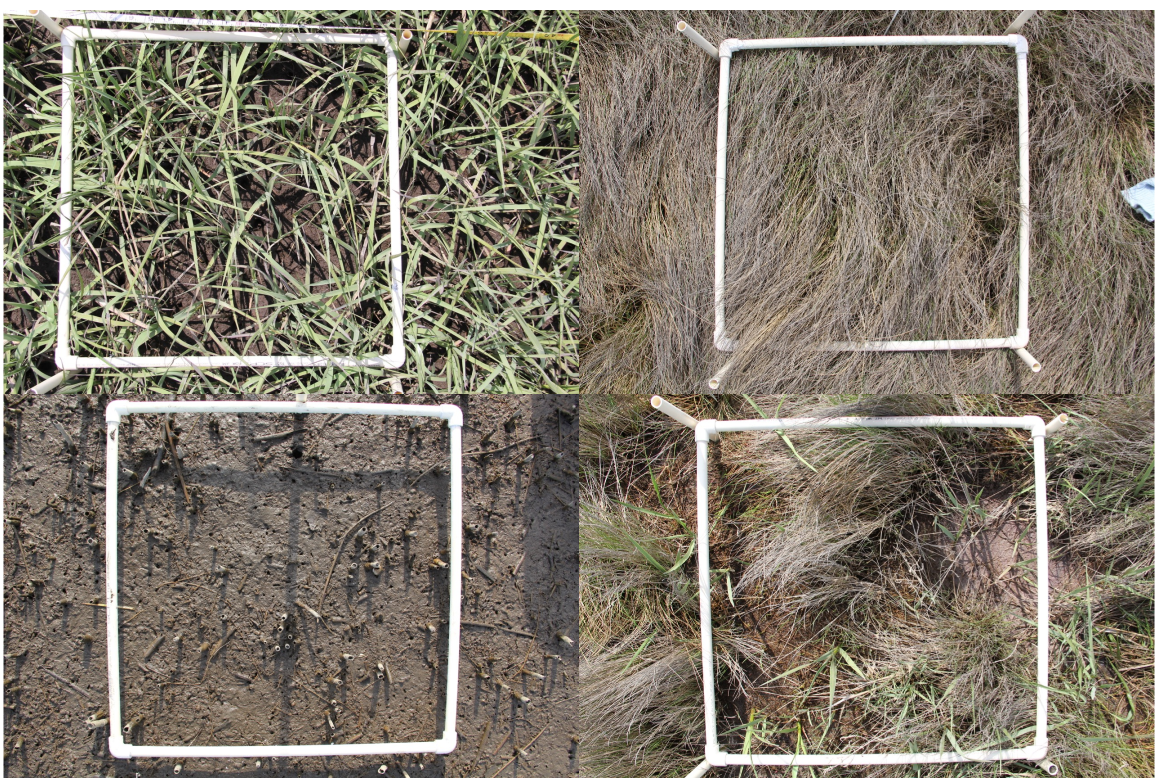
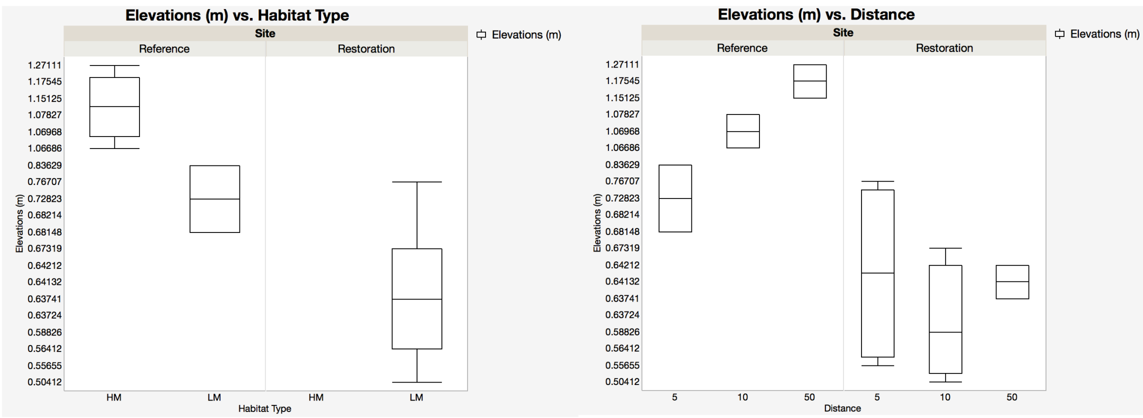


Figure 12: Examples of vegetation cover in marker horizon plots, clockwise from upper left a) Spartina alterniflora-dominated low marsh, b) S. patens-dominated high marsh, c) mixed species high-low marsh transition, and d) mudflat.

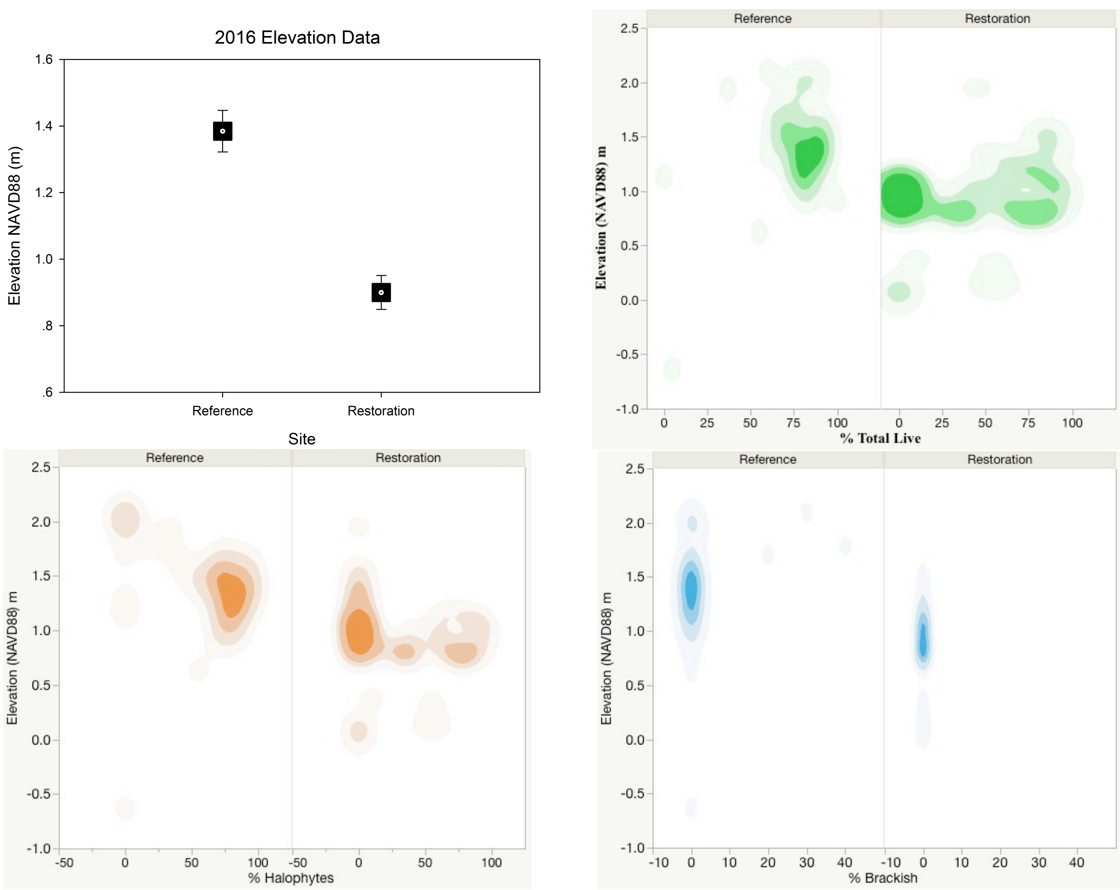
The RTK data show that the restoration area is significantly lower in elevation (~0.25m) than the reference site overall In fact, all the elevation plots in the reference area are under 1m NDVG. The break point between high and low marsh hovers just under the 1m elevation mark in the reference marsh. This finding is particularly evident in the sediment accretion plots (Figure 13-14) as further inspection of the data reveal that the bare, mudflat areas of the restoration area contribute significantly to these low elevations. In addition, we noted 22 of the ~130 vegetation plots occur in bare, mudflat areas in the restoration marsh with a mean elevation of 0.86m, well below the mean of vegetated plots in the reference. In contrast, the *vegetated* low marsh habitat elevations vary little between the reference and restoration areas. That said, we noted that one expected species in particular was absent from the restoration area. Slender grasswort (*Salicornia depressa*) was only noted in the reference marsh, occurring in varying density in roughly 30% of all plots.



Figures 13-14. Elevation of sediment accretion plots for reference and restoration marsh areas grouped by distance from creek edge (left) and by habitat type (right).

Figure 15. Example of a low marsh area in the restoration site showing evidence of rapid erosion – soon to become mudflat?

In the reference marsh, measured plot elevation follows a linear gradient, increasing as one moves landward from the creek edge. Arguably, this is not the case in the restoration area. Plots located 10m from the creek are lower in elevation than the plots located 5m and 50m from the creek edge. This distinction plays an important role in understanding why major portions of the restoration area remain unvegetated. There is some evidence these areas are eroding, such as exposed roots and rhizomes (Figure 15), acting as a source rather than a sink for sediment. But portions of these low marsh-mudflat areas in the restoration area are also consistently flooded by relatively deep water (20-40 cm) on daily tides and portions remain saturated at the sediment surface even during low tide periods. It is possible that some of these areas are too low in elevation to naturally recruit propagules or seeds that may be present in the system are not experiencing suitable condition to germinate under present conditions. Although we feel confident that the majority of the bare areas may be encouraged to colonize through direct planting of bare root seedlings or plugs since pore water conditions are not unfavorable for establishment. Finding those suitable locations may be as simple as using the RTK or Lidar to define the elevations that correspond with dense native low marsh communities in the adjacent reference – but planting lower elevations may still be of value given the dire need to stabilize these soft, eroding sediments.



Figures 16-19. Comparison of mean elevation between reference and restoration site (top left), distribution of total live plants by elevation (top right), and distribution for halophyte (bottom left) and brackish (bottom right) communities.

Figure 16 through 19 support this notion, as there is clear clustering of dense vegetation within core elevation ranges in the marsh. The reference marsh seems to have a tight clustering of vegetation around elevation ranges of 1-1.5m, while the restoration area is variable and spread around a much wider range with low density. Essentially, total live cover is concentrated at higher elevations in the reference marsh. Also note that total live cover in the reference is 'healthy', almost exclusively at 75-90%. In the restoration marsh, live cover is much more variable, spanning 0-90% with many plots that are bare, unvegetated mudflat. Drilling deeper into the data, we can see that when the total live data are sorted into halophytes vs. brackish species, the relationship remains quite similar but that halophytes are the dominant contributor to the pattern.

Task 5.0 Summary and Recommendations

The data collected in this study suggest that despite the successful removal of common reed (*Phragmites australis*), the site remains impacted and may require additional management actions to fully realize restoration goals. Low areas in the restoration area are slow to recolonize with native vegetation despite having suitable pore water chemistry overall. RTK-based elevation surveys support the obvious fact that this restoration site is significantly lower in elevation that the adjacent reference marsh and significantly less vegetated. Meanwhile, our sediment accretion study demonstrated significant accretion in all vegetated sampling plots, whether in the reference or restoration portions of the site. Accordingly, the barren, mudflat areas within the restoration area are acting as a source, rather than a sink for sediment and mist be addressed to slow the rate of sediment loss and erosion.

Despite shortcomings noted above, we did notice some new colonization of native plants within the restoration area and since suitable pore water conditions appear to occur broadly across the site, we believe that restoration planting of native species may hasten recovery of a robust, salt marsh plant community. Careful examination of plant community data and survey elevations at over 130 vegetation observation plots spanning the reference and restoration area provide strong evidence that a plant community can be encouraged across much of the area of concern. Use of LIDAR and field survey can facilitate delineation of suitable elevations for what we expect would have to be a low marsh dominated community under present conditions and elevations. However, based on sediment retention of vegetated plots, the site shows promise for sediment accretion to build the marsh platform once a dense plant community is re-established.

Since we gathered a significant amount of paired vegetation and elevation data for 2016, we recommend continued vegetation monitoring to better understand changes on the marsh surface at this fine scale. Likewise, our sediment accretion study should be continued to track the marsh building across the site, as our results are based on less than one year of accretion. Above all, we feel strongly that supporting a carefully planned restoration planting plan for the areas of concern is a critical next step. The draft restoration planting plan prepared by our project partners at APCC as designed provides a rigorous approach that should help this marsh meet the desired restoration trajectory and we look forward to an opportunity to provide further study, analysis, or recommendations to help see this important work through.

Appendix A: Photo Stations

Appendix B: Sediment Elevation Data

Date_Time	Ortho_Heig	Point_ID	Name	Distance	Habitat
05/17/2016 12:00:19	0.55655000000	1	SET 1_1	5	LM
05/17/2016 12:07:02	0.50412000000	2	SET 1_2	10	LM
05/17/2016 12:18:55	0.64212000000	3	SET 1_3	50	LM
05/17/2016 12:38:24	0.76707000000	5	SET 2_1	5	LM
05/17/2016 12:45:37	0.56412000000	6	SET 2_2	10	LM
05/17/2016 12:53:51	0.63741000000	7	SET 2_3	50	LM
05/17/2016 13:53:47	0.68148000000	13	SET 1_1	5	LM
05/17/2016 14:01:21	1.06968000000	15	SET 1_2	10	HM
05/17/2016 14:08:34	1.15125000000	16	SET 1_3	50	HM
05/17/2016 14:34:00	0.83629000000	17	SET 1_1	5	LM
05/17/2016 14:38:15	1.06686000000	19	SET 1_2	10	HM
05/17/2016 14:45:20	1.27111000000	20	SET 1_3	50	HM
05/17/2016 15:30:36	0.72823000000	31	SET 1_1	5	LM
05/17/2016 15:39:49	1.07827000000	32	SET 1_2	10	HM
05/17/2016 15:42:18	1.17545000000	33	SET 1_3	50	HM
05/17/2016 16:03:11	0.68214000000	34	SET 1_1	5	LM
05/17/2016 16:05:50	0.63724000000	35	SET 1_2	10	LM
05/17/2016 16:11:32	0.64132000000	36	SET 1_3	50	LM
05/17/2016 16:24:05	0.58826000000	37	SET 1_1	5	LM
05/17/2016 16:27:10	0.67319000000	38	SET 1_2	10	LM

Appendix B: Vegetation Elevation Data

Date_Time	Ortho_Heig	Point_ID
05/17/2016 13:05:19	0.54129000000	8
05/17/2016 13:05:43	0.52459000000	9
05/17/2016 13:06:18	-0.14968000000	10
05/17/2016 13:07:03	-0.32225000000	11
05/17/2016 13:07:50	-0.62860000000	12
05/17/2016 13:56:42	-0.39123000000	14
05/17/2016 14:35:13	-0.21030000000	18
05/17/2016 14:56:56	1.20050000000	21
05/17/2016 14:57:25	1.15247000000	22
05/17/2016 14:57:51	1.28584000000	23
05/17/2016 14:58:10	1.14272000000	24
05/17/2016 14:58:38	1.22900000000	25
05/17/2016 14:58:57	1.16304000000	26
05/17/2016 14:59:23	1.24419000000	27
05/17/2016 14:59:50	1.14240000000	28
05/17/2016 15:00:27	1.25214000000	29
05/17/2016 15:00:48	1.15688000000	30
05/17/2016 16:29:25	0.70194000000	39
05/17/2016 16:39:13	2.36945000000	40
08/16/2016 12:48:38	0.91403000000	42
08/16/2016 12:50:51	1.13612000000	43
08/16/2016 12:54:44	1.21276000000	44
08/16/2016 12:57:21	1.44146000000	45
08/16/2016 13:03:54	1.51607000000	46
08/16/2016 13:06:23	1.41793000000	47
08/16/2016 13:14:16	1.57203000000	48
08/16/2016 13:16:37	1.64829000000	49
08/16/2016 13:18:55	1.70355000000	50
08/16/2016 13:20:40	1.80242000000	51
08/16/2016 13:25:53	1.79360000000	52
08/16/2016 13:31:32	2.01767000000	53
08/16/2016 13:36:19	2.09721000000	54
08/16/2016 13:51:27	-0.17249000000	55
08/16/2016 13:53:04	1.08496000000	56
08/16/2016 14:02:32	1.41680000000	57
08/16/2016 14:07:10	1.50764000000	58
08/16/2016 14:11:38	1.49182000000	59
08/16/2016 14:19:15	1.52193000000	60
08/16/2016 14:26:00	1.48726000000	61
08/16/2016 14:34:05	1.63609000000	62
08/16/2016 14:37:52	1.70001000000	63
08/16/2016 14:41:27	1.97391000000	64
08/16/2016 14:48:34	2.02739000000	65
08/16/2016 14:56:12	2.04837000000	66
08/16/2016 15:10:09	0.93344000000	67
08/16/2016 15:12:37	0.96611000000	68
08/16/2016 15:13:14	0.97913000000	69
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08/16/2016 15:17:40	1.23840000000	71
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08/16/2016 15:24:03	1.35354000000	73
08/16/2016 15:27:44	1.42136000000	74
08/16/2016 15:29:34	1.50673000000	75
08/16/2016 15:34:34	1.48325000000	76
08/16/2016 15:36:10	1.46043000000	77
08/16/2016 15:39:33	1.32492000000	78
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08/16/2016 15:46:16	1.33503000000	80
08/16/2016 15:47:58	1.54657000000	81
08/16/2016 15:51:32	1.93222000000	82
08/16/2016 16:49:09	0.79974000000	83
08/16/2016 16:50:07	0.77162000000	84
08/16/2016 16:53:24	0.75245000000	85
08/16/2016 16:55:22	0.75571000000	86

Date_Time	Ortho_Heig	Point_ID
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08/16/2016 17:11:17	0.91080000000	89
08/16/2016 17:16:20	1.02681000000	90
08/16/2016 17:17:56	1.05464000000	91
08/16/2016 17:30:04	1.06366000000	92
08/16/2016 17:39:53	1.13345000000	93
08/16/2016 17:49:53	1.97688000000	94
09/23/2016 08:46:57	-1.13304000000	95
09/23/2016 08:55:25	-0.98325000000	96
09/23/2016 08:57:23	-0.63036000000	97
09/23/2016 09:02:00	0.62519000000	98
09/23/2016 09:03:59	1.25717000000	99
09/23/2016 09:09:43	1.35146000000	100
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09/23/2016 09:44:35	1.13726000000	105
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09/23/2016 10:42:28	0.08615000000	108
09/23/2016 10:44:29	0.13547000000	109
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