2018 Post-Project Monitoring Final Report: Long Reach Lane at Long Marsh, Harpswell

Year 5 of 5

Compensation for the Martin's Point Bridge Project, Falmouth-Portland
(PIN 16731.00)

March 13, 2019

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. OVERVIEW

In 2012, the Maine Department of Transportation (MaineDOT) proposed a mitigation project at Long Reach Lane (LRL) in Harpswell to compensate for the functional impacts to marine wetlands associated with the construction of the Martin's Point Bridge between Falmouth and Portland. The mitigation project was implemented in January and February 2014, and resulted in the successful replacement of a 36" (7.1 ft^2 flow area) round concrete pipe beneath Long Reach Lane with a larger 6' x 12' concrete box culvert (72 ft^2 flow area) in February 2014 (photo MaineDOT, below).

This report primarily presents the results of pre-project monitoring, which occurred during the 2013 growing season, and Year 5 of post-project monitoring, which occurred during the 2018 growing season, at the Long Marsh mitigation site. Years 1-4 post-project data from 2014-2017 are also included in some instances, for context.

1.1 Project Monitoring

The Casco Bay Estuary Partnership (CBEP), which is hosted by the University of Southern Maine, was contracted by MaineDOT to conduct monitoring within the Project Area for one year pre-project, and five years post-project. CBEP, one of 28 National Estuary Programs nationwide, has focused on assessment, restoration, and monitoring at tidal marshes since 2009.

The *Martin's Point Bridge Wetland Mitigation Plan* (*Mitigation Plan;* MaineDOT 2012) describes the mitigation site Project Area as the marsh area upstream (south) of Long Reach Lane, and north of a bedrock feature locally known as "the narrows" (Fig. 1). The *Plan* also states:

> In "*…the Marsh area south of the narrows … there are three large established patches of Phragmites that makes up approximately 7% of this portion of the marsh surface area. This area is outside of the project area."* (MaineDOT, Section J)

To monitor ecosystem change in response to the mitigation project, CBEP established a total of twelve monitoring stations, approximately evenly distributed. St. 1 was located to the north of

Long Reach Lane, serving as a reference area, and St. 2-10 were located within the Project Area, south of Long Reach Lane and north of 'the narrows' (Fig. 2). CBEP also established two stations south of the Project Area, Stations 11 and 12. Data from St. 11-12 are generally not referenced in this report, but are available from CBEP.

The mitigation plan specifies parameters for pre- and post-project monitoring:

- Hydrology signal – using continuous water level recorders deployed upstream and downstream of LRL.
- Pore water and surface water salinity.
- Vegetation – abundance (percent cover) of halophytic, brackish, freshwater, and invasive plant species.
- Channel morphology – cross sectional area.
- Erosion – post-project visual surveys within the construction area.
- Photo stations.

This report summarizes monitoring results for the above parameters as well as anecdotal observations or notes, if deemed relevant to mitigation project outcomes.

1.2 Summary of Mitigation Goals and Performance Standards

The stated objective of the mitigation project was to eliminate the tidal restriction created by LRL in Harpswell (MaineDOT 2012). The following performance standards were established for this objective:

1) *Tide curve data upstream of the crossing will be 80% or greater than that of the downstream area after crossing construction…The intention is that 80% (as opposed to 100%) removal will give us a comfortable operating margin, accounting for potential uncertainty in the model. If this standard is not met, the opening size will be enlarged to meet this standard. There may be a phase delay associated with this site after construction which will not be remediated.*
2) *All the constructed features such as slopes, soils, substrates within the mitigation site will be stabilized and free from erosion.* (MaineDOT 2012, Section I)

In addition, the *Plan* laid out a set of mitigation goals:

1) *Vegetation in the upstream marsh will transition from a salt marsh – brackish – freshwater system to predominately salt tolerant species. After the culvert replacement it is expected that a salinity gradient will limit freshwater species establishment. These species will be confined to the marsh edge fringe where overtopping does not occur and will include at a minimum the southernmost 30 acres of the marsh.*
2) *Invasive species, namely* Phragmites australis *(Common Reed) and* Lythrum salicaria *(Purple Loosestrife) will be monitored and controlled using integrated pest management techniques. The goal will be to eliminate the establishment of Common Reed and Loosestrife in the marsh*

restoration area. The project enhancement and restoration area does not support any Common Reed or Purple Loosestrife. (MaineDOT 2012, Section J)

Five years of post-project monitoring efforts indicate that conditions within the Project Area continue to adjust in response to the new culvert, in ways that are consistent with the mitigation project objective, performance standards, and goals. Table 1 summarizes the status of tidal hydrology, erosion, and other monitored parameters in the fifth growing season post-project (2018), based on a comparison with pre-project monitoring data collected in 2013, and describes whether the status is consistent with pre-defined standards and goals for the mitigation site.

Hydrology: The performance standard for hydrology was met immediately following project implementation, as documented by continuous water level monitoring in 2014. Additional information is provided in Section 3.1.

Erosion control: LRL overtopped on at least three occasions over the course of the post-project monitoring period, including during the winter of 2016-17 and the winter of 2017-18. Based on reports from local residents, the overtopping events likely co-occurred with astronomical high tides and storm surges. In at least one event (early 2017), overtopping resulted in erosion of road fill over and adjacent to the culvert. Subsequent road repairs by local residents stabilized the roadbed.

For remaining monitoring parameters, response to the new hydrological regime remains ongoing, with Year 5 post-project data indicating that changes remain consistent with project objectives.

Table 1. Summary of Performance Standards and Monitoring Parameters

Performance Standard/ Monitoring Parameters	Year 5 Findings	Meet Standard?
Hydrology signal*	*In 2014, the upstream tide curve was documented to exceed 80% of the downstream tide curve.*	Yes
Erosion control	*The road was overtopped on 3/5/18 at the culvert and the eastern road approach. Minor erosion of fill occurred. Slopes, soils, substrates were observed to be stable following remedial work by local residents.*	Yes
Pore water salinity	*Post-project pore water salinity levels remain elevated, and are elevated sooner in the growing season, compared with pre-project levels.*	On-track
Vegetation community	*Abundance of halophytic vegetation continued to increase in the Project Area, while abundance of brackish and glycophytic vegetation declined.*	On-track
Channel morphology	*The creek channel continued to widen and deepen throughout the Project Area in response to the new hydrological regime.*	On-track
Invasive species	*A small cluster of Phragmites australis stems was documented along the eastern marsh near St. 9. MaineDOT was immediately notified. Remedial action of basal herbicide application in the fall of 2018.*	On-track

* *Hydrology signal and erosion control are the only two performance standards. Assessment of other monitoring parameters provided for context.*

Figure 1. Map of Project Area.

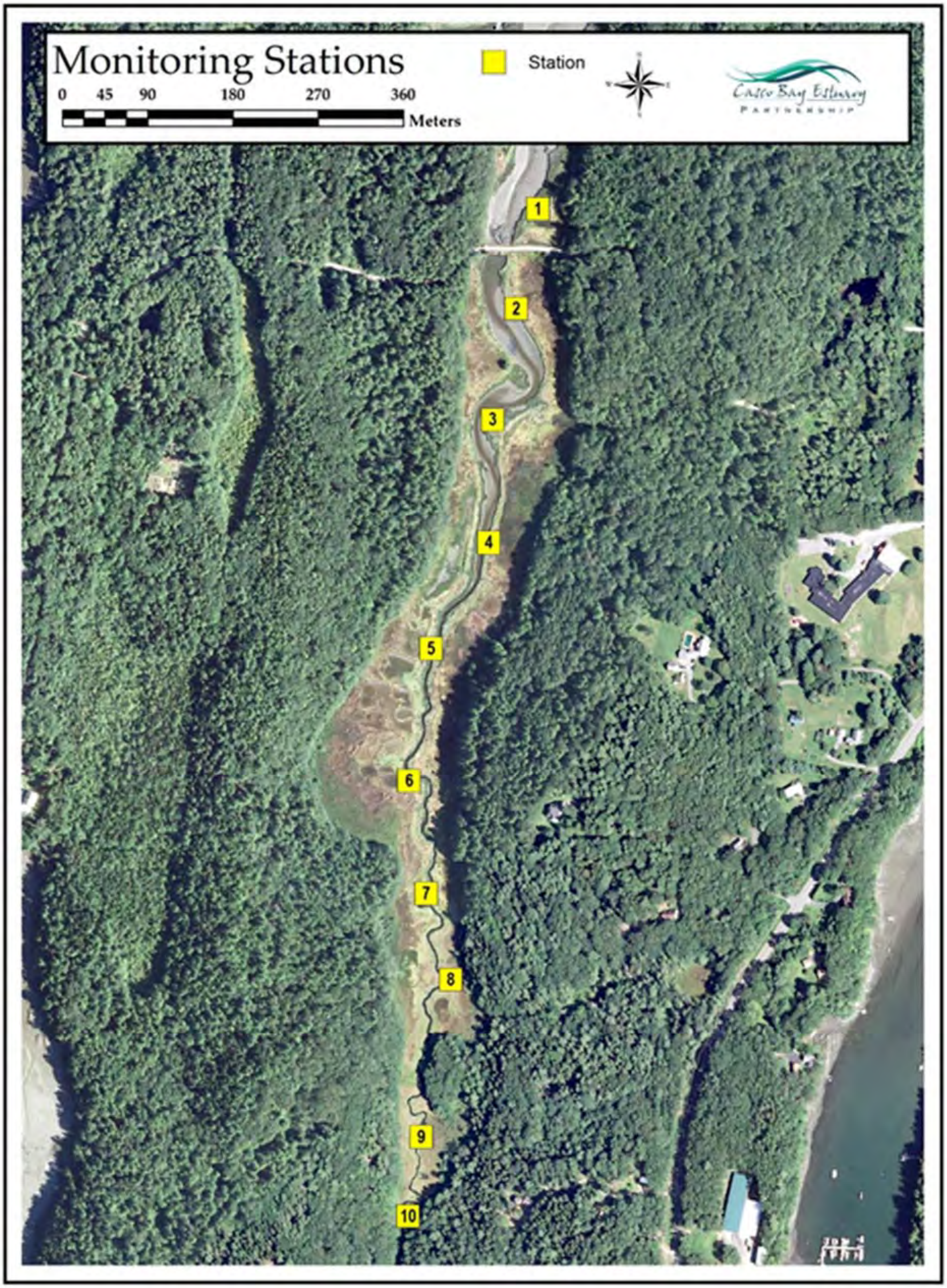


Figure 2. Monitoring Station location map.

1.3 Remedial actions

During an invasive species meander survey on July 16, 2018, CBEP's seasonal field crew observed clusters of live *Phragmites australis* in two regions within the southern Project Area. Two small clusters of approximately 20 plants each, approximately 15m away from the upland edge of the marsh at St. 9, were observed in approximately the same location where *Phragmites* had been observed and treated in 2016. Additionally, CBEP observed a second, new cluster slightly to the north, along the western edge of the marsh near St. 7. CBEP immediately reported the observations to MaineDOT, providing an occurrence map. MaineDOT's Deane VanDusen subsequently applied a mixture of Glyphosate and Imazapyr as a control agent in the fall. Additional information is provided in Section 3.6. Section 4 discusses recommendations for continued monitoring and management of *Phragmites australis.*

Remedial actions for erosion are described in Section 1.4.

1.4 Erosion control

Summary of Performance Standard

Erosion control is one of two performance objectives for the compensatory LRL culvert replacement in the *Mitigation Plan*. The performance objective for erosion control pertains to stability of the mitigation site:

> *All the constructed features such as slopes, soils, substrates within the mitigation site will be stabilized and free from erosion.* (MaineDOT 2012, Section I)

For the purposes of tracking erosion control, CBEP monitored the culvert and associated features within the footprint of the construction project. Based on CBEP observations during the monitoring season (April-October), and the remedial actions described below, CBEP concludes that this performance objective was met over the post-project monitoring period.

2018

On at least two occasions during the winter of 2018, unusually high water levels resulted in LRL being overtopped. These events followed at least one instance of overtopping during the prior winter of 2017. Based on descriptions provided to CBEP by local residents, and a review of water level data at the Portland Tide Station (Station ID: 8418150), these overtopping events coincided with combined astronomical high tides and coastal storms.

Local residents reported that on each occasion, the road was overtopped directly over the culvert. On at least one occasion in 2018, overtopping of the mitigation site at the culvert was photo-documented by residents (Fig. 3). The eastern road approach was also overtopped. In

2017, overtopping resulted in minor erosion of road fill off of the road and onto the upstream road bank and high marsh (Fig. 3, right; photo at bottom).

Figure 3. Photo-documentation of road overtopping and associated erosion of road material.

Subsequent road repairs by local residents, including additional fill and regrading, had fully re-stabilized the roadbed by the time CBEP directly observed the site. In 2017 CBEP observed areas of newly regraded fill over the culvert (photo below), suggesting erosion of fill occurred at this location, but had been addressed. Residents reported that they are concerned about the recent frequency of overtopping, and are investigating options to address the issue.

CBEP observed that rip-rap scour protection at the culvert inlet and outlet were stable. Rip-rap along the downstream road bank was also stable.

2. METHODS

CBEP followed monitoring methods based on the protocols laid out in Sections K and L of the *Mitigation Plan*. Methods follow protocols set forth in CBEP's *Quality Assurance Project Plan for Tidal Marsh Monitoring and Assessment* (Craig & Bohlen 2018), and generally align with protocols described in the *Regional Standards to Identify and Evaluate Tidal Wetland Restoration in the Gulf of Maine* for the selected parameters (Neckles & Dionne 1999). Parameters were monitored in association with the designated stations listed in Table 2 below, unless otherwise noted.

Table 2. Monitoring parameters by Station.

Station	Hydrology Signal**	Pore Water Salinity	Surface Water Salinity**	Vegetation	Channel Morphology	Plant Species of Concern
1	X	X		X	X	X
2	X	X	X	X	X	X
3				X	X	X
4		X		X	X	X
5				X	X	X
6		X*		X	X	X
7				X	X	X
8		X	X	X	X	X
9			X	X	X	X
10		X	X	X	X	X

* At St. 6, two pore water wells were monitored.
** Continuous monitoring of surface water hydrology and salinity limited to pre-project and Year 1 post-project.

2.1 Hydrology signal

MaineDOT used Solinst Levelogger Gold unvented loggers to monitor pre- and post- construction surface water hydrology in 2013 and 2014. A separate Solinst Barologger was deployed so that a barometric correction could be applied and logger data converted to water depth on logger. The depths were converted to elevation by relating surveyed elevations at known times to corresponding data logger water depths.

The *Plan* provided the following guidance for monitoring hydrology signal:

> *Two tide data loggers will be installed upstream and downstream of the LRL culvert and measurements conducted 2 months prior and post construction. The downstream logger will*

> *be located in the downstream transect and the upstream logger in the mid marsh area transect.* (MaineDOT 2012, Section L)

CBEP also monitored continuous surface water levels in the channel at St. 8-9 in 2017 and 2018 as part of an assessment of the impact of the rocky ford on surface water hydrology. Data and findings are available from CBEP.

2.2 Pore water salinity

CBEP constructed wells from 2" PVC consistent with established protocols for monitoring pore water salinity (Neckles and Dionne 1999). Pore water wells were installed at St. 1, 2, 4, 6, 8, and 10 approximately 10 meters from the tidal creek channel edge. A map is provided in Appendix A. An additional pore water well (6a) was installed approximately 10 m from the upland edge at St. 6 (s). Two wells are located beyond the Project Area (St. 11 & 12). Simultaneous surface water samples are taken from the tidal creek where vegetation transects intersect with the marsh channel. Water samples are collected using a syringe with a tube for extension into wells and the tidal creek, and sampled within two hours of predicted low tide. Salinity readings are read from a handheld refractometer that is calibrated with de-ionized water. Observations are recorded on a site-specific data sheet.

2.3 Surface Water Salinity

Surface water salinity was monitored in 2013 and 2014. In 2017, CBEP monitored continuous salinity levels in the channel at St. 8-9.

2.4 Vegetation

CBEP established vegetation transects at each station in the Project Area. An additional two vegetation transects were established at stations to the south of the Project Area (St. 11 & 12). Transects were set to allow for representative sampling of established marsh areas and adequate sampling intensity. Vegetation data are collected in meter-square plots located every 10-15 meters along the length of each transect. The number of plots collected along each transect varies from 10 to 12, with most transects having 11 plots. Observers replicate transect locations year over year by extending a tape measure from a PVC stake marking the channel edge (e.g., 1C) to another PVC stake located at the upland edge (e.g., 1U; see map, Appendix A). Transects run perpendicular to the tidal creek toward the upland edge, with 0' (zero) starting at the channel. Data collected in each plot includes: (1) a list of the well represented (>10% coverage) species in the plot; (2) percent coverage by those species; (3) overall percent coverage for the plot; and, (4) general hydrologic conditions. Data for each plot was recorded on a separate data sheet. All project vegetation data are entered into a Microsoft Access database and subsequently proofed by a second reviewer. Species identification and nomenclature follows Haines & Vining 1998. Alternative nomenclature is tracked within a database of plant species developed and maintained by CBEP.

2.5 Channel Morphology

CBEP established channel cross section transects at each station (map, Appendix A). An additional cross section transect was established beyond the Project Area at St. 11. In addition, CBEP surveyed a longitudinal profile of the channel bottom from St. 1 to St. 3 (approximate). Cross sectional areas are surveyed in identical locations from stakes on the east and west side of the channel (e.g., XS1E, and XS1W; see map Appendix A) proximate to where vegetation transects originate at the marsh channel. Elevations are surveyed at regular increments or where elevation grade changes are evident, using an auto level on a tripod and a stadia rod, and tied to local benchmarks with known elevations relative to NAVD 88. Cross section and longitudinal profile data are recorded onto project-specific data sheets and entered into the *Reference Reach Spreadsheet* (Mecklenburg 2006) to standardize and quantify survey data. The spreadsheet is used broadly in among natural resource managers as a tool for quantifying channel morphology (Alex Abbott, personal communication).

2.6 Plant species of concern

At least once per field season, an intensive meander survey for invasive plant species is conducted throughout the Project Area. Incidental observations of invasive plants during other monitoring activities are also documented. During the meander survey, invasive plant species are identified, photographed, described in field notebooks, geo-referenced, and flagged if possible. Any indication that invasive plant species of concern are establishing or expanding within the Project Area is immediately communicated to MaineDOT, with recommendations for control measures, if needed.

2.7 Erosion control

CBEP conducts regular visual surveys within the construction area to check for signs of erosion along the road bank, or structural failure within or adjacent to the culvert. Observations of erosion would be recorded and findings would be photographed, georeferenced, flagged, and immediately reported to MaineDOT if needed.

2.8 Photographic documentation

CBEP established a series of photo stations associated with the construction area, channel cross sections, and vegetation transects in order to provide a visual record of changes at and adjacent to the mitigation site and the Project Area during the monitoring period. Photos are taken annually at a minimum at each photo station.

2.9 Wildlife use

CBEP records incidental observations or signs of wildlife within or adjacent to the Project Area during each site visit.

2.10 Additional data

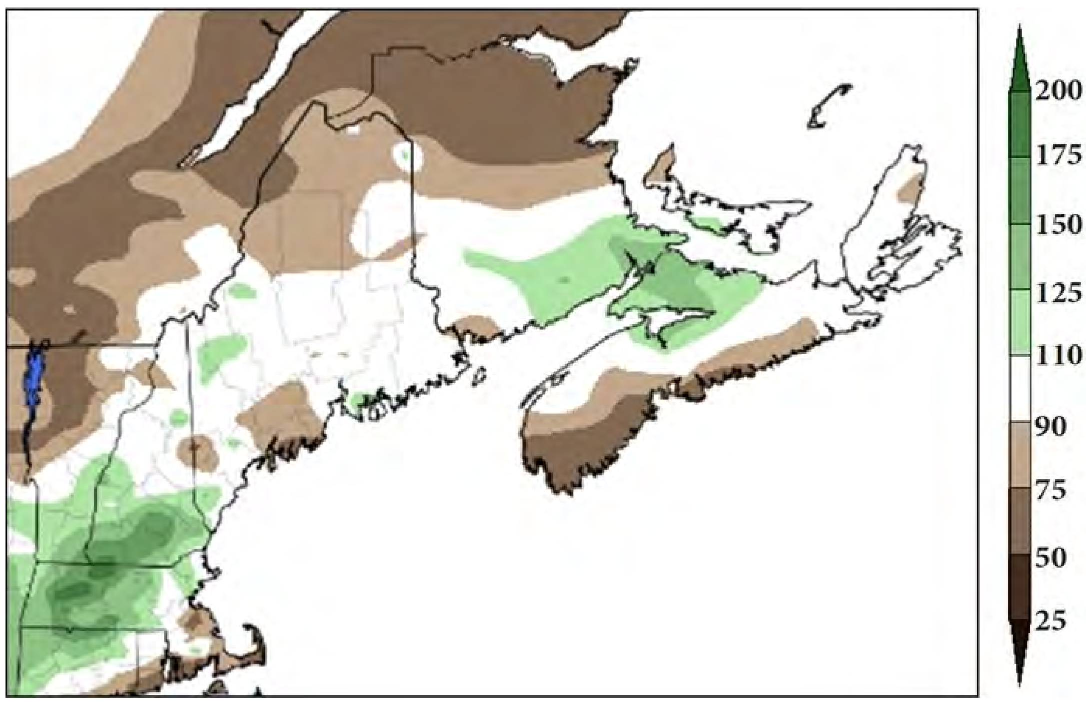
During the monitoring period, additional data have been collected at Long Marsh by CBEP and other researchers:

- Additional field observational data, such as dead vegetation, etc., was periodically collected during the course of field sampling activities, recorded in field notebooks, and photographed, by CBEP staff. These data were incorporated into the project report where applicable.
- To contextualize observations in the Project Area within the greater tidal marsh system, CBEP established two additional monitoring stations (St. 11 & 12) south of the Project Area and the section of the marsh referred to as "the narrows." CBEP incurred the expense of monitoring these additional stations. Parameters monitored included vegetation transects, pore water and surface water salinity, surface water hydrology, and channel cross sections. Generally, these data were not included in annual monitoring reports. Findings from the monitoring at St. 11 & 12 are available from CBEP upon request.
- Dr. Beverly Johnson, working with undergraduate students from Bates College, is collecting methane measurements as part of an ongoing research study. These data were not included in annual monitoring reports.
- Shri Andrea Verrill, a University of Southern Maine graduate student in the Biology Department and for two seasons a CBEP field staff, conducted research on the impact of tidal restoration on cattail species, at Long Marsh, over the course of the 2014 and 2015 field seasons. These data are not included in annual monitoring reports.
- Project SHARP (Saltmarsh Habitat & Avian Research Program), of which the University of Maine's School of Biology and Ecology is a collaborator, has a long-term bird monitoring station on Long Marsh, located within the Project Area.

3. RESULTS & DISCUSSION

This section summarizes results from monitoring of pore water salinity, vegetation, channel morphology, plant species of concern, wildlife use, erosion, and photo documentation. The Year 5 report draws primarily from 2013 and 2018 monitoring results, but data from 2014-17 are provided for context in some areas.

Precipitation. Drought conditions in 2016 were accompanied by a marked decline in plant cover within Project Area. Following drought contitions in 2016, the Eastern Casco Bay region experienced moderate drought conditions during the 2017 summer months, and 90% of normal conditions in the spring and summer of 2018, according to reports prepared by the Gulf of Maine Council Climate Network (graphic, below). Vegetative cover in the marsh continued to rebound in 2018. Additional information is provided in Section 3.4.



Above: Map illustrating percent of normal precipitation levels in the Gulf of Maine region from June – August 2018. Source: Gulf of Maine Council Climate Network, Quarterly Climate Impacts and Outlook – September 2018.

3.1 Hydrology Signal

Note: The text and figures in Section 3.1 were taken directly from the Year 1 post-project report prepared by CBEP in 2015. The figures referenced in the text have been grouped at the end of this section. This section was prepared by Charles Hebson, P.E., Chief Hydrologist with MaineDOT, for inclusion with the Year 1 monitoring report.

Summary of Performance Standard

Hydrology signal is one of two performance objectives for the compensatory LRL culvert replacement in the *Mitigation Plan*. The first performance objective pertains to hydraulic performance of the replacement box culvert:

> *Tide curve data upstream of the crossing will be 80% or greater than that of the downstream area after crossing construction (see Reference Elevations for Mean High Water). The intention is that 80% (as opposed to 100%) removal will give the sponsor a comfortable operating margin, accounting for potential uncertainty in the model. If this standard is not met, the opening size will be enlarged to meet this standard. There may be a phase delay associated with this site after construction which will not be remediated.* (MaineDOT 2012, Section I)

Based on the evaluation of pre- and post-construction water level data below, we conclude that this performance objective has been met.

Data Collection

MaineDOT collected water level data in the years 2012, 2013 and 2014. Construction was originally anticipated for winter 2012/13 and so 2013 was expected to constitute the post-construction period. However, construction took place in winter 2013/14 so 2014 constitutes post-construction.

Solinst Levelogger Gold unvented loggers were used; a separate Solinst Barologger was deployed so that a barometric correction could be applied and logger data converted to water depth on logger. The depths were converted to elevation by relating surveyed elevations at known times to corresponding data logger water depths.

The periods of data collection were:

> 2012: 11 June – 4 December
> 2013: 30 April – 10 December
> 2014: 23 April – 19 November

2012: Loggers were deployed at 3 locations: <u>downstream</u> (DS), i.e., the open water north of LRL that forces the tidal response in Long Reach Marsh; <u>lower marsh</u> (LM), just south of LRL;

mid marsh (MM), in the channel south of the lower marsh logger. These locations are proximate to monitoring St. 1, 2, and 4/5, established in 2013. A subset of the 2012 data (6/11 – 8/07) was presented in the *Mitigation Plan*.

2013: In addition to the 2012 locations, 2 additional locations (for a total of 5) were included, upper marsh (UM) and above narrows (AN). Altogether, these locations are proximate to monitoring St. 1, 2, 4, 8 and 10.

2014: The same general locations were used as in 2013. The UM logger was located above the rock ford in the upper marsh (approximately at St. 9).

Data Evaluation

For consistency with the *Mitigation Plan* document, data for 6/11-8/07/2012 were used as the baseline pre-construction data set for comparison to the 2014 post-construction data; the 2013 data are not presented here. The stage drop across LRL is the difference in stage at the DS and US locations and is the basis for evaluating the effectiveness of the new box culvert. The upper marsh (more southerly) loggers provide useful information on the propagation of the tidal signal into the upper marsh. However, since they do not figure directly in the evaluation of the mitigation performance objective they are not discussed here.

The original culvert at LRL, prior to replacement, was 36" diameter and thus constituted a serious restriction to tidal exchange with Long Reach Marsh south of LRL. The restriction manifested as a "head (stage) drop" from one end of the culvert to the other on both incoming and outgoing tides. On incoming tides, the restriction reduces the tidal flow that would otherwise pass under LRL. On outgoing tides, the restriction inhibits drainage of the marsh. The head drop is greatest at high tides, limiting inflow. Comparing downstream (open water) high tides to upstream (or lower marsh) high tides, the head ranged from 0.5' to over 2' at spring tides. The objective of the compensatory culvert replacement was to significantly reduce and effectively eliminate this restriction.

These high tides are critical to establishment of salt marsh vegetation on the high marsh surface. The marsh surface was rarely inundated. With outgoing tides, the restriction prevented adequate drainage, thereby inhibiting development of intertidal vegetated and mudflat habitat.

The performance objective is posed as a percentage reduction in the head drop across the culvert. Head is defined between corresponding high tides downstream (open water; north of LRL) and upstream (lower marsh; south of LRL):

$$\Delta = {}_{ht}Z_{ds} - {}_{ht}Z_{us}$$

Hereafter, the subscript "ht" will be dropped, with the understanding that we are referring to high tides. The percent reduction from pre-construction to post-construction, as compared to pre-construction head drops, is:

$$\% \text{ Reduction} = 100 \times \{(\Delta_{post} - \Delta_{pre}) / \Delta_{pre}\}$$

For the purposes of this evaluation we will be using tidal data sets from 2012 (pre) and 2014 (post). We also collected data pre-construction data in 2013, but are using the 2012 data set for consistency with the *Mitigation Plan*. Then our % reduction is calculated as:

$$\% \text{ Reduction} = \{(\Delta_{2014} - \Delta_{2012}) / \Delta_{2012}\}$$

We present most of our results as a side-by-side comparisons of data from 2012 and 2014. Figure 4 shows Portland high tides vs. downstream high tides. As expected, the results are the same for both years. Open water (downstream) high tide elevations are essentially identical to Portland. Similarly, high tide times of occurrence are also nearly identical, as shown in Fig. 5. The scale obscures the actual differences in time of occurrence, which can be as large as 10 minutes or so.

Figure 6 shows a typical high tide window, taken in July. (Note that the date of highest tide has shifted from 2012 to 2014.) Figures 8-9 show the impact of replacing the 36"D pipe with the 6'R x 12'S box culvert. Note how the 2012 maximum drop of 2' (7/8/12) has been reduced to less than 6". The upstream low tide has also been reduced, reflecting improved drainage due to the lower invert of the new culvert. However, drainage is now controlled by the channel elevation upstream of the head cut, not by the culvert invert. These figures, while illustrative, are not particularly useful for further analysis.

Figure 7 shows the extracted high and low tides for upstream (US), downstream (DS) and Portland (Port). This shows how the drop in 2012 ranges from 3"- 6" at the lowest high tides to slightly more than 2' at the highest high tides. In 2014, the drop across the culvert has been eliminated, at least by visual examination at this scale. Again, the upstream low tide has not changed much, because it is controlled by channel elevation and not culvert invert.

Fig. 8 shows the head drop for the same data window in the previous figures. The maximum head drop, occurring at the maximum high tides, has been reduced from 2' to 0.33', a percent reduction of 100 x {(2 – 0.33)/2} = 83.5%, exceeding the performance standard. The graphs in Fig. 8 have essentially the same shape, and might suggest that there has been no change if one does not pay careful attention to the vertical scale. Therefore, the time series have plotted to the same scale in Fig. 9. The reduction in head drop is immediately evident.

The graphs presented thus far are useful in showing the improvement that has been achieved, how it evolves over the tidal cycles, and how it relates to higher and lower high tides. However, such time series graphs are not ideal for systematically evaluating the entire data sets, with particular attention to high tides. Therefore, the remainder of the discussion will focus in the high tides that have been extracted from the complete data series.

Fig. 10 compared downstream to upstream high tides. The red line is the line of perfect match; flow restriction and consequent head drop are indicated when the data pairs fall below the match line. The drops are always smaller with the lower high tides and larger with the higher high tides. The improvement from 2012 to 2014 is obvious. Fig. 11 shows the data for 2012 and 2014 plotted together, as well as showing the "best fit" quadratic curves fitted to the data. These curves will be used later to numerically evaluate the head drop reduction that has been achieved.

The head drop data are shown explicitly in Fig. 12, with the drops plotted against the downstream stage. The vertical horizontal "zero line" indicates the hypothetical case of no drop and perfect match between downstream and upstream. Again, careful attention should be paid to the vertical scale. The data show the same shape, and superficially are similar except that there is much more scatter in the 2014. However, the magnitudes of the 2014 data are much smaller than the 2012 data (2014 vertical scale maximum = 0.5 vs. 2012 vertical scale maximum = 2.0). The scatter in the 2014 data is explained by the fact that the magnitude of the drops, particularly at the lower high tides, is of the same magnitude as the noise in the data. The 2012 drops are significantly larger the noise, and so the scatter is not as pronounced.

The same data are depicted in Fig. 13, with linear and log vertical scales, as well as with "best fit" exponential curves. The noise in the 2014 data is much easier to see in the log-linear graph. The noise also manifests itself in the lower R^2 statistic for the 2014 data. In fitting the 2014 data, data points for $Z_{DS} < 5'$ (yellow-ish "+" symbols) were not used, because there is essentially no meaningful head drop and the calculated differences are almost entirely noise.

A final depiction of the change in the tidal regime at Long Marsh is shown in Fig. 14, a stage duration curve. Pre-construction, the upper limit on US high tide precludes nearly any inundation of the high marsh surface. Post-construction, US stages are greater than the maximum pre-construction value 7% of the time. Furthermore, the US duration curve is virtually indistinguishable from the DS open water curve for stage values above the US channel invert.

We have presented strong evidence for greatly improved tidal exchange under LRL, based on visual inspection of data plots and evaluation of isolated individual data points. We conclude this discussion by evaluating the entire data sets utilizing the “best fit” curves for $\Delta = f(Z_{DS})$ and $Z_{US} = g(Z_{DS})$.

The functions for $\Delta = f(Z_{DS})$ are:

2012: $\Delta = 0.0338 \times \exp(0.6094Z_{DS})$

2014: $\Delta = 0.0009 \times \exp(0.8804Z_{DS})$

The functions for $Z_{US} = g(Z_{DS})$ are:

2012: $Z_{US} = -0.0128Z^2_{DS} + 1.7762Z_{DS} – 1.4137$

2014: $Z_{US} = -0.0381Z^2_{DS} + 1.3007Z_{DS} – 0.6134$

The equation for calculating percent reduction in head drop was given above. The results are shown in Fig. 15.

When calculated using the direct equations for Δ, the result is a simple monotonically decreasing function. This makes sense, as we expect the head drop in the new box culvert to be larger at the higher high tides (larger Z_{DS}). Percent reduction of over 90% has been achieved for Mean High Water (MHW, approximately 4.5’), and it is still greater than 80% for the Portland Highest Astronomical High Tide (HAT, approximately 6.7’).

When calculated using the functions $Z_{US} = g(Z_{DS})$, the results for tides greater than Mean High Water are nearly identical to using the best-fit Δ equations: percent reductions range from 91% - 94% at MHW, to 83% - 84% at HAT. However, this curve shows the odd behavior of decreasing improvement with high tides. This is an artifact of the curve fitting, data noise, and the fact that the magnitude of head drop at these lower high tides is exceedingly small (3” or less).

An independent calculation of percentage improvement was made by considering the change in Mean Higher High Water (MHHW). Based on the 2012 data subset, the MHHW were 5.06’ (DS) and 4.23’ (US); the corresponding 2014 values were 5.03’ (DS) and 4.96’ (US). The percentage improvement in MHHW drop across the culvert is 100 x (0.83 – 0.07)/0.83 = 92%. By this measure, the stage drop has been effectively eliminated.

Based on this analysis, we conclude that the performance objective of reducing the head drop across LRL by at least 80% has been achieved.

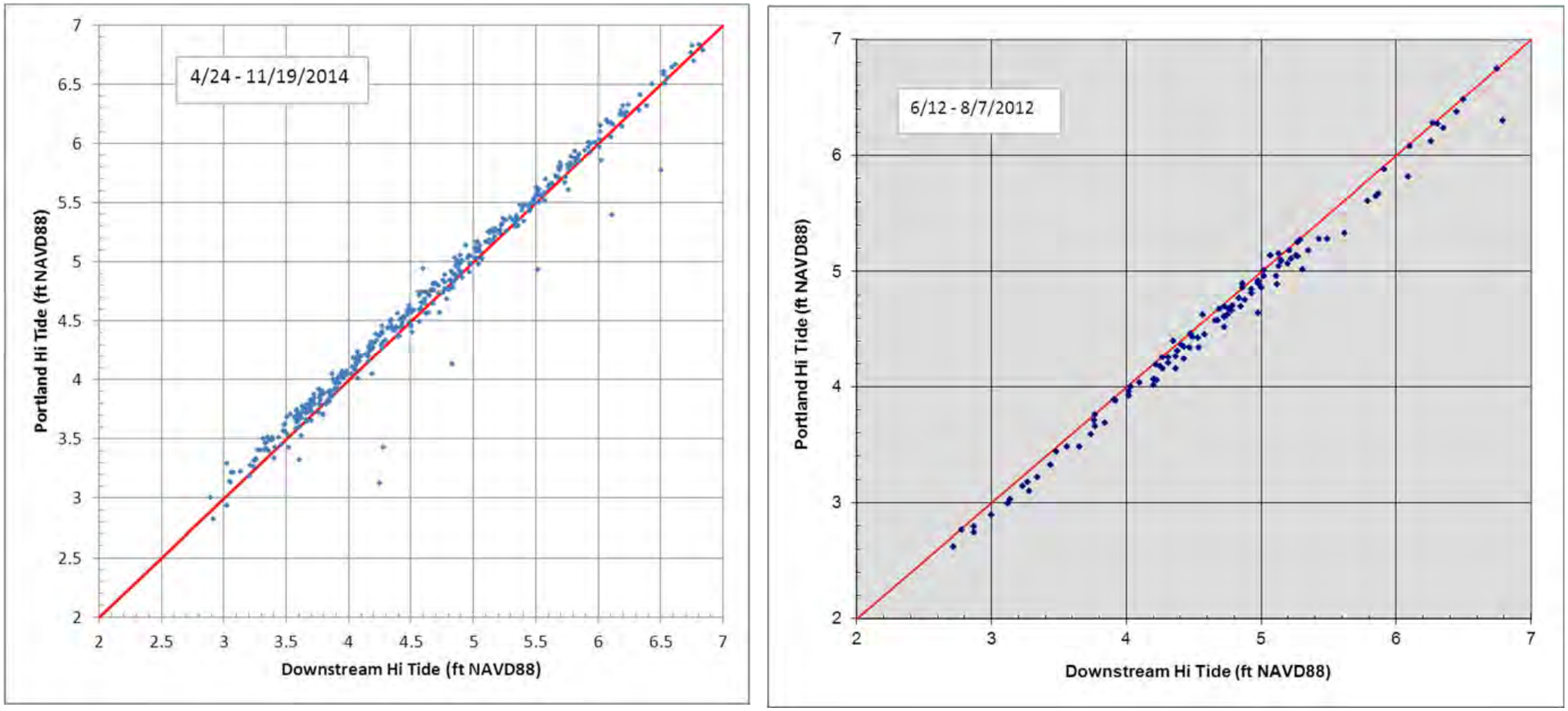


Figure 4. Portland High Tide vs Long Reach Downstream High Tide.

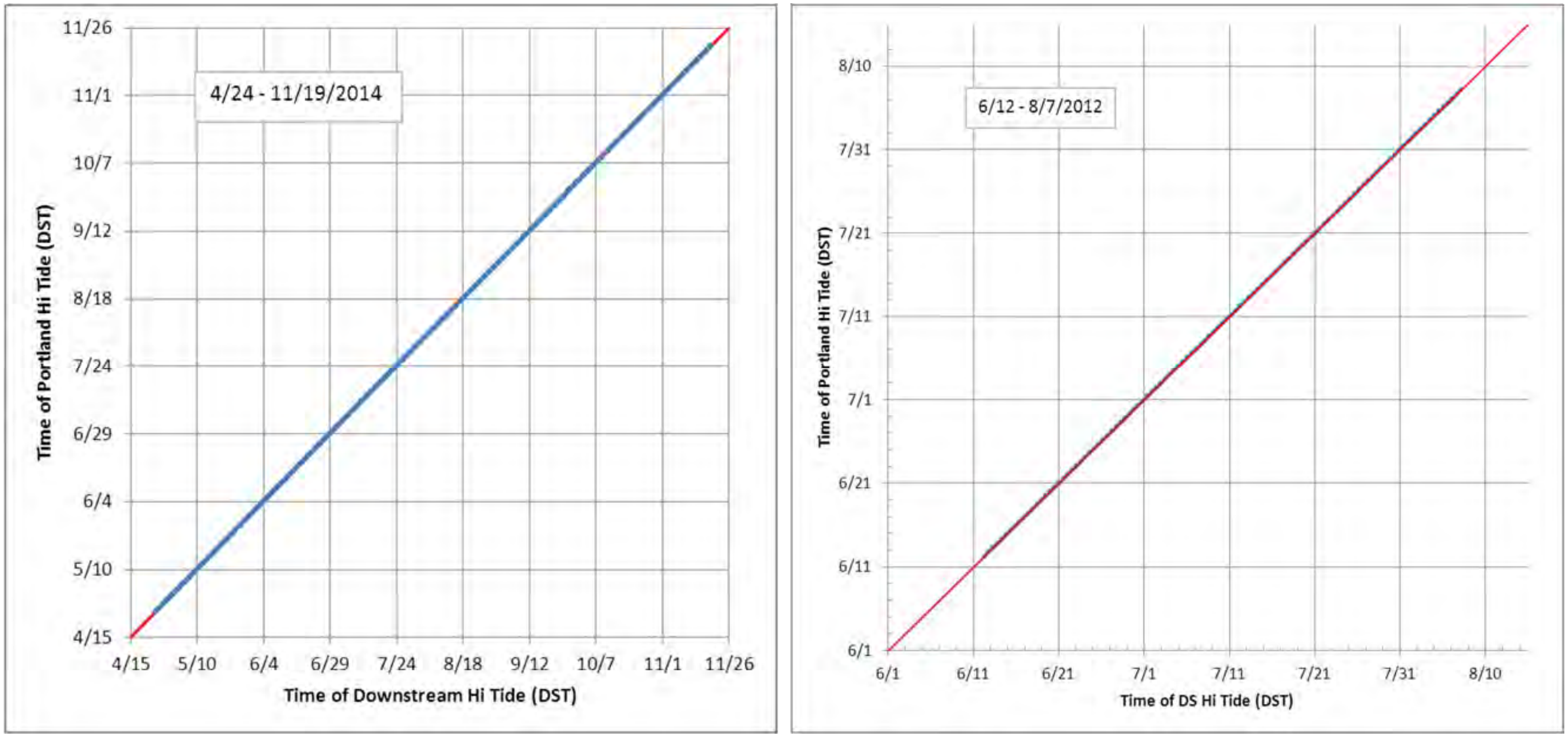


Figure 5. Time of High Tides in Portland and Long Reach Downstream.

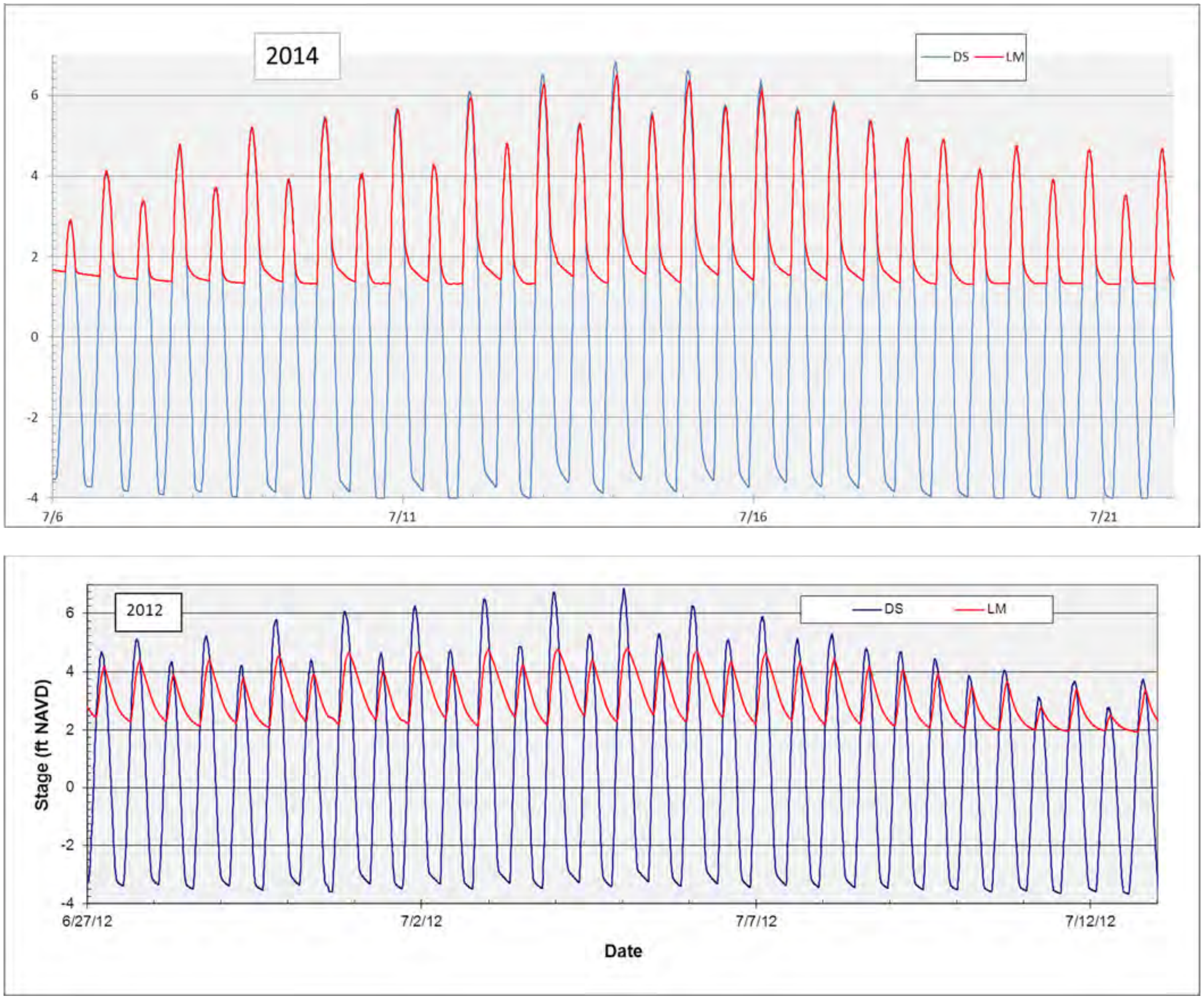
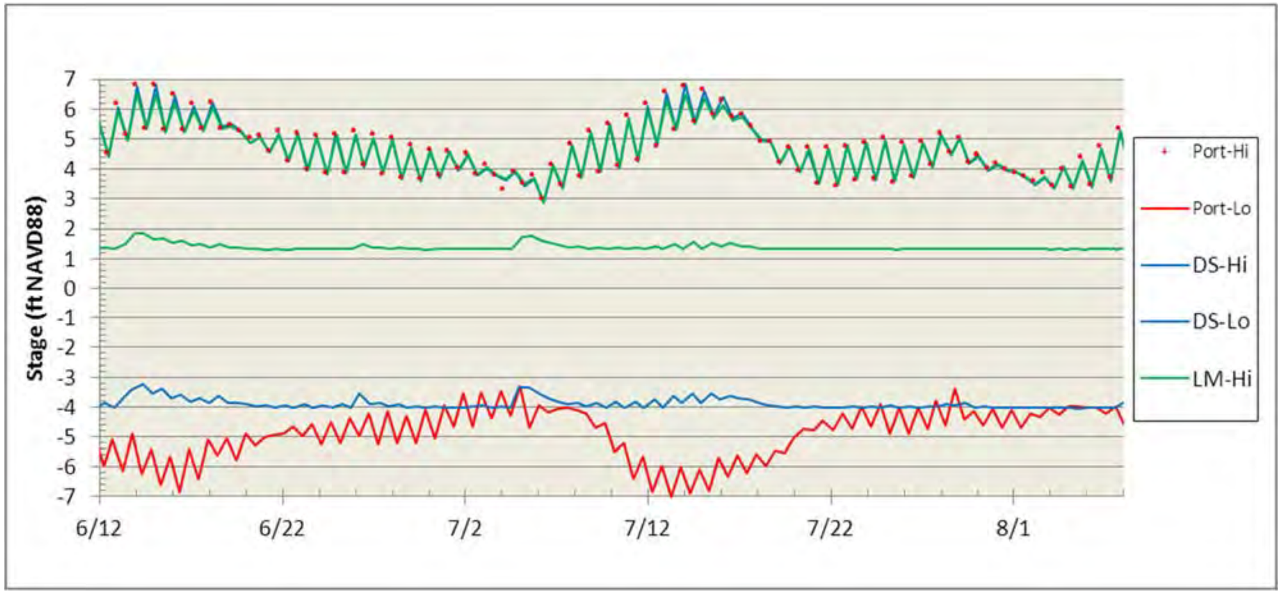


Figure 6. Typical High Tide Data Windows.



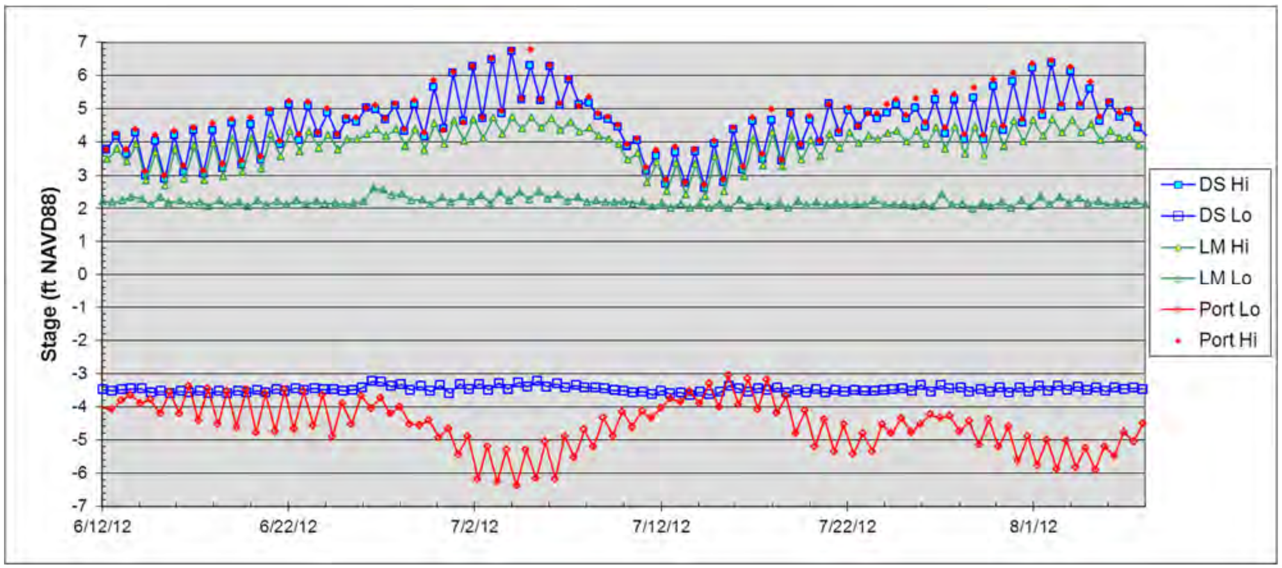
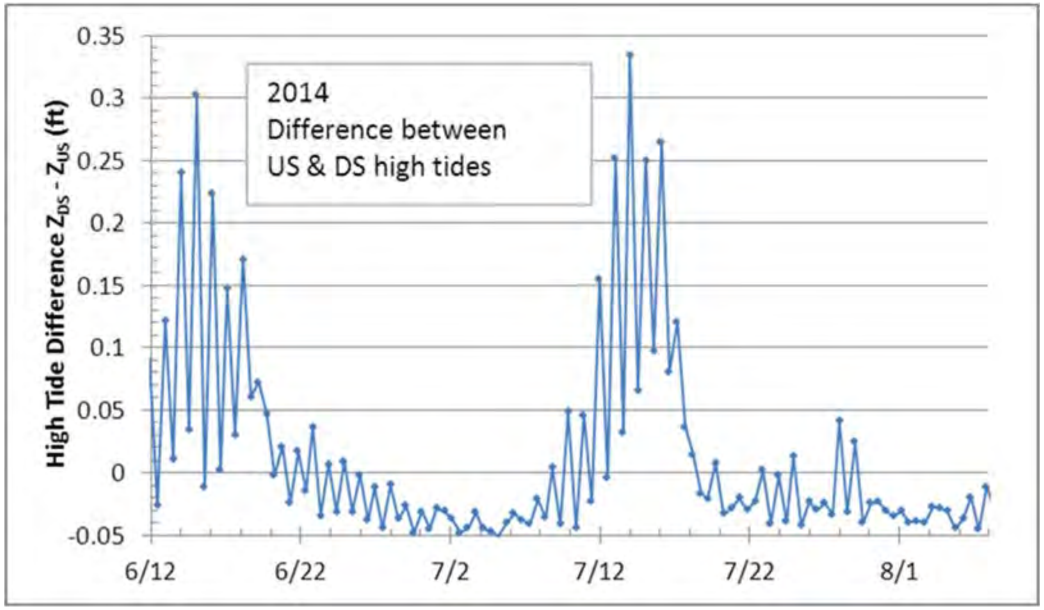


Figure 7. Time Series of High and Low Tides During Summer Period.



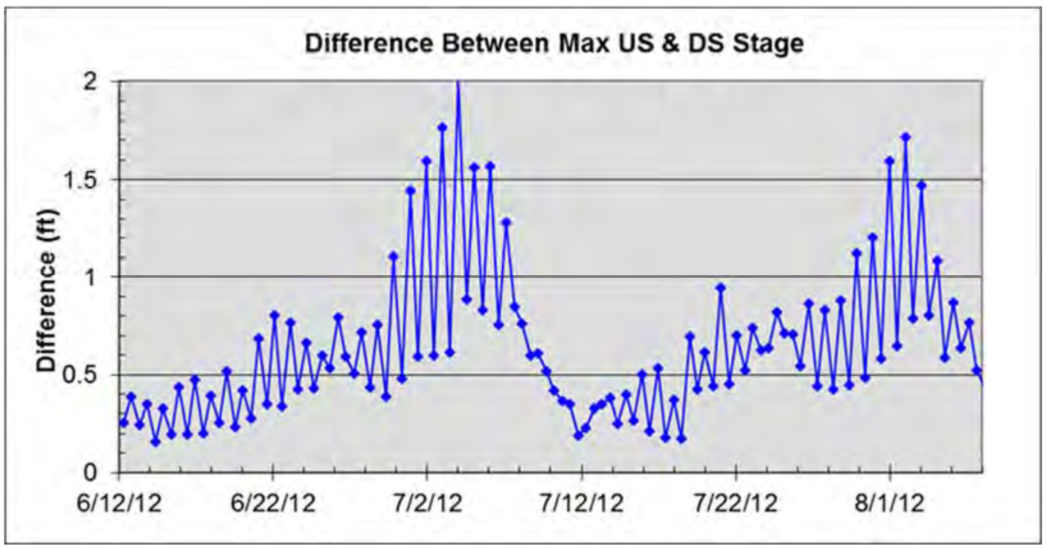


Figure 8. Time Series of Differences in High Tides Across Culvert, 2012 and 2014.

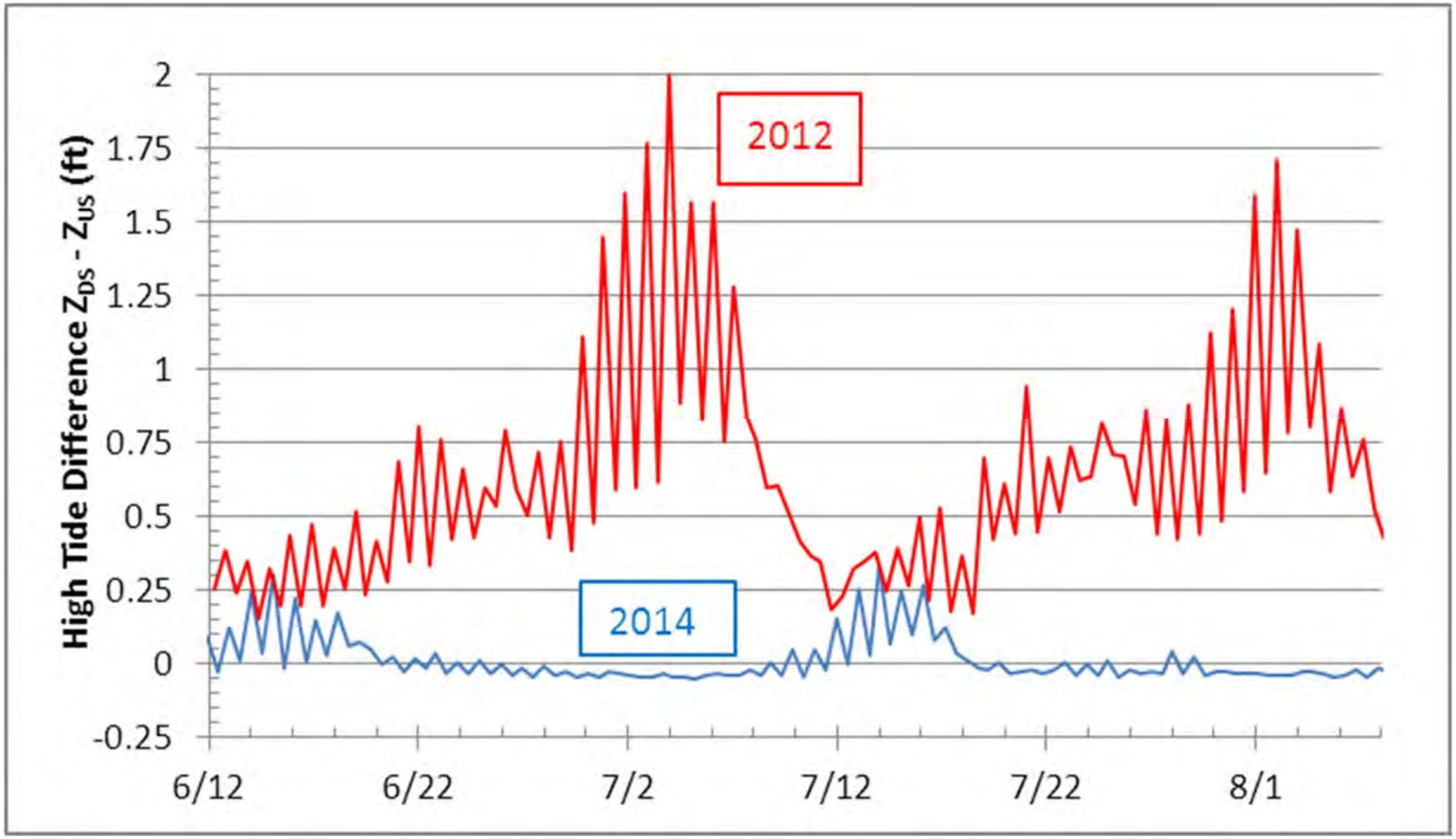
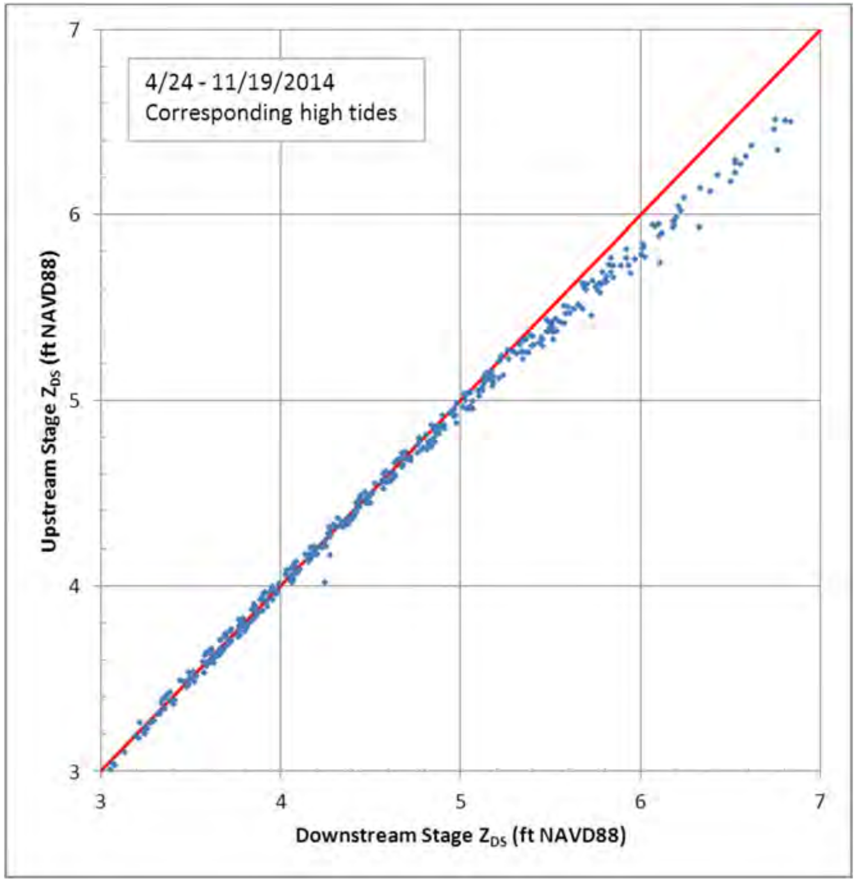
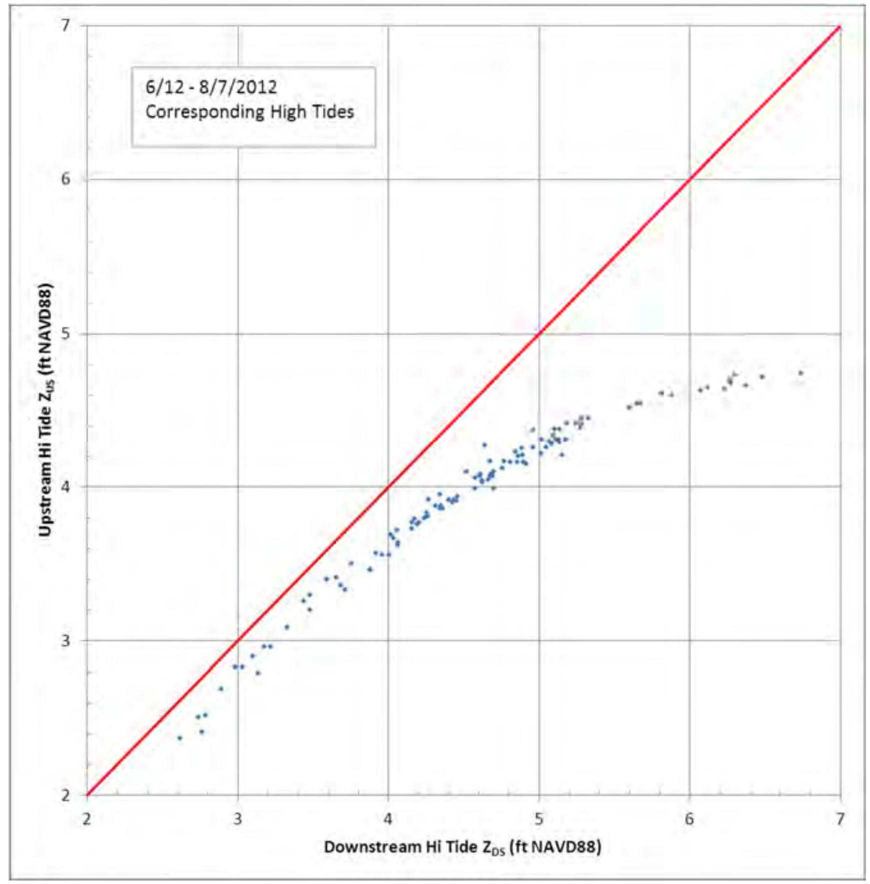


Figure 9. Time Series of Differences in High Tides Across Culvert, 2012 and 2014 (to same scale).

Figure 10. Upstream vs. Downstream High Tides, 2014 and 2012.





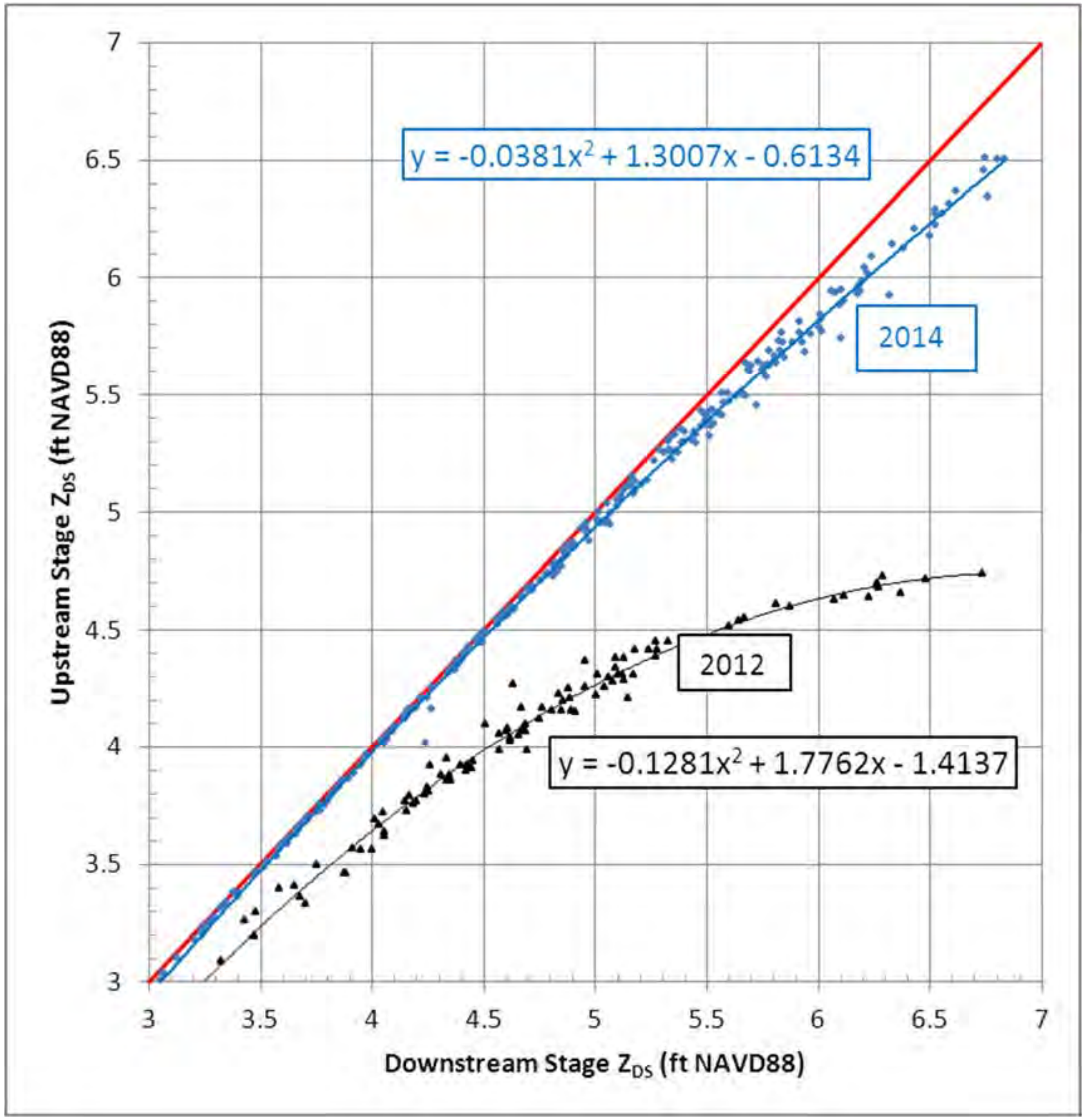


Figure 11. Upstream vs Downstream High Tides, 2014 and 2012 (plotted together with best-fit lines).

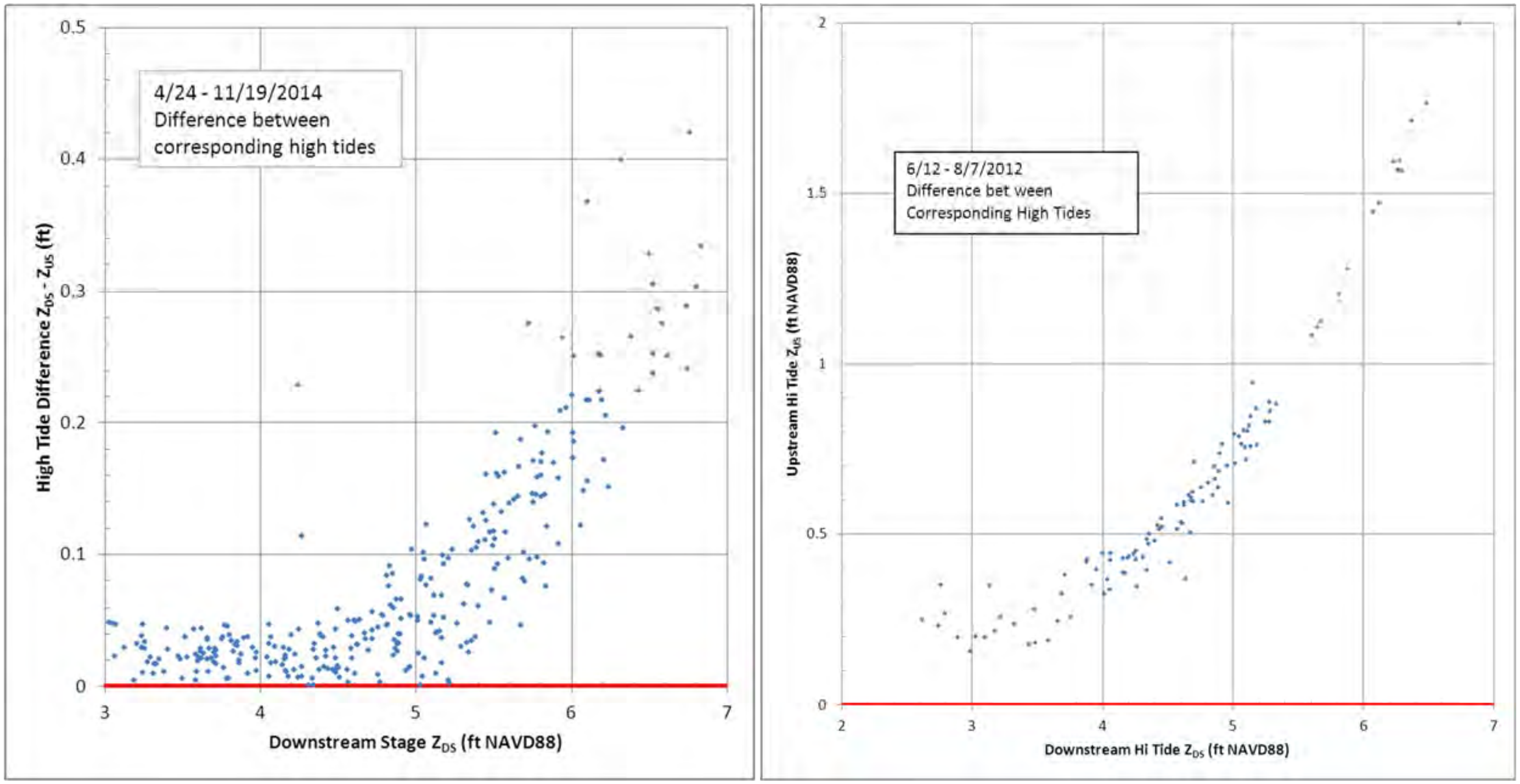


Figure 12. Difference in High Tides Across Culvert, 2014 and 2012.

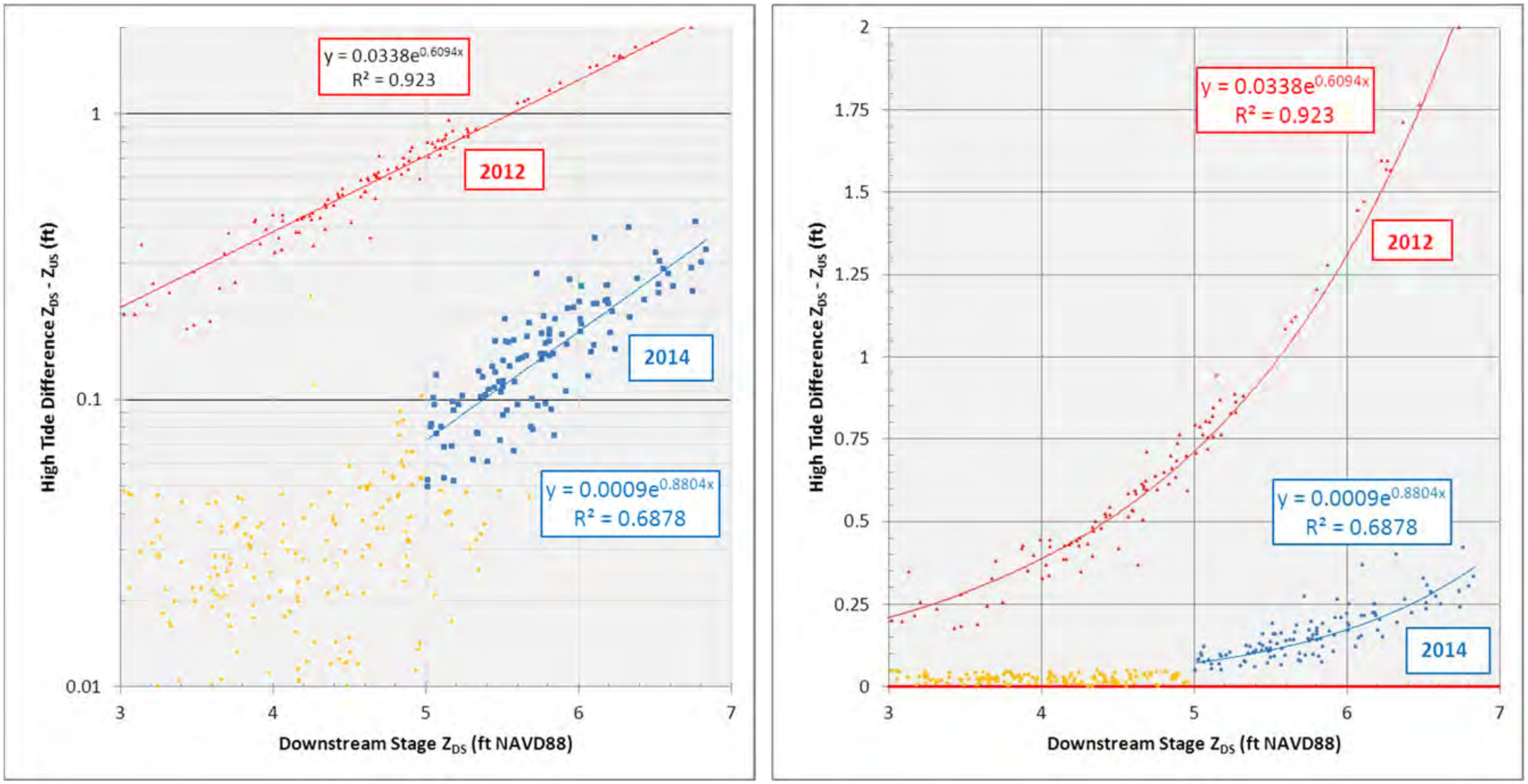


Figure 13. Difference in High Tides Across Culvert, 2014 and 2012 (plotted together with best-fit lines, linear & log-linear scales).

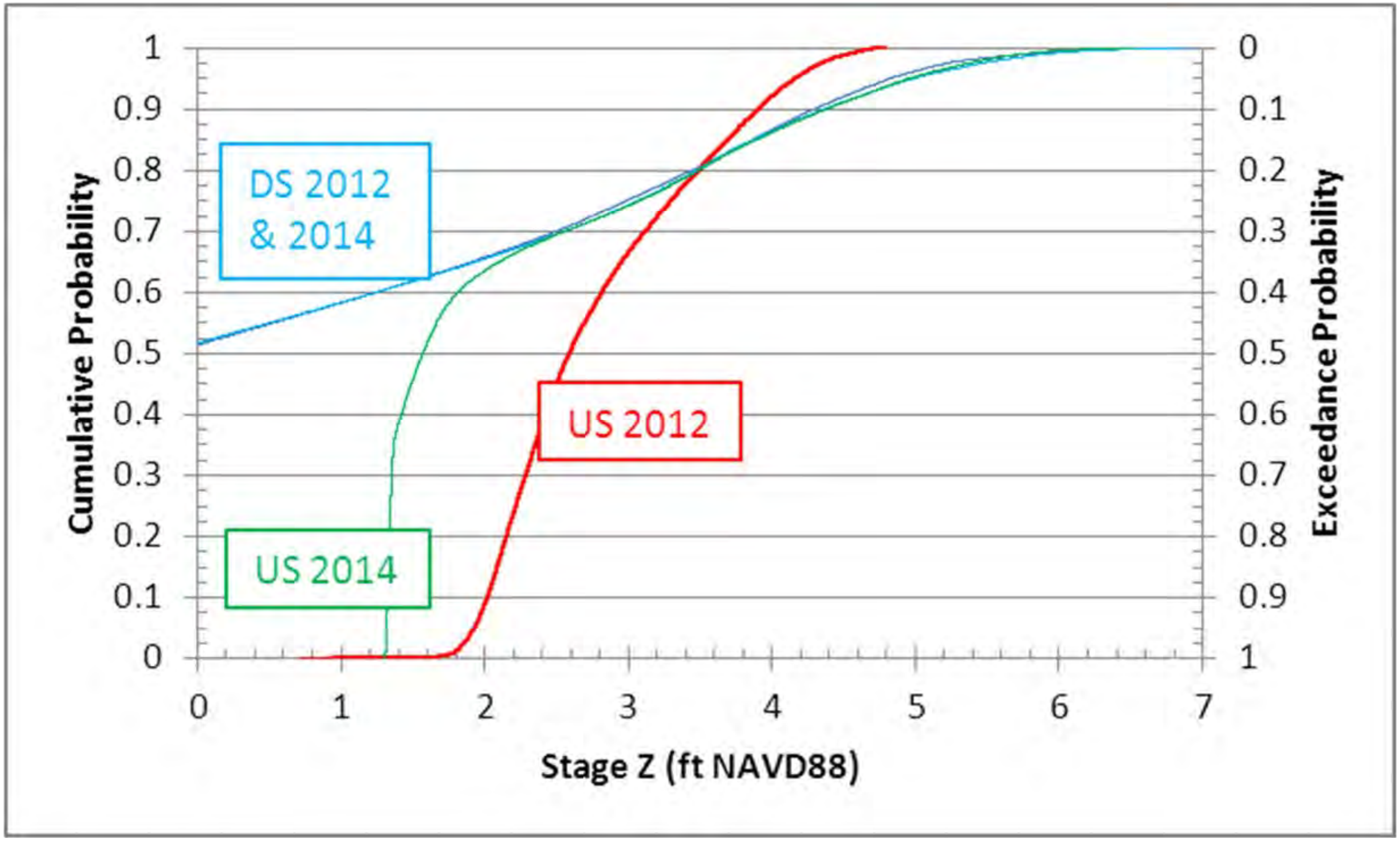


Figure 14. Stage Duration Curve.

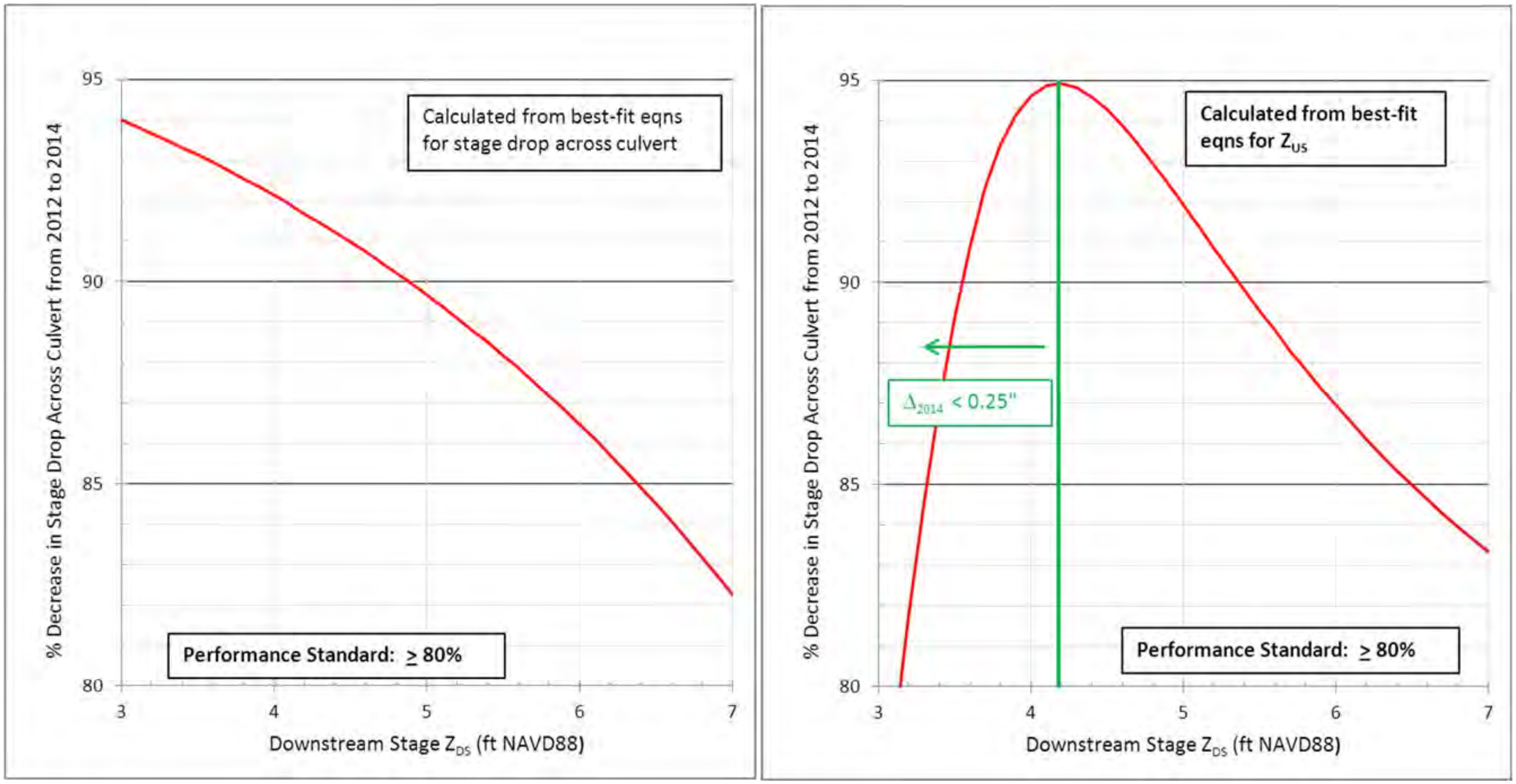


Figure 15. Percent Decrease in Stage Drop Across Culvert (by two different sets of best-fit equations).

3.2 Pore Water Salinity

Summary of monitoring results

Pore water salinity was a core monitoring parameter specified in the *Mitigation Plan*. The objective of monitoring was to document changes in pore water salinity from pre to post-project:

> *Pre and post-construction pore water and channel water salinity will be measured both upstream and downstream of the LRL crossing. Measurements will be conducted at various locations along the transects in the channel and on the marsh surface. Changes in salinity will be documented in the annual monitoring report.* (MaineDOT 2012, Section K)

Based on the following evaluation of pre- and post-project pore water salinity data, we conclude that changes in pore water salinity are consistent with transitions observed in the Project Area from a salt marsh/brackish/fresh water system to predominantly salt tolerant species and a salt marsh.

Surface water salinity is discussed in Section 3.3.

Background

Prior to the start of sample collection each year, pore water wells were located, flagged, and their condition assessed following winter ice buildup and movement. If necessary, CBEP removed and rinsed wells to clear out accumulated sediment. In 2018, CBEP collected seven rounds of pore water salinity samples (Table 3).

Table 3. Pore water salinity sampling dates.

Year	April	May	June	July	August	September	October
2013		5/21		7/1, 7/25	8/29	9/25	10/21
2014	4/23, 4/25	5/21	6/6, 6/24	7/8	8/28	9/17	10/28
2015	4/28	5/8	6/12	7/9	8/13	9/18	10/23
2016	4/27	5/17	6/15	7/15	8/24	9/22	10/24
2017	4/28	5/18	6/19	7/21	8/14	9/29	
2018		5/15, 5/18	6/1	7/16, 7/30	8/20	9/17	

Pore water salinity levels appear to be impacted by seasonal precipitation, particularly at wells located away from surface water. Daily precipitation totals for 2018 are shown in Fig. 16. Table 4 compares monthly precipitation totals with 'normal' conditions.

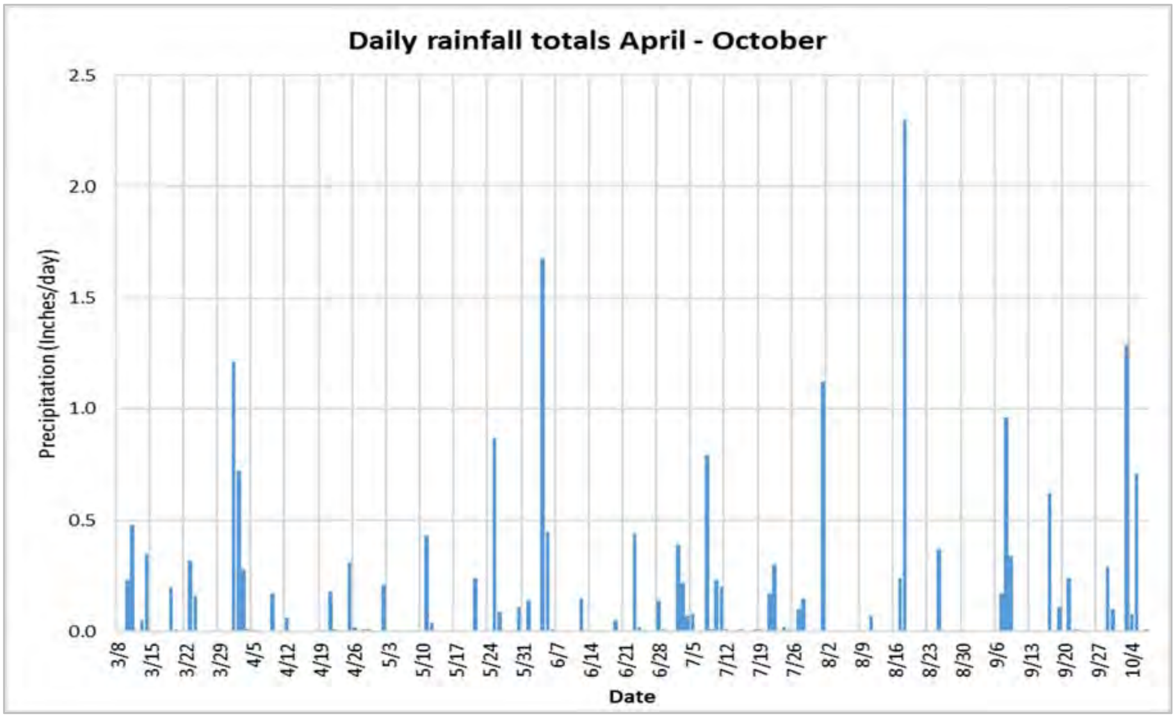


Figure 16. Daily rainfall totals at Harpswell Station KMEHARPS28 for the 2018 field season.

Table 4. Summary of monthly precipitation compared with historic levels.

Year	March	April	May	June	July	August	Sept.	Oct.	Cum.
2013	1.9	2.4	5.3	3.6	3.3	2.0	3.7	1.5	23.7
2014	4.2	2.7	3.4	6.0	7.2	2.9	1.3	4.5	32.1
2015	1.3	3.3	2.2	6.7	1.7	2.1	6.1	3.0	26.4
2016	4.5	2.7	1.8	2.7	2.2	0.6	.2	2.1	16.7
2017	1.5	4.6	5.5	2.3	1.0	3.1	2.3	5.0	25.3
2018	3.2	4.0	1.0	4.1	1.6	3.1	3.0	4.9	24.9
Normal*	*3.7*	*4.1*	*3.6*	*3.4*	*3.1*	*2.9*	*3.1*	*3.9*	*27.8*

*Historic 'normal' monthly rainfall at Portland Jetport (1961-1990).

Although studies incorporating more recent data than the "normal" rainfall totals shown in Table 4 suggest that precipitation totals may be increasing in spring, summer, and fall seasons (Wake *et. al.*, 2009), the Portland Jetport data still provides a useful baseline to compare monthly rainfall totals against for the monitoring period. Looking only at freshwater inputs during the monitoring season (and excluding precipitation from the preceding winters), the

2014 monitoring season was generally the wettest. In contrast, 2016 was exceptionally dry, with 2017 and 2018 only slightly lower than normal.

Pore water salinity levels were generally higher throughout the Project Area post-project (2014-18) than in 2013, consistent with improved tidal exchange and freshwater drainage (Table 5). At St. 1, used as a reference site, mean pore water salinity has been consistently lower post-project.

Table 5. Mean, minimum and maximum pore water salinity for the monitoring period.

St	Mean salinity (‰)					
	2013 (Pre)	2014	2015	2016	2017	2018
1	22.7	14.5	15.4	20.9	20.3	22.4
2	23.0	30.6	27.0	33.4	33.9	35.1
4	19.8	25.7	26.4	30.8	30.3	30.4
6	21.6	29.2	28.1	30.7	29.5	32.3
6a	8.6	24.7	23.7	27.2	27.5	30.9
8	27.2	28.4	23.5	27.0	28.3	30.2
10	25.4	27.0	24.6	25.3	24.8	27.9
11	8.6	18.0	22.5	19.1	21.8	25.2

Figure 17 plots observed pore water salinity levels at St. 1-12. Each point represents the mean of three readings taken per a given sample. Pre-project samples are shown in blue, and post-project samples in orange, differentiated by symbols, with the most recent data plotted with an orange dotted line. St. 11 and 12 are outside the Project Area but included for context.

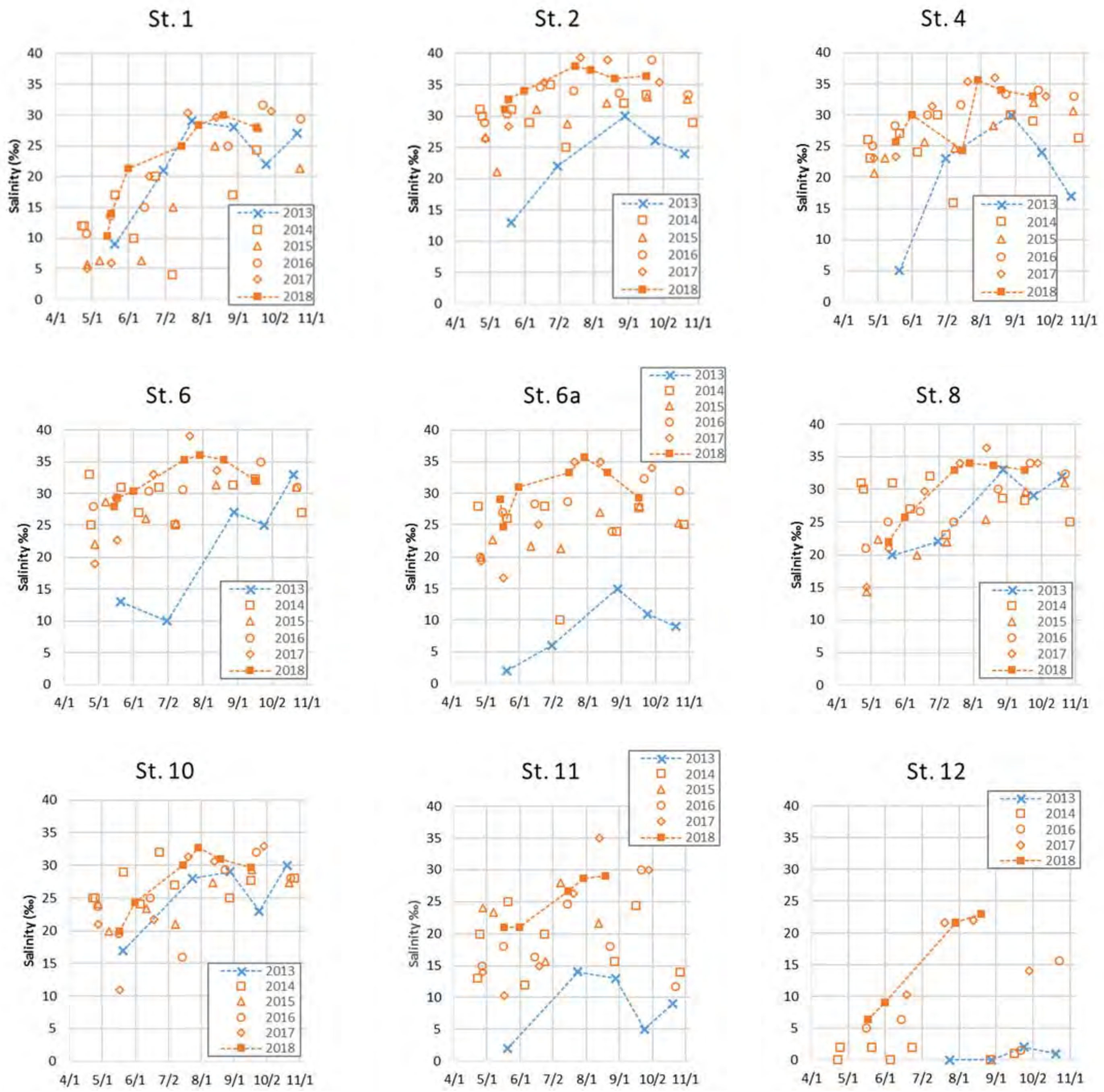


Figure 17. Plotted pore water salinity Stations 1, 2, 4, 6, 6a, 8, 10, 11, and 12

Within the Project Area (excluding St. 1, 11, 12), measured samples of pore water salinity increased from 20.9 ppt. pre-project (2013) to 27.9 ppt. post-project (2014-2017). Within the Project Area, the greatest increase in pore water salinity levels has been at St. 6a, which increased from a mean of 8.6 ppt. in 2013 to 27.1 ppt. post-project (Table 5). Of the monitoring wells, St. 6a is laterally the furthest away from the tidal creek channel.

Fig. 18 plots mean, minimum, and maximum pore water salinity levels by year for each station. In 2018, observed pore water salinity in the Project Area ranged from a low of 20‰ at St. 10 to a high of 39‰ at St. 2. Other than St. 4, observed mean pore water salinity levels were higher throughout the Project Area in 2018 than any prior year, although this may be partially due to the fact that there were no samples collected in April or October (comparatively wetter months). The greatest post-project change in pore water salinity was at St. 6a. St. 6a was placed near the upland edge, and is furthest from the creek channel of all the wells. The dramatic increase in salinity is consistent with observations from vegetation monitoring that generally, the biggest shifts in vegetation community type were at locations further from the creek channel. A similar increase was observed at St. 11, outside the Project Area. St. 11 is adjacent to stands of invasive *Phragmites australis*, which shows signs of stress in response to the new hydrological regime. The impact of the culvert replacement extends well south of the Project Area and the Narrows, into the southern reach of the marsh.

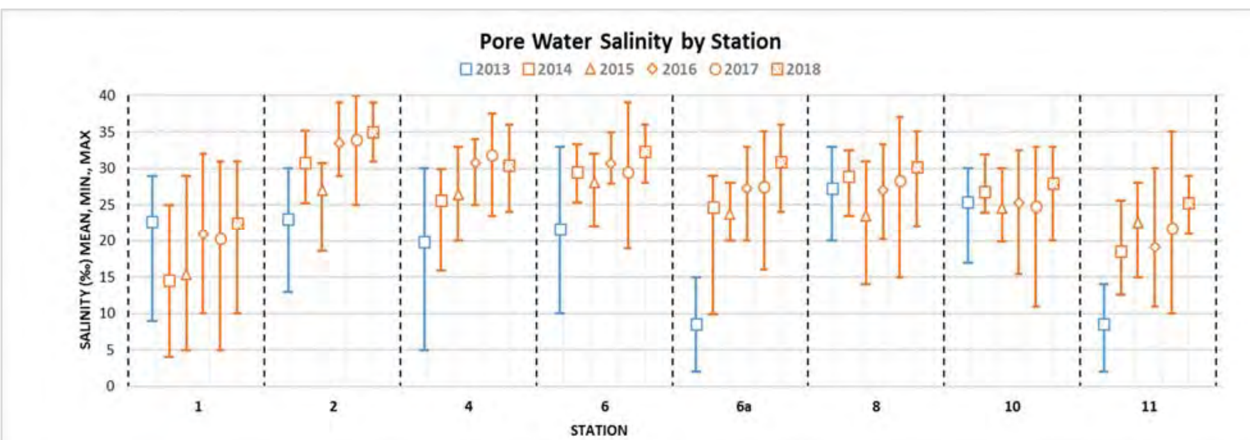


Figure 18. Mean (symbol), min. (low bar), and max. (high bar) pore water salinity readings, 2013-2018.

In 2016, consistent with drought conditions, mean pore water salinity in the Project Area rose to 29.1‰, with individual readings approaching 40‰ at St. 2, which is adjacent to a large pool. Mean salinity levels were 29‰ in 2017, and 31‰ in 2018.

Figure 19 plots individual salinity readings from samples collected in the Project Area with best-fit trendlines for pre- and post- project data. Although there aren't enough pre-project samples to make statistically significant observations, pore water salinity levels appear to be higher post-project, earlier in the growing season, than pre-project. The post-project mean of pore water salinity samples (28.6‰, 2014-2018) is higher than pre-project levels (20.9‰, 2013).

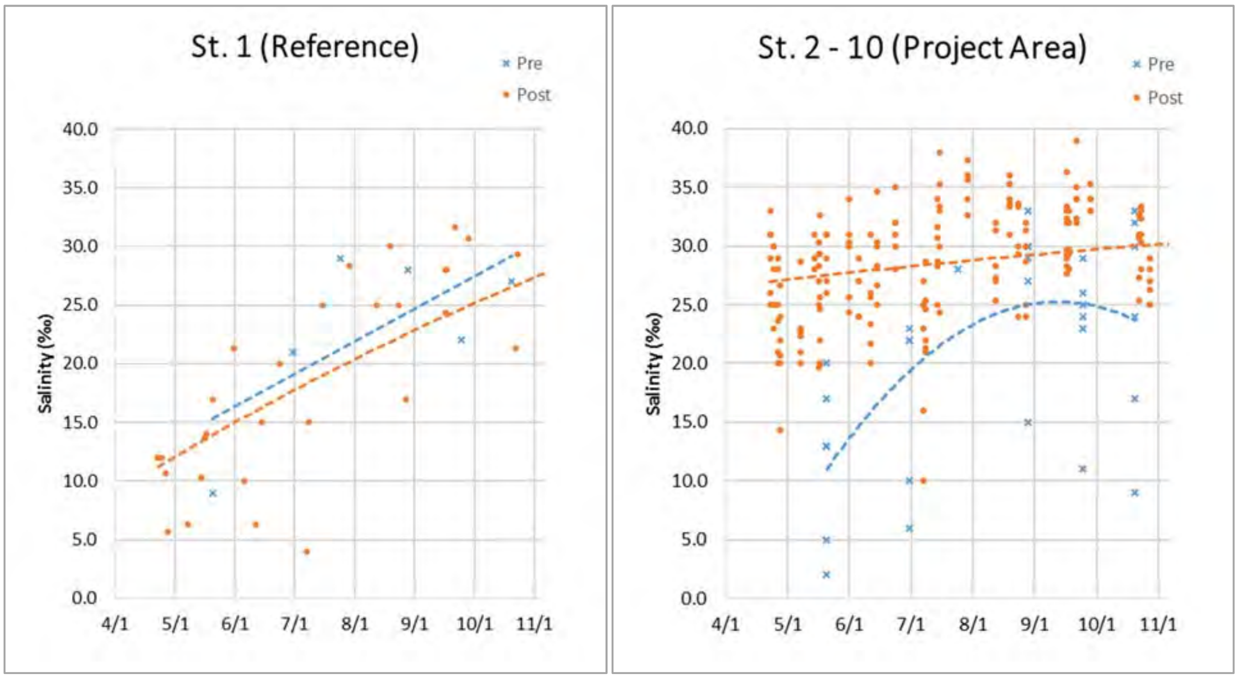


Figure 19. Pore water salinity comparison between Reference Area and Project Area. .

These findings are consistent with improved tidal exchange into the marsh, and improved freshwater drainage out of the marsh, and the surface water hydrology discussed previously. The replacement culvert is delivering salt water onto a greater extent of the marsh surface more frequently and for longer periods of time. Pore water salinity levels appeared to be higher throughout the spring and summer in 2014, 2015, 2017 and 2018 than in 2013, which, over time, is gradually influencing the vegetation community. These data suggest that the vegetation community in the Project Area is likely to continue shifting toward more salt tolerant plant communities and salt marsh, from brackish and freshwater communities, in the years to come.

3.3 Surface Water Salinity

Summary of monitoring results

Surface (channel) water salinity was a core monitoring parameter specified in the *Mitigation Plan*. The objective of monitoring was to document changes in surface water salinity from pre to post-project:

> *Pre and post-construction pore water and channel water salinity will be measured both upstream and downstream of the LRL crossing. Measurements will be conducted at various locations along the transects in the channel and on the marsh surface. Changes in salinity will be documented in the annual monitoring report.* (MaineDOT 2012, Section K)

Based on the following evaluation of pre- and post-project pore water salinity data, we conclude that changes in surface water salinity are consistent with transitions observed in the Project Area from a salt marsh/brackish/fresh water system to predominantly salt tolerant species and a salt marsh.

Background

CBEP monitored surface water salinity in two ways: 1) collection of surface water grab samples during pore water salinity monitoring for the duration of the monitoring period; and, 2) continuous monitoring of surface water salinity using automated equipment for several weeks in both 2013 and 2014.

Table 3 (Sec. 3.2) lists the dates of channel water grab samples. Surface water salinity readings appeared to be highly variable and associated with changes in tide direction, precipitation, stratification of fresh and salt water within the channel. Because of this variation, grab samples were deemed to be less informative for monitoring changes pre and post-project. Therefore, this section summarizes the results of continuous salinity monitoring using automated In-Situ *Aquatroll 200* data loggers. Surface water salinity readings are available from CBEP upon request.

Figures 20 (2013) and 21 (2014) plot pre- and post- construction salinity of the tidal creek in the Project Area. Fig. 20 illustrates that in 2013, surface water salinity decreased moving south into the marsh, away from open water, with salinity at St. 2 rising to above 30 PSU at high tide, and dipping with outgoing tides. Salinity ranged lower at St. 8, and at St. 9/10 (at the "narrows"), salinity remained nearly fresh during a the neap tide phase (10/25 – 11/1/2013). Figure 22 illustrates that post-construction (April-May 2014), surface water salinity showed increased variation over 2013, ranging between the ~28 PSU at high tides, and dropping as low as single digits PSU at low tides. Similarly, in the upper marsh, Fig. 21 illustrates that post-construction, surface water salinity at St. 8 and 9/10, which were located less than 100 feet apart, become more similar. Notable differences in surface water salinity between St. 8 and 9/10 were observed in 2014, however, due to a combination of freshwater inputs from the southern extent of the marsh (beyond the Project Area), and the presence of the “old road bed” or “ford” located in the channel between St. 8 and St. 9 (see Sec. 4). A plot of surface water salinity at St. 8 (downstream of the ford) vs. salinity at St. 9 (upstream of the ford, Fig. 23) illustrates the effect of the ford on upstream salinity levels. The ford is impounding lower salinity water upstream. The instantaneous difference in salinity levels is particularly apparent during the neap tide phase, when tide water does not appear to pass beyond the ford’s rock pile in the channel (Fig. 24).

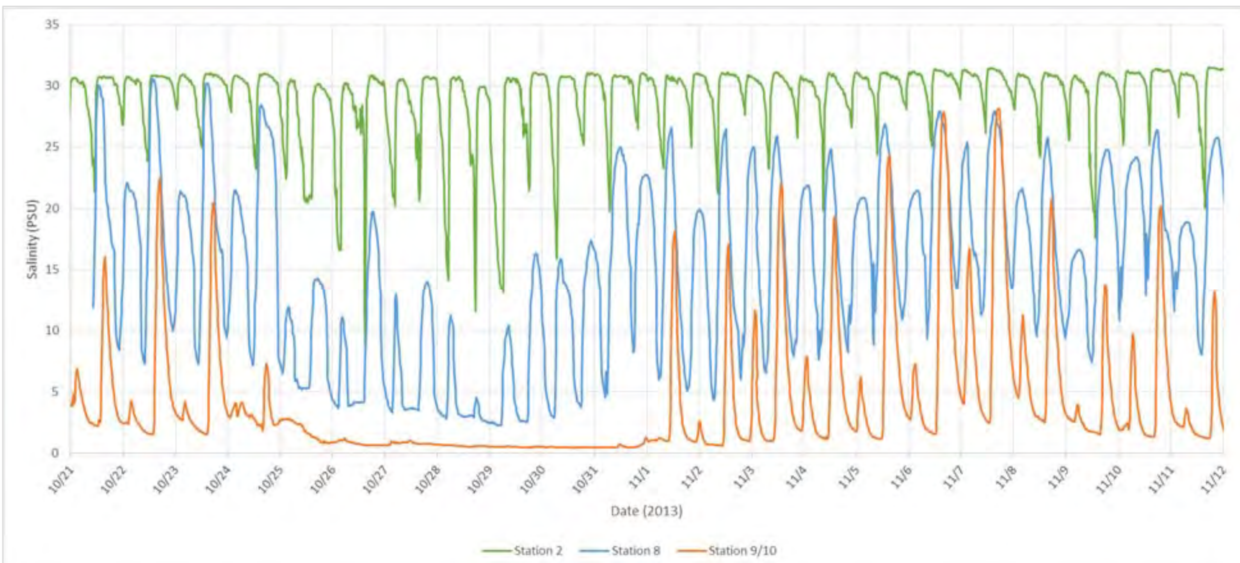


Figure 20. Surface water salinity readings in the Project Area, 2013.

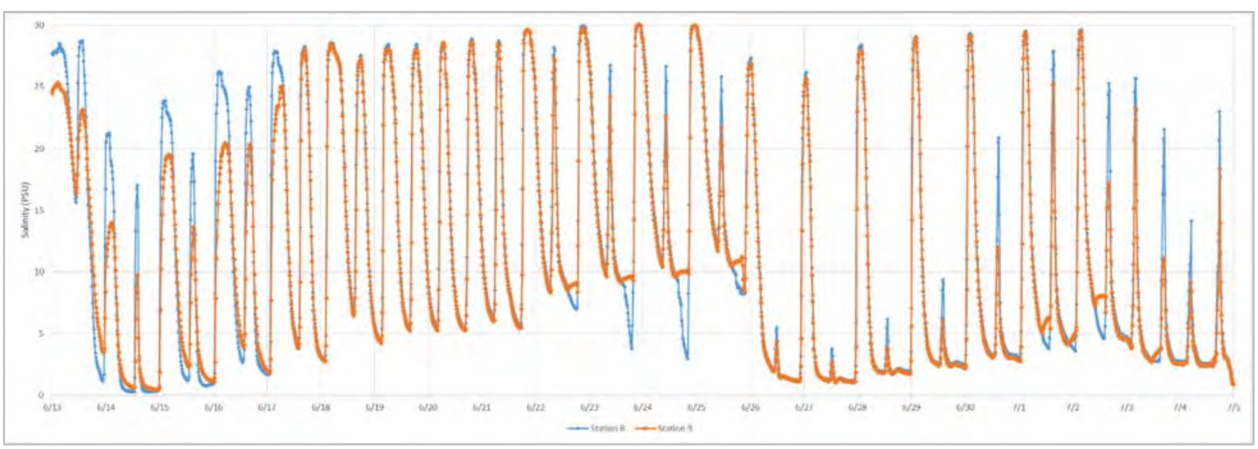


Figure 21. Surface water salinity readings at Stations 8 and 9/10, June 2014.

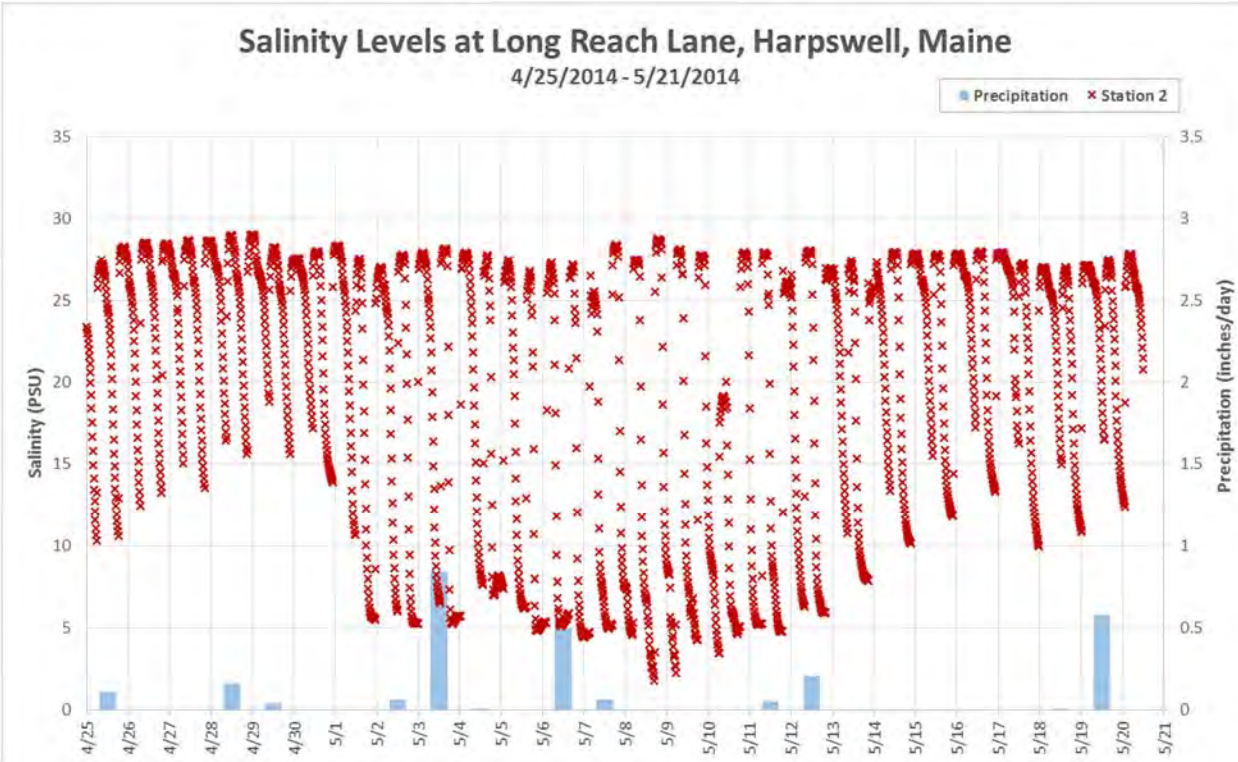


Figure 22. Surface water salinity plotted with precipitation, April-May 2014.

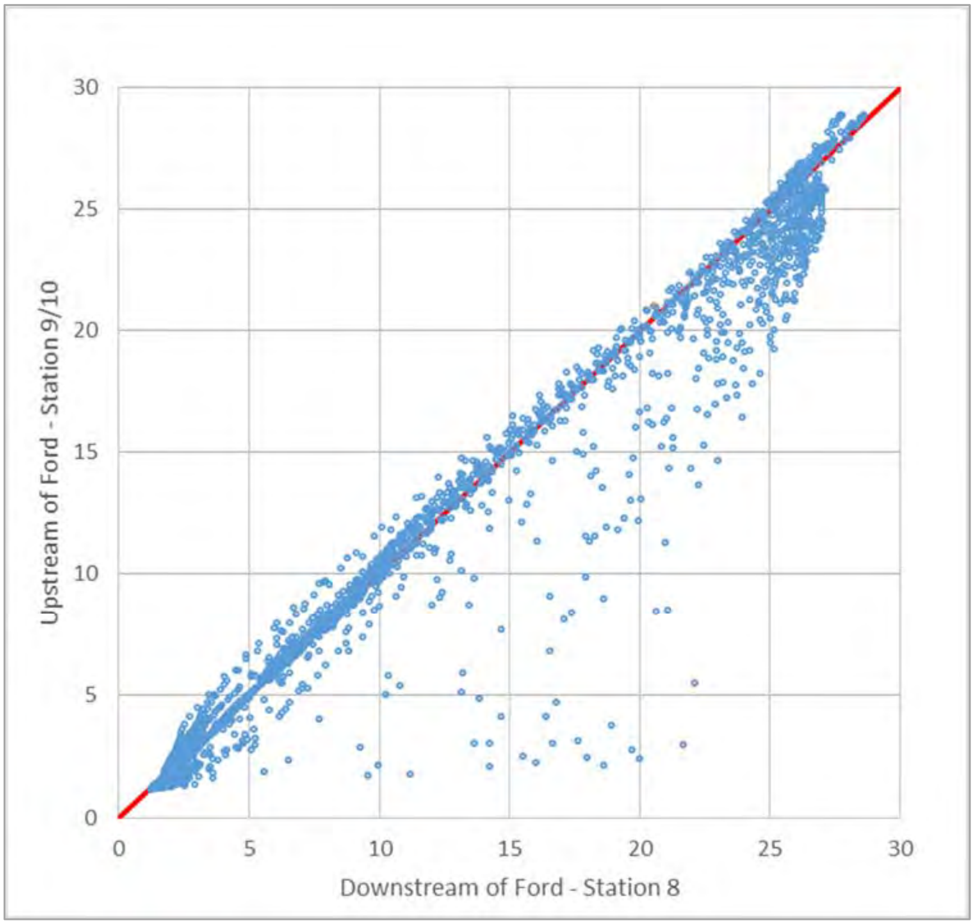


Figure 23. Downstream vs. upstream surface water salinity levels (PSU) at the "ford", spring 2014.

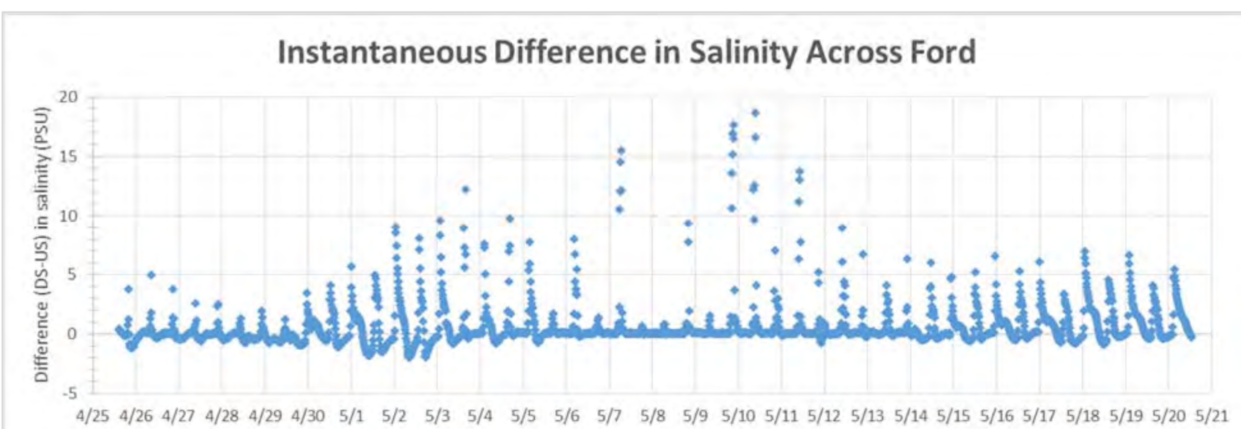


Figure 24. Instantaneous difference in surface water salinity across ford, spring 2014.

3.4 Vegetation

Summary of monitoring results

The *Mitigation Plan* identifies marsh vegetation as a core monitoring parameter indicating progress toward one of two mitigation goals:

> *Vegetation in the upstream marsh will transition from a salt marsh – brackish – freshwater system to predominately salt tolerant species. After the culvert replacement it is expected that a salinity gradient will limit freshwater species establishment. These species will be confined to the marsh edge fringe where overtopping does not occur and will include at a minimum the southern most 30 acres of the marsh.* (MaineDOT 2012, Section J)

Specific monitoring guidelines for marsh vegetation were provided within the *Plan*:

> *10 vegetated transects will be set up to monitor the changes in marsh vegetation and the establishment of salt tolerant wetland species. 9 of these transects will be evenly distributed throughout the marsh upstream of the Long Read Lane culvert. The 10th transect will be situated on the ocean side of the culvert. The plant make-up at each transect will be documented before culvert construction and annual for a 5 year period following construction.* (MaineDOT 2012, Section K)

Based on the following evaluation of pre- and post-project vegetation data, we conclude that changes to the vegetation community within the Project Area are consistent with transitions from a salt marsh/brackish/fresh water system to predominantly salt tolerant species.

Background

CBEP monitored vegetation once annually, providing a summary of findings in annual monitoring reports. The section below summarizes findings from 2018, with additional analysis retrospectively to examine additional changes in the plant community over time. Table 6 lists the dates of vegetation surveys over the monitoring period.

Table 6. Dates of annual vegetation monitoring.

Location	2013	2014	2015	2016	2017	2018
Station 1	7/15	7/9	7/16	7/7	7/13	7/18
Station 2	7/15	7/9	7/16	7/7	7/13	7/18
Station 3	7/15	7/9	7/22	7/8	7/13	7/18
Station 4	7/15	7/8	7/22	7/8	7/13	7/7
Station 5	7/15	7/9	7/21	7/11	7/10	7/18
Station 6	7/15	7/9	7/21	7/8	7/10	7/16
Station 7	7/16	7/8	7/22	7/8	7/10	7/7
Station 8	7/16	7/8	7/22	7/8	7/10	7/16
Station 9	7/16	7/8	7/21	7/8	7/10	7/17
Station 10	7/16	7/8	7/21	7/8	7/10	7/17

In 2018, CBEP surveyed vegetation in a total of 114 plots, including 12 plots at St. 1, and 102 plots in the Project Area. An additional 23 plots were surveyed at St. 11-12 in the southern marsh. Plot locations were at identical distances along each transect year over year, but at St. 1, transect markers were lost and the transect location was different in 2013 than in 2014-18.

A total of 27 plant species were identified within plots at St. 1-12 in 2018, including overhanging canopy near upland transitions. This continues a decline in the number of species observed at the stie, from 67 in 2013 to 27 in 2018 (Fig. 25). The decline corresponds to fewer observations of glycophytic and brackish species.

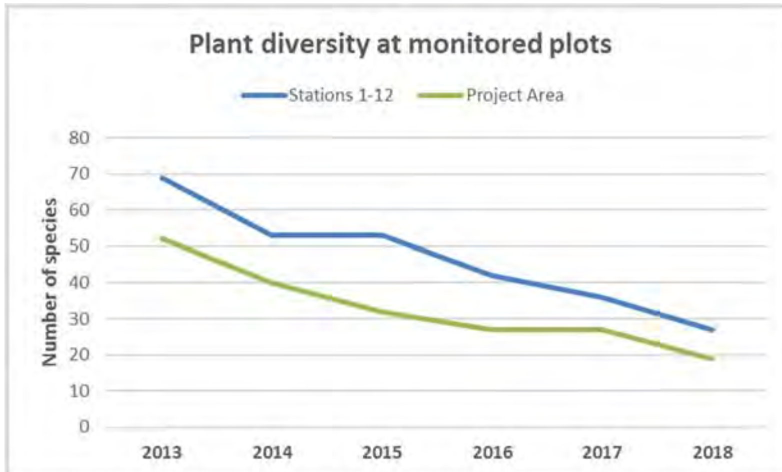


Figure 25. Plant species diversity at monitored plots.

Table 7 lists plants observed within the entire marsh system, including the reference area, Project Area, and the southern marsh. Vegetation groupings are based on Salinity Index Scores developed by Verrill and Bohlen 2017, after Tiner 2009. Species only identified outside the Project Area are marked with an asterisk.

Table 7. List of observed plant species and associated community types.

Latin Name	Common Name	Community Group	2013	2014	2015	2016	2017	2018
Abies balsamea	Balsam Fir	Fresh	X*				X*	X*
Acer rubrum	Red Maple	Fresh		X	X	X		
Agrostis stolonifera	Creeping Bent Grass	Brackish	X	X	X	X	X	X*
Alnus incana	Speckled Alder	Fresh	X	X	X	X	X	
Atriplex prostrata	Orach	Halophyte	X	X	X	X	X	X*
Bolboschoenus maritimus	Alkali Bulrush	Brackish	X	X	X	X	X	X
Calamagrostis Canadensis	Bluejoint Grass	Fresh	X	X	X*			
Calystegia sepium	Hedge Bindweed	Brackish	X					
Carex crinata	Fringed Sedge	Fresh	X					
Carex hystericina	Bottlebrush Sedge	Fresh	X*	X*	X*			
Carex lacustris	Lake Sedge	Fresh	X	X				
Carex lurida	Shallow Sedge	Fresh	X*					
Carex nigra	Smooth black sedge	Fresh				X	X	X
Carex paleacea	Chaffy Sedge	Brackish	X					
Carex scoparia	Broom Sedge	Fresh	X	X*	X*	X*		
Carex stipata	Stalk-Grain Sedge	Fresh	X		X		X	
Carex utriculata	Common Beaked Sedge	Fresh		X	X*	X*		
Cladium mariscoides	Smooth Sawgrass	Fresh	X*	X*	X*	X*		
Distichlis spicata	Salt Grass	Halophyte		X	X	X	X	X
Dryopteris cristata	Crested Wood Fern	Fresh	X					
Dulichium arundinaceum	Three Way Sedge	Fresh	X*		X*			
Eleocharis sp.	Sedge		X*		X			
Eleocharis palustris	Common spikerush	Fresh				X*		
Elymus pycnanthus	Tick Quackgrass	Brackish	X		X			
Elymus repens	Creeping Wild Rye	Fresh	X	X		X	X	
Equistem pratense	Horsetail	Fresh	X	X				X
Euthamia graminifolia	Flat-Top Goldentop	Brackish	X					
Festuca rubra	Red Fescue	Brackish	X	X	X	X	X	X*
Galium asprellum	Rough Bedstraw	Fresh		X				
Galium trifidum	Threepetal Bedstraw	Fresh	X	X*	X*	X*		
Glaux maritima	Milkwort	Halophyte		X			X	
Glyceria canadensis	Rattlesnake Mannagrass	Fresh	X			X		
Hordeum jubatum	Foxtail Barley	Halophyte	X	X				
Hypericum mutilum	St. John's Wort	Fresh	X	X	X*	X*	X*	
Ilex verticillata	Winterberry	Fresh	X	X*	X*		X*	X*
Impatens capensis	Jewelweed	Fresh	X	X*	X*			
Juncus arcticus	Arctic Rush	Halophyte	X	X	X	X	X	X
Juncus effuses	Common rush, soft rush	Fresh					X	
Juncus gerardii	Black Grass	Halophyte	X	X	X	X	X	X
Lemma minor	Duckweed	Fresh				X*		
Lycopus americanus	Cut-Leaf Water Horehound	Fresh	X					
Lycopus uniflorus	Northern Bugleweed	Fresh	X*	X*	X*	X*		
Lysimachia terrestris	Swamp Candle	Fresh	X	X	X	X*	X*	
Lythrum salicaria	Purple Loosestrife	Fresh	X	X	X	X	X*	
Onoclea sensibilius	Sensitive Fern	Fresh	X	X*	X*	X*	X*	
Osmunda cinnamomea	Cinnamon Fern	Fresh		X				
Osmunda regalis	Royal Fern	Fresh	X*					
Panicum dichotomiflorum	Panic Grass	Fresh	X	X*				
Persicaria sagittata	Tearthumb	Fresh	X	**X**	X			
Poa palustris	Fowl bluegrass	Fresh					X	
Populus tremuloides	Poplar	Fresh				X		X
Proserpinaca palustris	Marsh Mermaidweed	Fresh	X*	X	X*			
Puccinellia tenella	Alkali Grass	Halophyte	X*					

Quercus rubra	Northern Red Oak	Fresh	X*	X	X	X	X	X
Ribes hirtellum	Currant	Fresh	X					
Rosa palustris	Swamp Rose	Fresh	X					
Rubus hispidus	Blackberry	Fresh	X*	X				
Ruppia maritima	Widgeon Grass	Halophyte	X	X	X	X	X	X
Salicornia depressa	Common Glaswort	Halophyte	X	X	X	X	X	X
Schoenoplectus acutus	Hardstem Bulrush	Brackish	X	X	X	X	X	X
Schoenoplectus pungens	Three-Square Bulrush	Brackish	X	X	X	X	X	X*
Scirpus sp.	Sedge		X					
Scutellaria galericulata	Hooded Skullcap	Fresh	X	X	X			
Solidago altissima	Tall Goldenrod	Fresh	X	X	X			
Solidago sempervirens	Seaside Goldenrod	Halophyte	X	X	X	X		
Spartina alterniflora	Smooth Cordgrass	Halophyte	X	X	X	X	X	X
Spartina patens	Salt Hay	Halophyte	X	X	X	X	X	X
Spartina pectinata	Freshwater Cordgrass	Brackish	X	X	X	X	X	X
Spirea alba	White Meadowsweet	Fresh	X	X	X		X*	X*
Spirea tomentosa	Steeplebush	Fresh	X		X*	X*		
Sueda maritima	Sea blite	Halophyte						X
Symphyotricum novi-belgii	Aster	Brackish	X		X*			
Thelypteris palustris	Eastern Marsh fern	Fresh	X	X*	X*	X*	X*	
Toxicodendron radicans	Poison Ivy	Fresh	X	X	X	X	X	X
Triglochin maritima	Seaside Arrowgrass	Halophyte	X	X	X	X	X	X*
Typha angustifolia	Narrow-Leaf Cattail	Brackish	X	X	X	X	X	X
Typha latifolia	Broad-Leaf Cattail	Fresh	X	X	X	X	X	X
Typha x glauca	hybrid cattail	Brackish	X*	X*	X*		X	X
Vaccinium macrocarpon	Large Cranberry	Brackish	X*	X*	X*	X*	X*	
Viola pallens	Violet	Fresh	X		X			
Unknown	Unknown forb						X*	

CBEP used a community salinity index developed by University of Southern Maine graduate student Shri Verrill to track changes in vegetation community type (Verrill and Bohlen 2017). The index references a standard field guide (Tiner 2009) to assign salinity index scores, with freshwater plants = 1, brackish plants = 2, and halophytic plants = 3.

Based on data from 2013-2015, CBEP plotted index scores of individual plots by station (Fig. 26 & 27). The figures illustrate a general pattern of transitions throughout the Project Area toward salt tolerant (brackish and halophytic) species. Closer to the project site (St. 2 & 3), a rapid transition to salt marsh is evident, with similarities to the reference site (St. 1), and similar distribution shifts are occurring at St. 5-8. At the furthest end of the Project Area, St. 10, a similar immediate shift is evident closer to the channel, but less so away from the channel. The effects of the mitigation project clearly extend beyond the Project Area, as a marked shift toward halophytic plants is evident at St. 11, adjacent to invasive *Phragmites australis* stands, in the first several plots away from the channel. At the time of this analysis, St. 12 appeared to not yet have been affected by the change in hydrology, based on data through 2015, but the community in the southern marsh has begun to shift, based on data collected in 2016-2018.

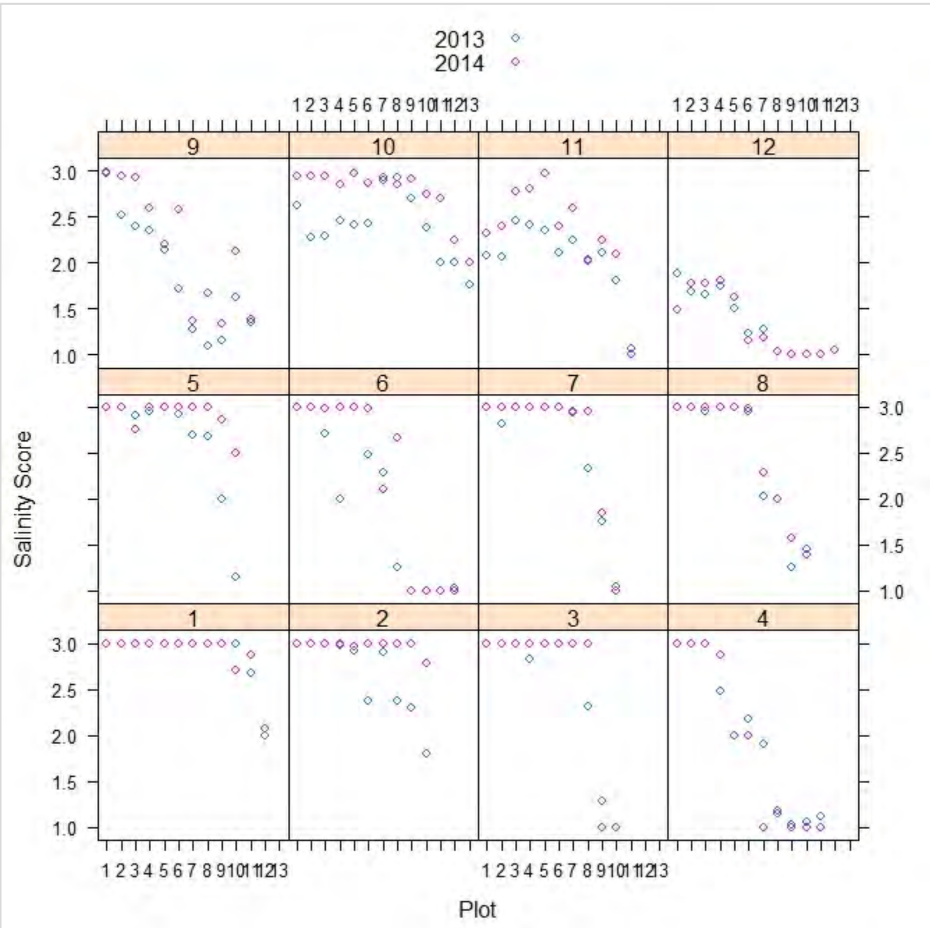


Figure 26. Salinity index scores of vegetation plots, 2013 to 2014.

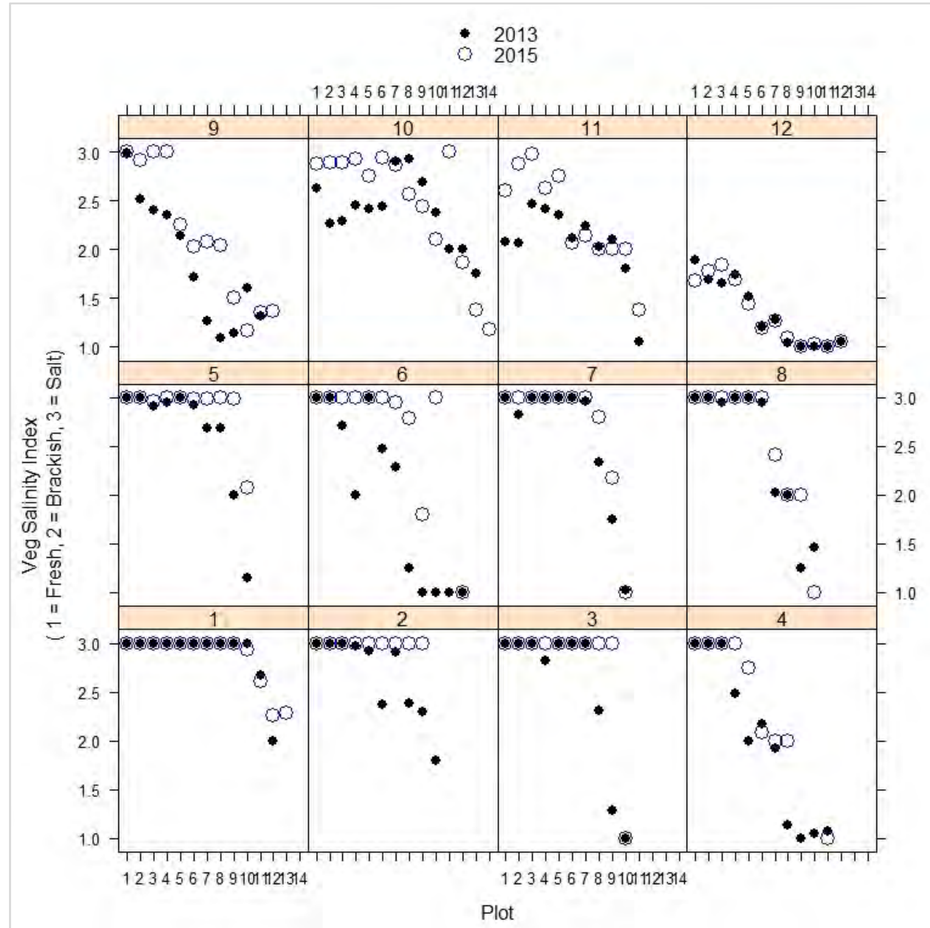


Figure 27. Salinity index scores of vegetation plots, 2013 to 2015.

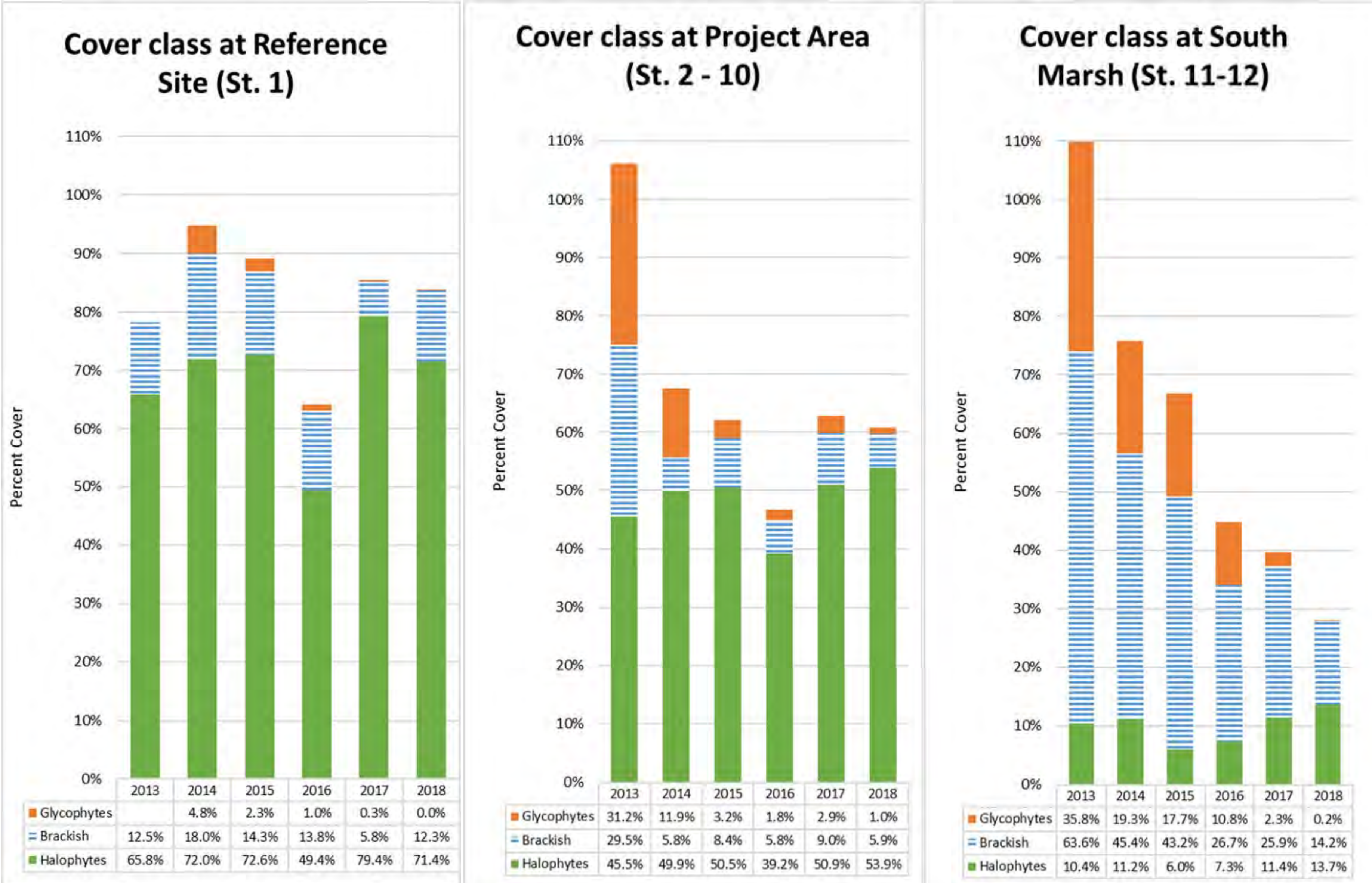


Figure 28 a-c. Changes to vegetation community at the reference area, Project Area, and southern marsh.

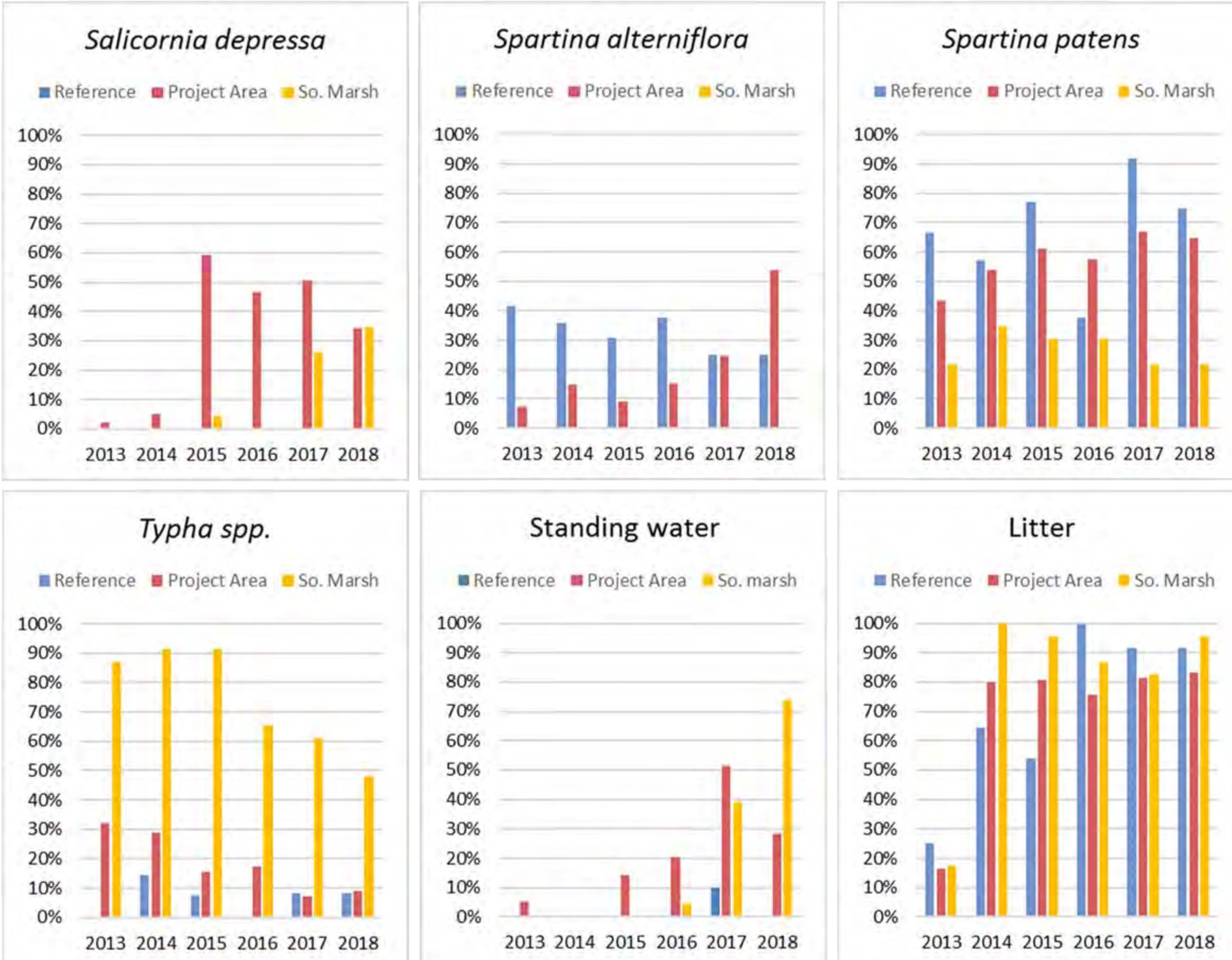


Figure 29 a-f. % of plots with Salicornia depressa, Spartina alterniflora, Spartina patens, Typha *spp., standing water and litter.*

Figures 28a-c utilizes the Verrill/Bohlen salinity index to illustrate year-to-year shifts in vegetation community type within monitored plots at the reference site, Project Area, and in the southern marsh. Distinguishing between these regions is useful for evaluating mitigation project outcomes. The graphs also suggest that the mitigation project has affected each section of the marsh differently, and that each section is in a different state of adjustment to the new hydrological regime.

Reference Area

At plots along the Reference transect (St. 1; Fig. 27a), vegetative cover was predominantly by halophytic plants, ranging from 65% in 2013, to 45% during the drought of 2016, to 71% in 2018. The percent cover by brackish species ranged from 12% in 2013 to 5% in 2017 and 12% in 2018. The percent cover by glycophytes, at the upland edge, varied somewhat from year-to-year and appeared to depend somewhat on where the upper end of the transect was located. In sum, living plants covered between 78% to 95% of the plots for each year of monitoring with the exception of 2016, in which just 65% of plot cover was by living plants.

Glasswort (*Salicornia depressa*) is a halophytic succulent that is a common salt marsh pioneer species in Maine. This early successional species was not present in any of the monitored plots within the Reference Area for the six-year monitoring period (Fig. 28a). In contrast, *Spartina patens* was present in at least half of the monitored plots, and *S. alterniflora* was present in 20-40% of plots (Fig.29c, 29b).

Although some variability in plant cover is evident, the Reference Area can be described as relatively stable over the course of the monitoring period in comparison to the Project Area and the southern marsh. The most notable observed change in the Reference Area was in the percent of plots that included partial cover by litter (dead plant matter), which increased markedly from 25% of plots in 2013 to 60% in 2014 and 90% in 2018. This observation is consistent with ongoing transport of organic matter out of the system.

Project Area

At plots within the Project Area (St. 2-10; Fig. 28b), vegetative cover classifications shifted dramatically from pre-project to post project. In 2013, total plant cover within the plots consisted of 45% halophytes, 31% glycophytes, and 30% brackish plant species. Post-project, the proportion of cover by glycophytic plants declined consistently following the project and continuing from year-to-year up to 2018, when the percent of glycophytes fell to 1%. The abundance of brackish plants also declined markedly immediately following project implementation, from 30% to 6% in 2014, but for the remaining years, brackish plants consistently covered between 6% to 9% of the plot area. By 2018, the relative proportion of community types in the Project Area was comparable to the Reference Area. However, total plant cover in the Project Area (61%) remains well below total plant cover at the Reference area (84%).

Within the Project Area, the percent of plots with *Salicornia* present increased dramatically in 2015 and remained over 30% in 2018 (Fig. 29a). The percent of plots with *Spartina alterniflora* also increased over the monitoring period, from less than 10% in 2013 to over 50% in 2018 (Fig. 29b), consistent with a corresponding increase in the prevalence of standing water on the marsh surface (Fig. 29e). *Spartina patens* was found in 42% of plots in 2013, and over 60% in 2017 and 2018. Live cattails declined from 31% in 2013 to less than 10% of plots in 2017 and 2018, to levels that are comparable to the Reference Area (Fig. 29d). Similarly to the Reference Area, the prevalence of litter within plots increased dramatically from 16% in 2013 to over 80% in 2018.

Overall, the plant community in the Project Area has shifted to become more like the plant community within the Reference Area, consistent with project objectives. The decline in brackish and glycophytic species is consistent with increased salt delivery into the marsh, and improved freshwater drainage out of the Project Area. There are also several indications that the marsh system, and the vegetation community within the Project Area, remains in a state of ongoing adjustment to the new hydrological regime.

Southern marsh

At plots in the southern marsh (St. 11-12; Fig. 28c), a steady decline in year-to-year cover by glycophytes and brackish plants was observed within monitored plots. This decline was accompanied by only a slight increase in the percent cover by halophytes, from 10% in 2013 to 14% in 2018. Total cover by living plants in this section of the marsh has dramatically declined, from over 100% in 2013 to less than 30% in 2018.

The vegetation transects for St. 11-12 ran predominantly through cattail stands (Fig. 29d). Species present include *Typha angustifolia*, *T. latifolia*, and *T. x glauca.* From 2013-2015, over 90% of plots contained live *Typha* spp. In 2016, the distribution of live cattails began to decline, down to 65% of plots in 2016, 60% in 2017, and 48% in 2018. In 2017 and 2018, *Salicornia depressa* became more common in plots (Fig. 29a), at the same time that standing water on the marsh surface was more prevalent (70% of plots in 2018; Fig. 29c).

Based on pore water salinity data from St. 11-12, and anecdotal observations, the southern marsh has been affected by restored tidal hydrology at LRL. More salt water is being delivered to the southern marsh; however, drainage out of the southern marsh appears to be constrained by a combination of factors including: a) the natural topography at "The Narrows", b) the continued impoundment of surface water at the rock ford between St. 8 & 9, and c) the corresponding lack of channel development upstream of the rock ford. Additionally, accumulation of dead plant material (particularly cattail stems), wood, and seaweed in the channel has been observed to choke off the channel draining out of the southern marsh, at times resulting in impoundment of water upstream, including standing water on the marsh surface (Fig. 29e). Standing water is generally more common earlier in year (April – June) than during the dry months. This poor drainage during the start of the growing season may be contributing to the slow vegetation response to the change in hydrology.

There are several stands of *Phragmites australis* in the southern marsh. These stands were not included in project monitoring, but anecdotal observations suggest that the stands appear to be stressed (stunted, fewer seed heads, smaller footprint), and retreating back from the channel. In 2018, CBEP observed that *Phragmites* appeared to be moving slightly upslope along the upland edge (photos available from CBEP) at St. 11.

Overall, the southern marsh appears to be at an earlier stage of response to the restored tidal hydrology. Although the southern marsh falls outside of the Project Area, CBEP monitoring indicates it has clearly been impacted by the restored tidal hydrology at LRL. If large areas of the marsh surface continue to be submerged beneath standing water for weeks at a time, vegetative response to the new hydrological regime could be hindered.

Surface water impounded at St. 11, May 2018. Phragmites stand in the background.

Table 13 (Appendix B; not updated since 2015) shows graphed percent cover for each community type against distance from the creek channel, by station, in 2013, 2014, and 2015. Proximity to the creek channel appears to be associated with community type as shown by the prevalence of salt marsh community assemblages in proximity to the creek channel, even near the “narrows” at St. 10, in all years. The 2013 vegetation data show that community type shifted markedly moving toward the upland edge, so that brackish and freshwater assemblages were increasingly abundant at distances of 100 feet or more from the creek edge, particularly at the higher stations. In 2014 and 2015, a change in this pattern is evident, with salt tolerant plants increasing in abundance in plots further away from the creek channel, and brackish and freshwater-grouped plants showing a marked decrease in area covered. This decrease is often associated with an increase in litter, which includes standing dead vegetation. The percent of plots covered by litter is particularly high at transects 4 and 6, which pass through large cattail stands. This illustrates a trend in evidence around the perimeter of much of the Project Area, where cattail stands died off in response to the higher tidal inundation, with mostly dead stands remaining (Table 11, vegetation transect photo stations). This trend is likely to continue as the energy stores of individual plants are depleted. Over the next few years, as light availability increases on the marsh surface within former cattail stands, salt tolerant and brackish plant community cover is anticipated to increase.

As with changes in pore water salinity, Year 5 post-project results from monitoring Long Marsh’s vegetative community shows a marked change consistent with what we would expect in response to the new culvert and increased tidal exchange. Together, the salinity and vegetation data indicate that the vegetation community within the Project Area is shifting in response to the new tidal hydrology. Effects of increased tidal elevation and duration of inundation are evident in the plant community shifts at stations furthest from the construction site, in plant community shifts mid-way through the transects and at approaching the upland edge, and widespread increase in litter as a result of dead freshwater loving and brackish plants. Viewed at the scale of the Project Area, the shift in community type is particularly evident in looking at living cattail plants (Fig. 30), which declined from 8.34 acres in 2013 to .64 acres in 2015. Standing dead cattails covered much of the remaining 7.7 acres in 2015. Remaining cattail stands appear to be associated with freshwater seeps from adjacent uplands.

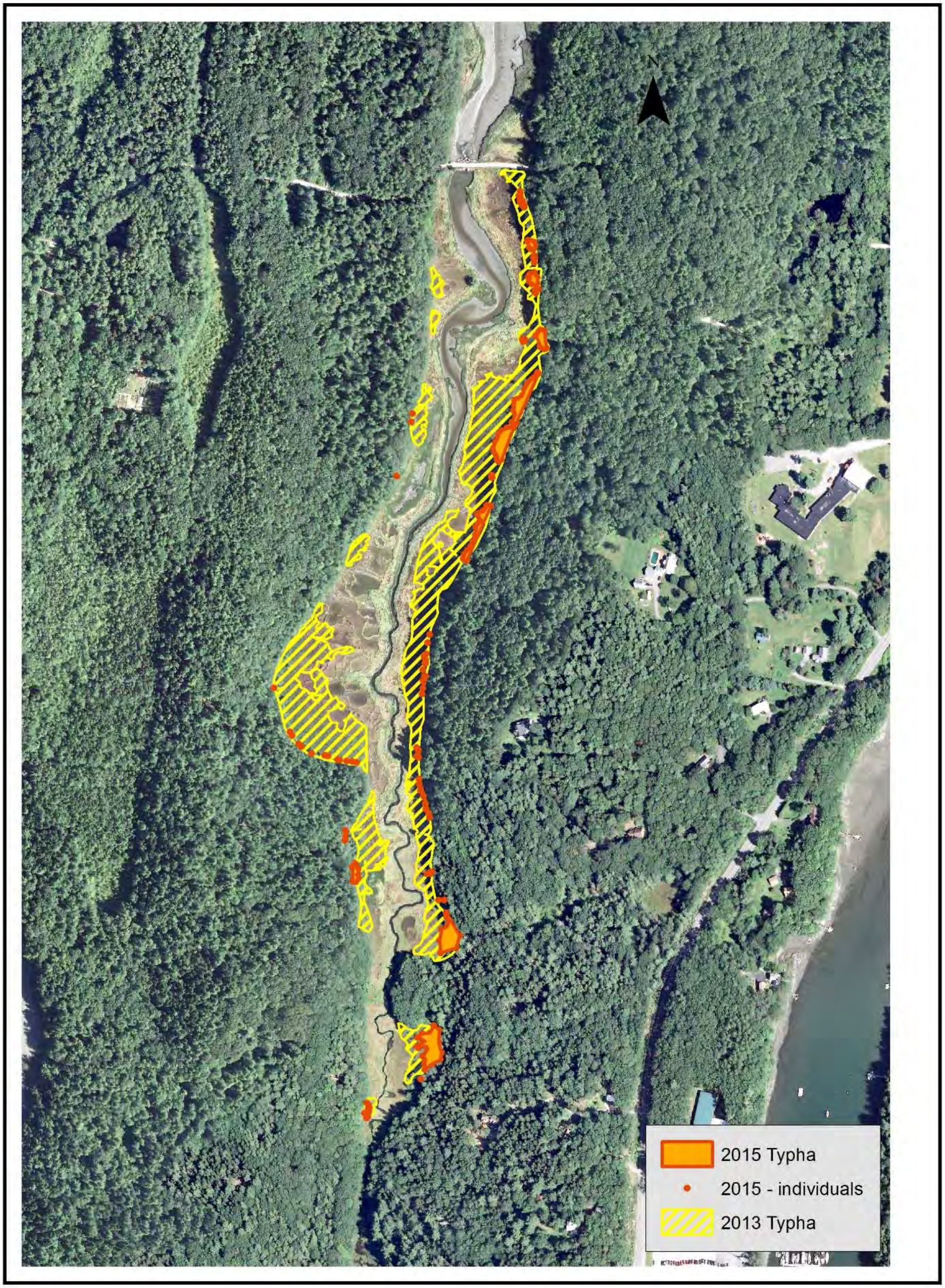


Figure 30. Map of Typha spp. stand extent in 2013 and 2015.

3.5 Channel Morphology

Summary of monitoring results

Collection of marsh channel cross sections was specified in the Plan as a core monitoring parameter:

> *Marsh channel cross sections above and below the LRL crossing will be taken before construction and annually through the monitoring periods to document changes in channel profile and sediment movement. Any changes will be reported and remedial measures taken if necessary.* (MaineDOT 2012, Section K)

The channel is continuing to adjust to improved flow beneath LRL, as indicated by data from 2018. Based on the following evaluation of pre- and post-project channel cross sections, as well as the channel profile through the culvert, we conclude that the observed changes to channel morphology, and implied transport of sediments, are consistent with project objectives and performance standards.

Although project monitoring was not designed to quantify sediment dynamics within the marsh system and downstream mudflats, there is evidence that sediments were transported both outside of, and within, the Project Area. Changes in the marsh channel at St. 1 are consistent with pulses of sediments moving north onto downstream mudflats. We also observed that each spring, large areas of the marsh surface within the Project Area were blanketed in channel sediments and chunks of marsh peat from ice rafting over the winter. These depositional processes enhance marsh resilience to sea level rise, and are likely to continue as the channel continues to evolve to accommodate increased flows into and out of the marsh.

Example of sediment deposition onto marsh surface following winter ice rafting. Spring 2016.

Background

Channel morphology (channel cross sections and longitudinal profile) was a core monitoring parameter specified in the *Mitigation Plan*. CBEP monitored channel morphology each field season and provided a summary of findings with annual monitoring reports. The following section summarizes findings from 2018, as well as comparisons with prior data. Table 8 lists the date channel surveys were conducted.

Table 8. Channel morphology survey dates.

Location	2013	2014	2015	2016	2017	2018
St. 1	7/25	6/17	7/23	6/16	6/30	5/23
St. 2	7/31	6/17	7/23	7/15	6/30	5/23
St. 3	8/5	6/18	6/25	6/16	6/30	5/24
St. 4	8/5	6/18	6/25	6/16	6/26	5/24
St. 5	8/5	6/18	6/25	6/14	6/26	5/21
St. 6	8/5	6/18	6/25	6/14	6/26	5/22
St. 7	8/5	6/18	6/25	6/14	6/30	5/22
St. 8	8/5	6/18	6/25	6/14	6/20	5/21
St. 9	7/25	7/8	6/25	6/8	6/20	5/21
St. 10	7/25	7/8	6/25	6/8	6/20	5/22
Long. Profile	8/30; 12/10	8/5	7/23	6/14	6/20	8/17

Longitudinal profile

Longitudinal profiles for 2013 and 2018 are plotted in Figures 31 and 32, with elevations in feet relative to NAVD 88. Mean high water (MHW, 4.12' NAVD) at the Portland Tide Station is shown for context. Although transect lengths and the location of start and end points differ, the location of channel cross sections at St. 1–3 is shown for context, allowing for comparison year-to-year.   The 2013 profile begins with mudflat downstream of the road, rip-rap at the base of the outlet, the invert of the original round pipe, a deep scour pool hidden beneath water impounded upstream, and acculated sediment upstream of the scour pool.   Upstream of the scour pool, sediment elevations level off consistent with the invert of the culvert.

The 2018 profile shows mudflat downstream of the road, with elevations comparable to 2013. Rip-rap at the base of the outlet remains, but the invert of the new culvert is lower. A series of sediment deposits are evident upstream of the culvert inlet, resulting in a series of shallow ripples and pools in the former upstream scour pool. A head cut migrated up the channel, evident all the way to St. 8 (not shown). The thalweg elevation is two feet lower than pre-project, indicating significant sediment mobilization.

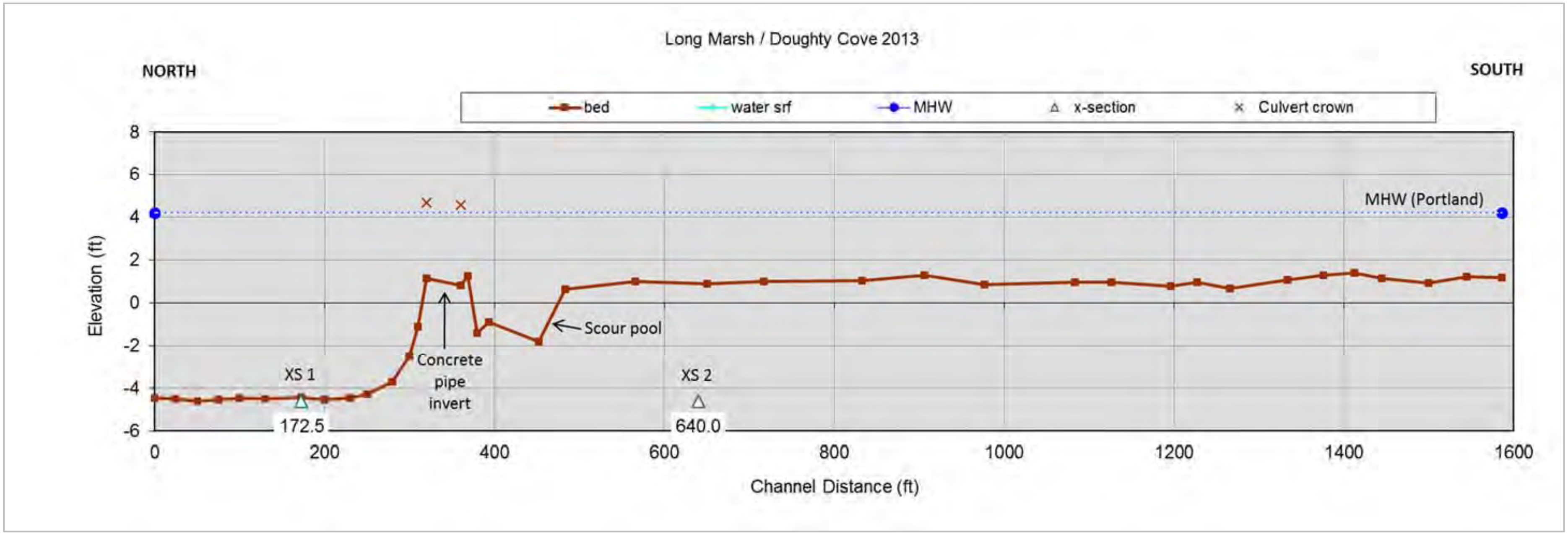


Figure 31. Longitudinal channel profile, 2013. Elevations shown in NAVD 88.

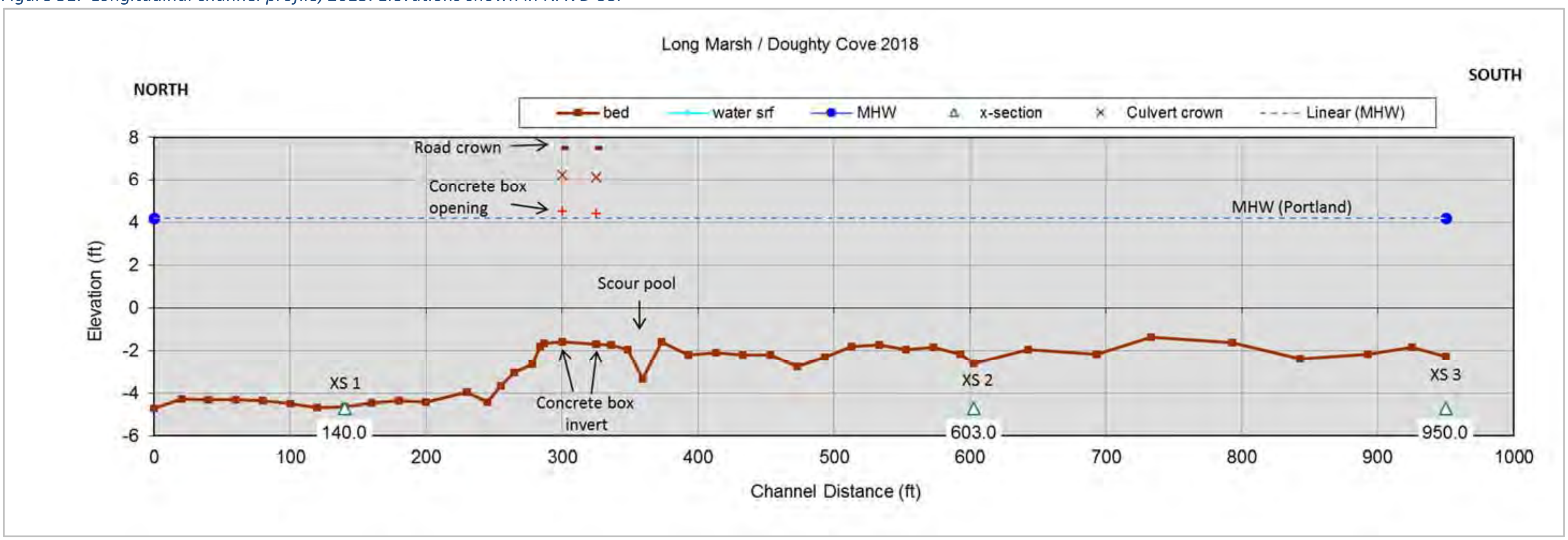


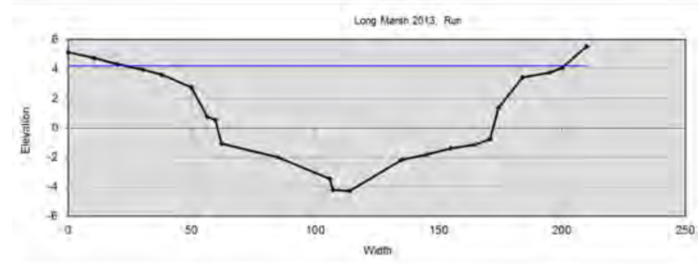
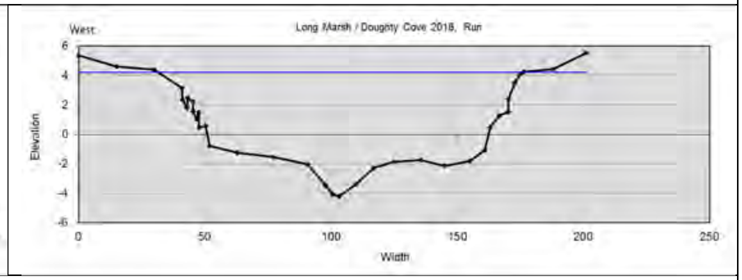
Figure 32. Longitudinal channel profile, 2018. Elevations shown in NAVD 88.

Channel cross section

Channel cross sections are plotted in Fig. 33 and 34 for St. 1-10, with MHW (4.12' NAVD) at the Portland Tide Station for context. MHW was used in the Reference Reach Spreadsheet (Mecklenburg 2006) to calculate channel dimensions and cross sectional area, allowing for a standardized comparison of change in channel characteristics from one year to the next, which is particularly useful for looking at channel evolution in relation to increased inundation of the marsh surface.

At each station, the west side of the marsh is shown on the left side (0') of the transect. Elevations at St. 1-5 are shown in feet relative to NAVD 88; elevations other stations are approximated in NAVD. At most stations, transects begin and end at fixed points that are higher than MHW, with the exception of St. 7. The location of cross section transects was identical each year, but slight differences in transect length occur due to conditions in the field, such as wind.

View of channel and scour pool upstream of culvert inlet.

Pre-Project (2013)	Post-Project (2018)
Station 1	
	
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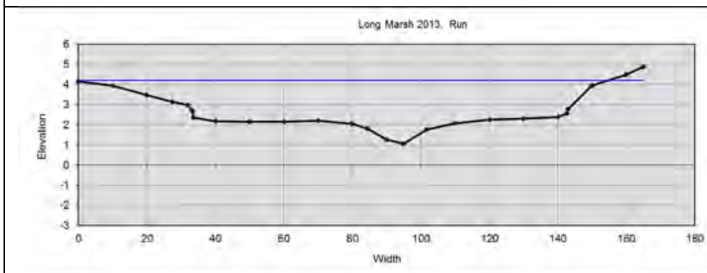	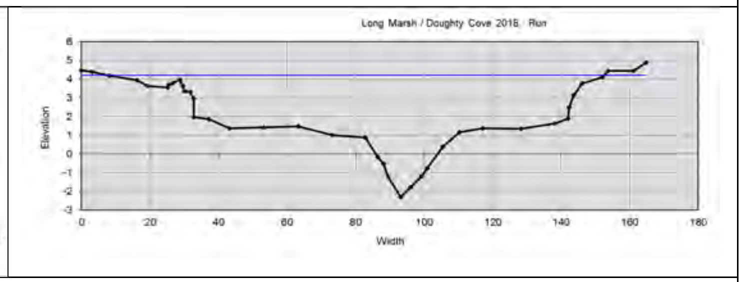
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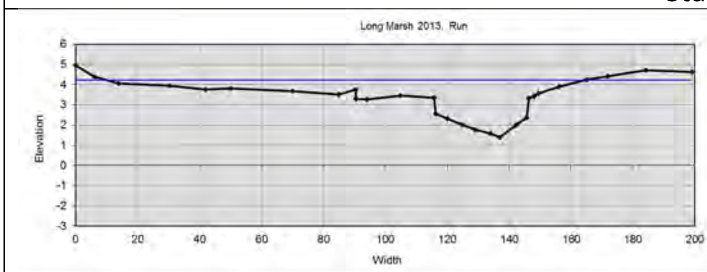	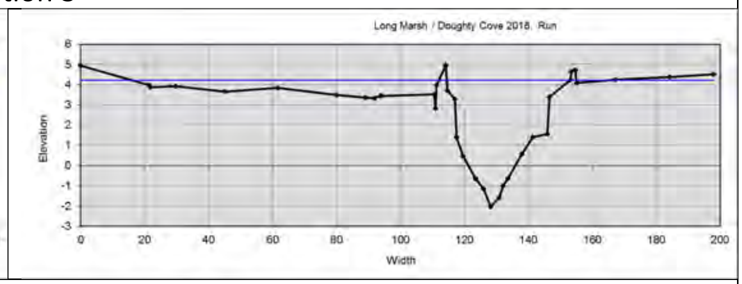
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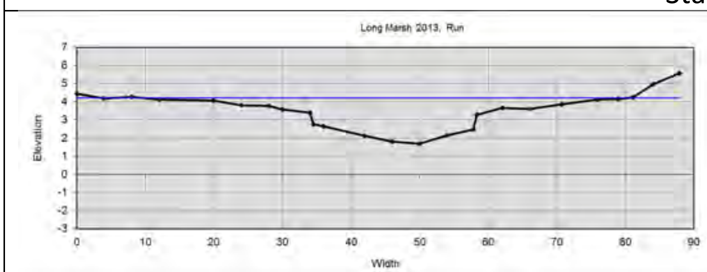	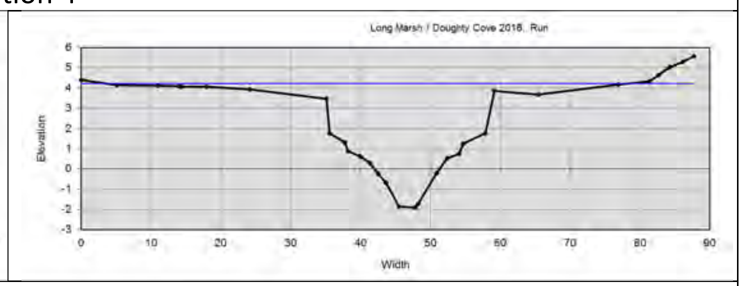
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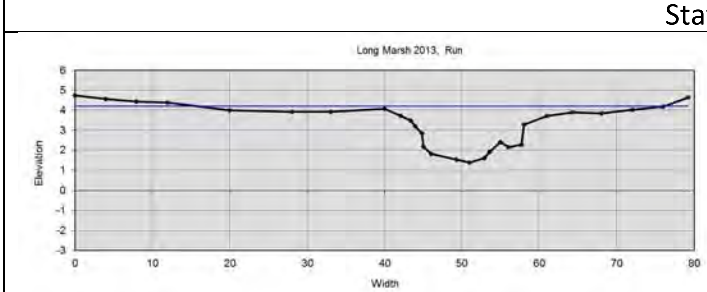	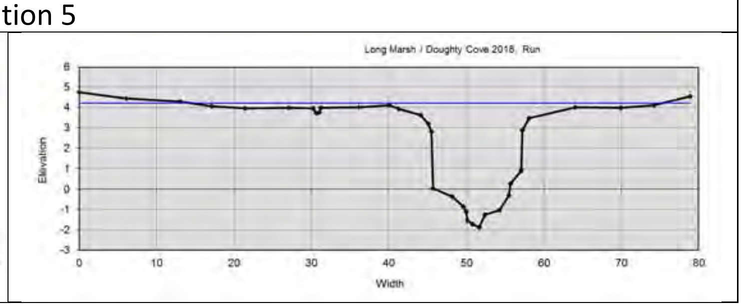

Figure 33. Plotted channel cross sections (Stations 1-5).

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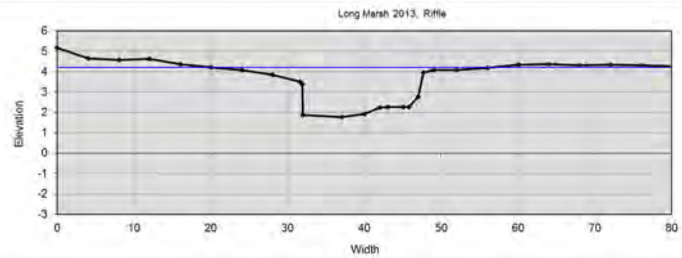
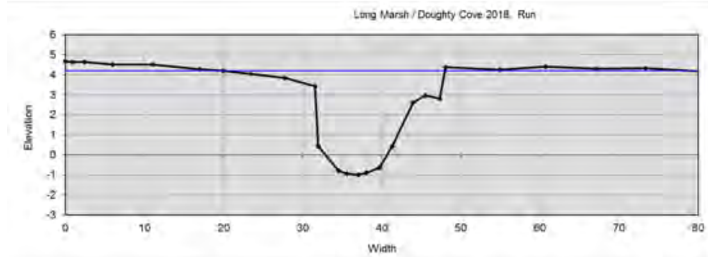
<tr><td>
</td><td>
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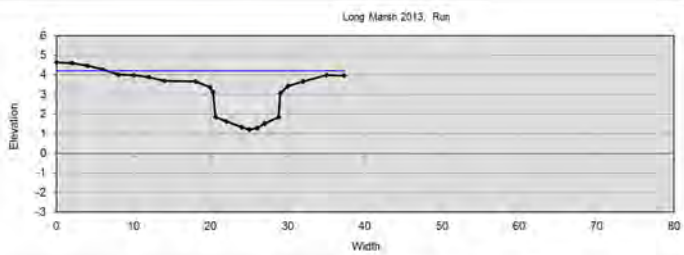
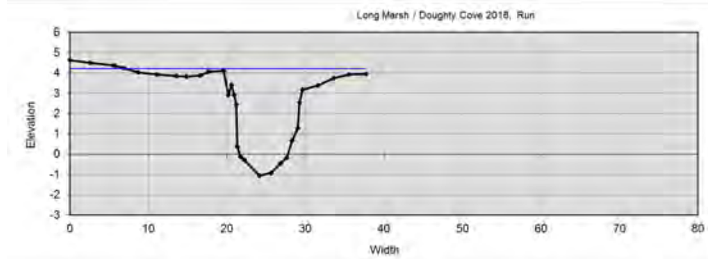
<tr><td>
</td><td>
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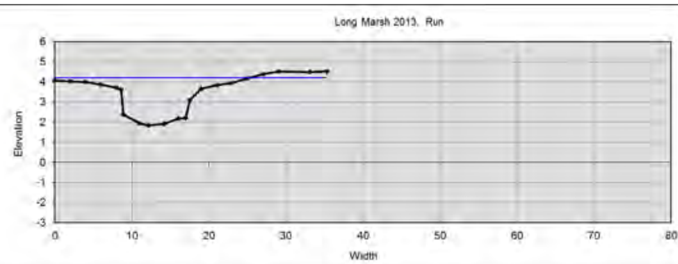
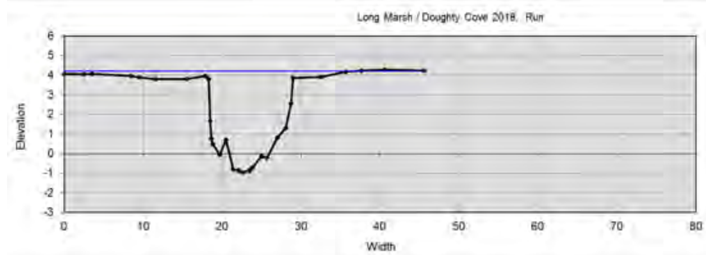
<tr><td>
</td><td>
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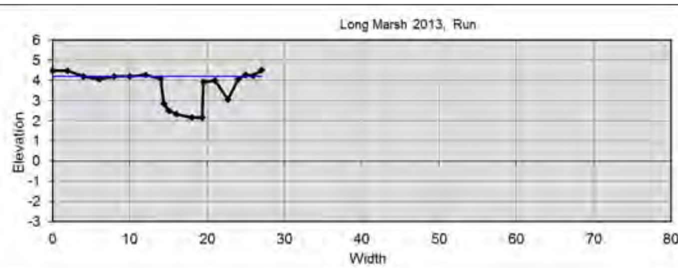
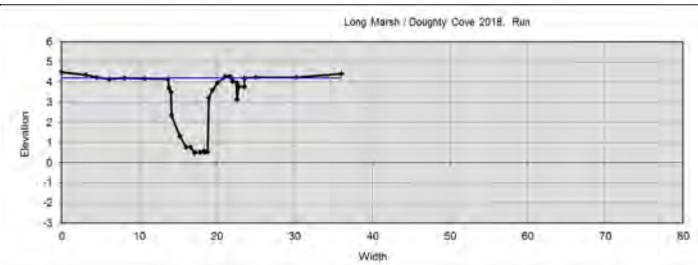
<tr><td>
</td><td>
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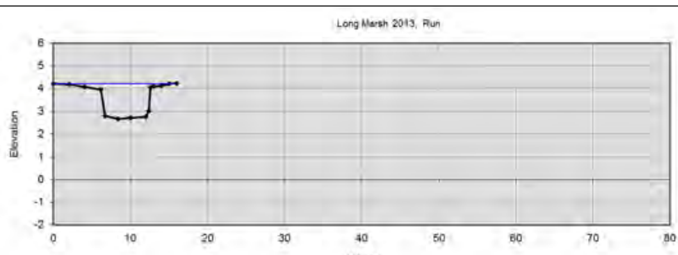
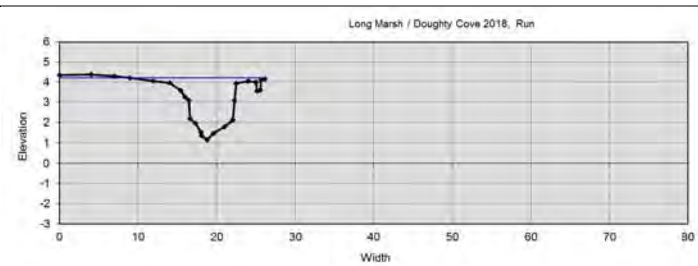
<tr><td>
</td><td>
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Figure 34. Plotted channel cross sections (Stations 6-10).

Channel cross section summaries:

St. 1 – Station 1 represents the Reference Area for monitoring purposes. The cross section transect at this location occurs along a gradual transition from the open mudflats of Doughty Cove to the tidal creek in Long Marsh. The channel dimensions are roughly twice the size of the channel upstream of LRL (Fig. 33), limiting its utility for absolute comparative purposes to the upstream channel, but nonetheless allowing for some relative comparisons. The channel shape at St. 1 remained consistent from 2013 to 2018. Calculated cross sectional area was 800 $ft.^2$ in 2013, and 755 $ft.^2$ in 2018 (Fig. 37; calculated using Mecklenburg *et. al* 2006), a 5% reduction in area. Maximum channel depth remained essentially constant (Fig. 36). Being so large, and using a tape reel to measure transect distance, the decline in area may be partially due to human error during measurements, which frequently were affected by wind. However, cross sectional area at St.1 varied somewhat each year (Fig. 38-39), which also raises the possibility that eroding sediment from the upstream channel is being transported out of the marsh onto downstream mudflats in pulses. Bank slumping indicates the channel is widening. Overall, in relative terms, the channel at St. 1 has changed very little compared with stations in the Project Area (Fig. 39).

St. 2 – The channel at St. 2 has visibly changed from 2013 (Fig. 33). Initially, it was dangerous to survey the channel at this location due to the deep soft sediments, combined with the impounded water behind the road. In 2018, sediments are much firmer, particularly at the thalweg, which has formed a pronounced "V" shape. The channel thalweg at this location is more than 3.5' deeper than it was in 2013 (Fig. 36), accompanied by a change in area from 215 $ft.^2$ in 2013 to 380 $ft.^2$ in 2018, a 77% total increase that relocated 165 $ft.^2$ of sediment (Fig. 37-8). In absolute terms, the channel at St. 2 increased more than any other station within the Project Area in 2018 (Fig. 38). The channel depth seems to have stabilized near the depth of the culvert invert, but the thalweg will likely continue to widen into more of a "U" shape. The flat 'shelf' of channel bottom adjacent to the thalweg is essentially a mudflat, perhaps too low to support colonization by *S. alterniflora*. Substantial quantities of softshell clam, quahog, and oyster were exposed between St. 2 and the road as this reach of the channel eroded.

St. 3 – The channel at St. 3, which is located at a bend in the creek, has changed dramatically from its pre-project condition. The channel lacks the flat shelf of mudflat found at St. 2 and 3, and instead has a steep V-shaped channel between the banks of the marsh. Channel area increased from 124 $ft.^2$ in 2013 to 179 $ft.^2$ in 2018 (Fig. 37), an increase of 44%. Approximately 55 $ft.^2$ of sediments have been removed from the channel since 2013. Maximum channel depth at the thalweg is now almost identical to the channel at the adjacent stations, and the culvert invert.

St. 4 – The cross section transect at St. 4 is located in a straight section of the channel, and has evolved more quickly than the channel at St. 3. A U-shape is increasingly evident (Fig. 33). The maximum channel depth at the thalweg seems to have stabilized at a depth close to that of the culvert invert, which is about 3.5’ deeper than it was in 2013 (Fig. 36). Cross sectional area increased from 66 ft.^{2} in 2013 to 109 ft.^{2} in 2018 (Fig. 37), an increase of 65%. The photos in Fig. 35 below point out a rill forming near St. 4, resulting in pooled standing water parallel to the eastern creek bank, even at low tide. The rill may be becoming more pronounced as a result of freezing and thawing, and may indicate that a substantial bank slough will occur.

Figure 35. Photos: channel edge near St 4 showing expanding rill, indicative of ongoing channel erosion.

St. 5 – The creek channel is considerably smaller at St. 5 than at St. 4, although this transect also lies along the relatively straight reach of the tidal creek (Fig. 33). Cross sectional area has increased from 45 ft.^{2} in 2013 to 70 ft.^{2} in 2018 (Fig. 37), a total increase of 56%. The channel depth at the thalweg is identical to that at St. 4, and appears to have stabilized at approximately the same depth as the culvert invert (Fig. 36). The channel area decreased by 3% in 2018, possibly explained by measurement error or sediment transport from erosion further upstream (Fig. 39).

St. 6 – The U-shaped channel at St. 6 is not as deep as the stations downstream (Fig. 34, 36). Channel area increased from 38 ft.^{2} in 2013 to 61 ft.^{2} in 2018 (Fig. 37), a total increase of nearly 62%. Similarly to St. 5, the channel area did not change much in 2018 compared with 2017 (Fig. 39). A remnant plane/toe of peat is exposed on the south side of the channel. This is the first station that has yet to reach a depth equivalent to the culvert invert.

St. 7 – The channel at St. 7 has a similar U-shape to the adjacent Stations (Fig. 34). Cross sectional area increased from 33 ft.2 in 2013 to 46 ft.2 in 2018 (Fig. 37), an increase of 39% that is among the smallest changes on a percentage basis (Fig. 39). The U-shaped channel continues to deepen. Maximum channel depth continues to increase, and the channel is about as deep as at the adjacent stations (Fig. 36).

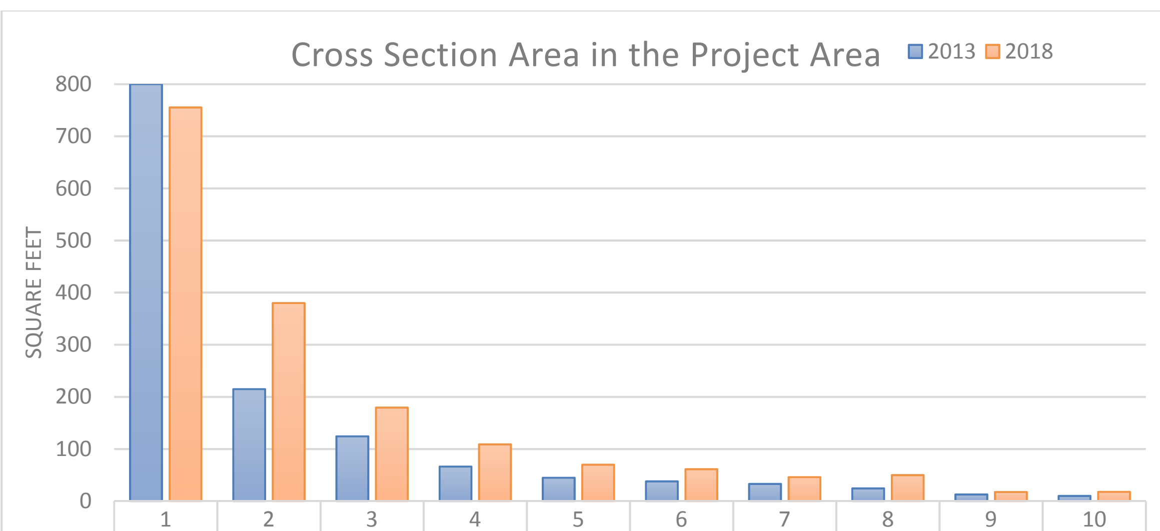
St. 8 – This station is the last one downstream of the rocky ford in the channel. The U-shaped channel is similar to the channel at St. 6 and 7 (Fig. 34). Channel area has more than doubled since 2013, increasing from 24.4 $ft.^2$ to 49.8 $ft.^2$ in 2018. On a percentage basis, the channel at St. 8 increased in area more than any other station in 2018 (Fig. 39). A 'head cut' reached St. 8 in 2018, as the channel depth dropped to levels similar to St. 6-7 (Fig. 36).

St. 9 & 10 – These stations are upstream of the "old road bed" / ford, and downstream of "the narrows." The ford is clearly impeding channel response to the restored tidal hydrology (Fig. 34). Compared with other stations in the Project Area, the channel in this reach has experienced relatively little change in depth or area (Fig. 36-39). The channel bottom in this reach is soft, and a layer of unconsolidated organic matter lies atop of sediments. Transport of organic matter and sediments out of the channel toward the bay is limited by the ford. A few small patches of *Ruppia maritima* remained present in the channel in 2018, but not to the extent observed in 2013.

St. 11 & 12 – CBEP collected cross section measurements at St. 11, which lies to the south of the Project Area, in 2014. Generally, minimal changes to the channel dimensions were observed in this section of the marsh. Channel data for St. 11, including photos, are available from CBEP but were not incorporated into this report. No channel cross sections were collected at St. 12.

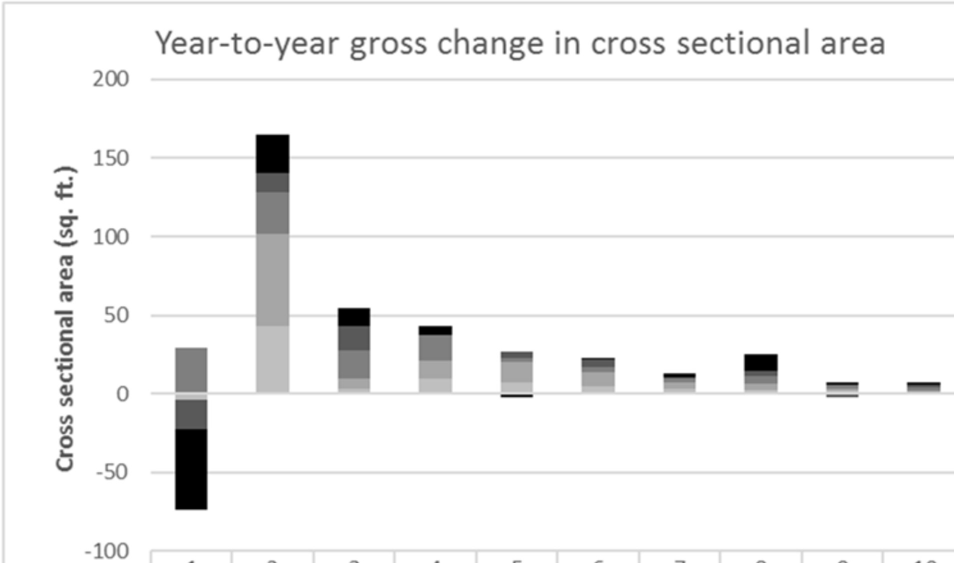
	1	2	3	4	5	6	7	8	9	10
2013	-4.3	1.4	1.4	1.7	1.4	1.7	1.2	1.8	2.1	2.6
2014	-4.19	0.71	1.11	0.71	0.01	0.71	0.71	1.31	1.71	2.61
2015	-4.4	-0.7	0.5	-1.2	-0.5	0.0	0.1	0.7	1.2	2.3
2016	-4.59	-1.49	-0.69	-1.49	-1.29	-0.69	-0.59	-0.29	1.01	0.59
2017	-4.69	-2.19	-1.59	-1.79	-1.79	-0.89	-0.89	-0.59	0.41	1.61
2018	-4.19	-2.29	-1.99	-1.89	-1.89	-0.99	-1.09	-0.99	0.51	1.11
Invert	-1.65	-1.65	-1.65	-1.65	-1.65	-1.65	-1.65	-1.65	-1.65	-1.65

Figure 36. Maximum channel depth by station, with approximate elevations relative to NAVD.



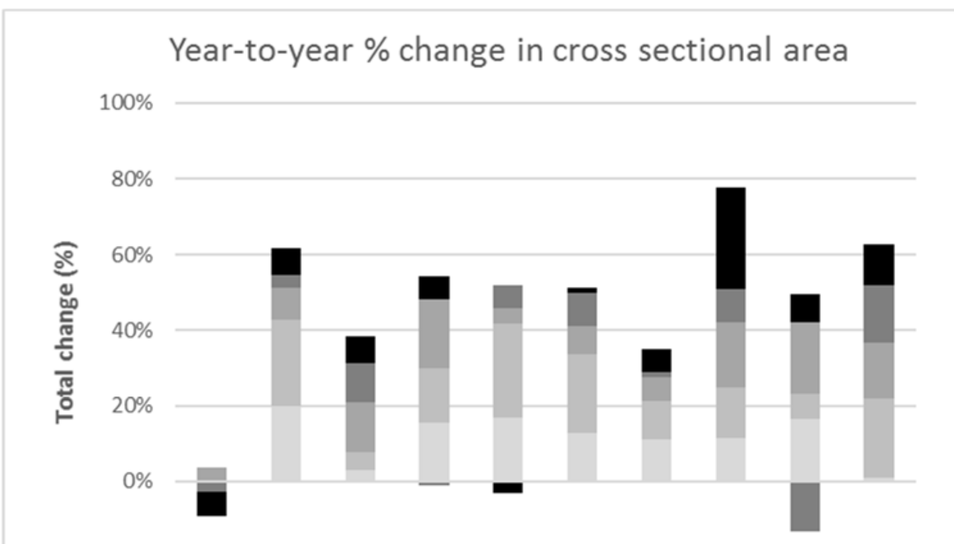
	1	2	3	4	5	6	7	8	9	10
2013	800.0	214.9	124.3	66.3	44.7	37.9	32.9	24.4	12.7	9.9
2018	755.4	380	179.4	108.8	69.7	61.2	46	49.8	17.5	17.7

Figure 37. Comparison of channel cross sectional area 2013-2018.



	1	2	3	4	5	6	7	8	9	10
2017-18	-51.1	24.7	12	6	-2.3	0.8	2.6	10.5	1.2	1.7
2016-17	-19.3	12.0	15.6	-1.0	4.0	4.9	0.6	3.1	-2.5	2.1
2015-6	29.1	26.5	17.8	16.2	2.8	3.8	2.6	5.3	3	1.8
2014-5	0.3	58.9	5.9	11	13	9	3.6	3.7	1	2.1
2013-4	-3.6	43.0	3.8	10.3	7.5	4.8	3.7	2.8	2.1	0.1

Figure 38. Year over year gross change in cross sectional area.



	1	2	3	4	5	6	7	8	9	10
2017-2018	-6%	7%	7%	6%	-3%	1%	6%	27%	7%	11%
2016-17	-2.3%	3.5%	10.3%	-1.0%	5.9%	8.8%	1.4%	8.6%	-13.3%	15.1%
2015-6	3.7%	8.4%	13.3%	18.5%	4.3%	7.4%	6.5%	17.2%	19.0%	14.9%
2014-5	0.0%	22.8%	4.6%	14.4%	24.9%	21.1%	9.8%	13.6%	6.8%	21.0%
2013-4	-0.5%	20.0%	3.1%	15.5%	16.8%	12.7%	11.2%	11.5%	16.5%	1.0%

Figure 39. Year over year percent change in cross sectional area.

3.6 Plant Species of Concern

Summary of monitoring results

The *Mitigation Plan* (Plan) identifies invasive species as a core monitoring parameter indicating progress toward one of two mitigation goals:

> *Invasive species, namely Phragmites australis (Common Reed) and Lythrum salicaria (Purple Loosestrife) will be monitored and controlled using integrated pest management techniques. The goal will be to eliminate the establishment of Common Reed and Loosestrife in the marsh restoration area. The project enhancement and restoration area does not support any Common Reed or Purple Loosestrife. The Marsh area south of the narrows [hosts] three large established patches of Phragmites that makes up approximately 7% of this portion of the marsh surface area. This area is outside of the project area.* (MaineDOT 2012, Section J)

The following monitoring guidelines for invasive species were provided within the *Plan*:

> *Invasive species of hydrophytes will be monitored and controlled using various methods* (MaineDOT 2012, Section K)

Based on monitoring for the presence of halophytic plants in the Project Area, we conclude that invasive species are being controlled through a combination elevated salinity levels within the Project Area following culvert replacement and integrated pest management techniques, including application of herbicides. *Lythrum* has not been observed since 2016 and appears to have been eliminated from the Project Area. Clonal patches of *Phragmites* were observed in 2016 and again in 2018, in areas that experienced abrupt die off of freshwater plant communities resulting from increased inundation by tidal waters after culvert replacement. These ecologically disturbed areas at the marsh fringe, particularly where groundwater seeps may be influencing pore water salinity levels, are likely to remain susceptible to colonization by *Phragmites* into the future. For this reason, we recommend continuing with monitoring for *Phragmites australis* on an annual basis.

Background

CBEP monitored for invasive species at least once per field season through a meander survey of the Project Area, with particularly detailed attention paid to areas of the marsh undergoing abrupt vegetation transitions, and those adjacent to the upland edge. CBEP also noted observations of non-native plants during vegetation surveys. Invasive species monitoring did not include the forested area upslope of the upland edge, which is noteworthy due to the fact that non-native plants and shrubs appear to be abundant in the adjacent forest. A summary of monitoring results was provided with annual reports. The following section summarizes findings from 2018, with reference to prior years provided for context.

Common reed

Prior to the mitigation project, several stands of invasive common reed (*Phragmites australis*) were documented in the southern marsh, upstream of the Project Area. Because of this pre-existing seed source and the potential for colonization within the Project Area, *Phragmites* was a primary plant species of concern. CBEP observed *Phragmites* within the Project Area in 2016 and 2018, but not in 2013, 2014, 2015 or 2017 (map, Fig. 40). Observations were immediately reported to MaineDOT. Remedial actions are described in Section 1.3.

One of two clonal patches of Phragmites australis observed near St. 9 in 2018.

<u>2016</u>. During a meander survey in early August 2016, CBEP's seasonal field crew observed a small patch of *Phragmites* in a southeastern portion of the Project Area, approximately 15m away from the upland edge of the marsh near St. 9. At subsequent site visits, the patch was estimated to include 390 stems in an area of approximately 100m^2. The patch was located amongst standing dead alder, cattails, and white pine, in an ecologically disturbed area of the marsh that now experiences regular tidal inundation, post-project. CBEP contacted Deane VanDusen of MaineDOT to report the discovery. VanDusen subsequently applied a mixture of Glyphosate and Imazapyr as a control agent in a fall application.

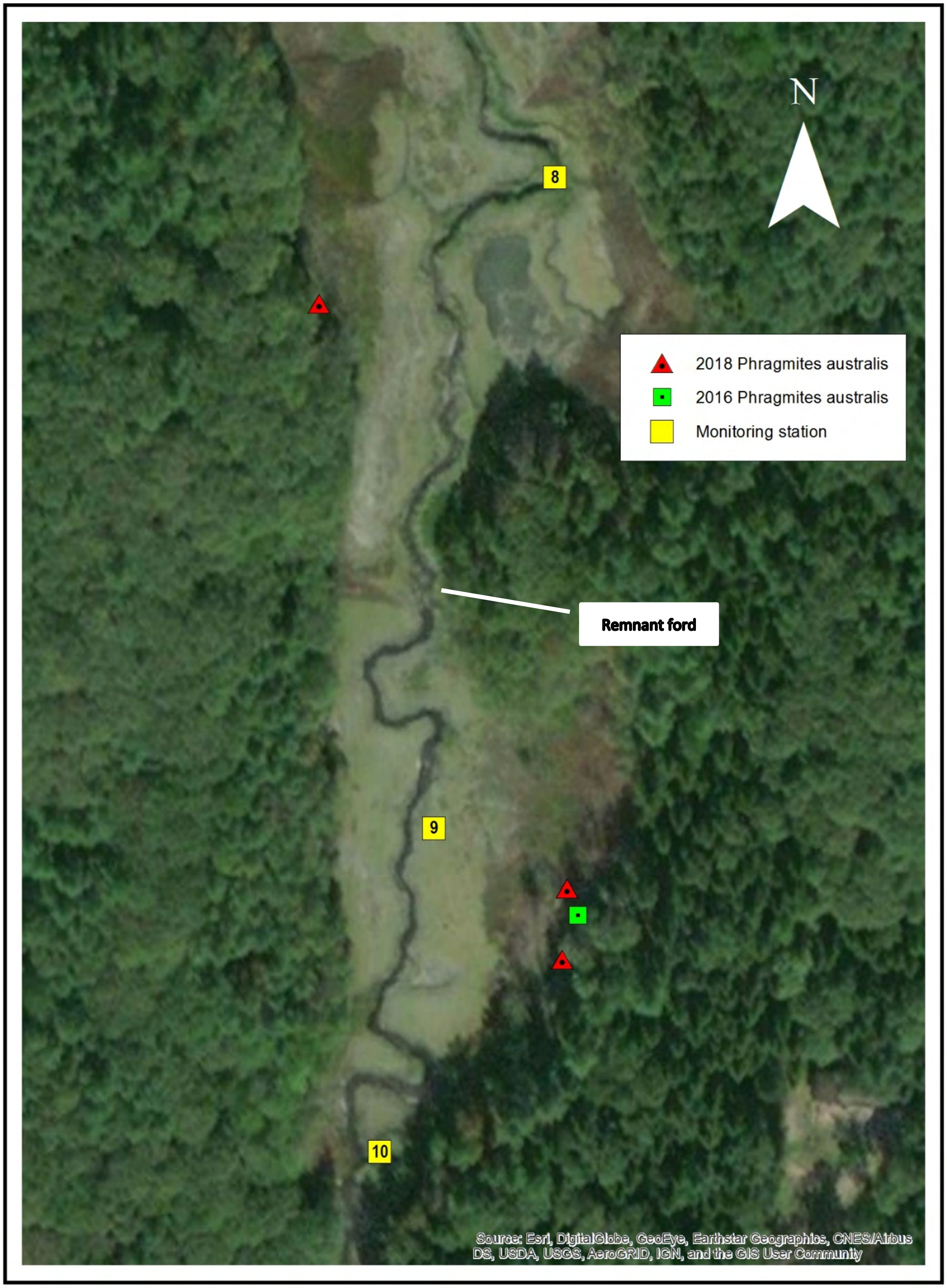


Figure 40. Mapped locations of Phragmites australis *stands in 2016 and 2018.*

2018. *Phragmites* was once again observed during a meander survey in mid-July 2018, in three separate locations: 1) two sets of 20-25 clustered stems near St. 9, in the same area of the marsh as 2016, and 2) a couple of stems near St. 9, at the upland edge of the western side of the marsh north of the remnant ford. CBEP contacted Deane VanDusen of MaineDOT to report the observation. VanDusen subsequently applied a mixture of Glyphosate and Imazapyr as a control agent in a fall application.

Invasive *Phragmites* continues to grow in three distinct patches downstream (south) of St. 10. Anecdotal observations of apparently reduced stem height, fewer seed heads, and a retreat away from the tidal creek suggest that stands adjacent to St. 11 are stressed by increased salt water delivery south of the "narrows". These observations would be consistent with increased pore water salinity levels observed in the area (mean salinity of 25.2 PPT at St. 11 in 2018), and recent studies that find a relationship between higher salinity levels and stress in *Phragmites* (Achenbach *et. al* 2013). Nonetheless, the stands in the southern marsh are presumed to be the seed source of the cloned Phragmites found within the Project Area in 2016 and 2018.

Purple loosestrife

Purple loosestrife (*Lythrum salicaria*) has not been observed within the Project Area since 2016. Loosestrife had previously been observed during each year of monitoring, however frequency declined to a single individual observed in both 2015 and 2016 at the upland edge of the vegetation transect at St. 9.

3.7 Photo Stations

CBEP established photo stations to visually document conditions at fixed locations adjacent to the project site (Table 9), as well as at each station (cross sections and vegetation transects). Photos were taken at least once annually over the duration of the monitoring period. At most stations, photographs were taken during cross section surveys looking upstream, downstream, and from each channel bank, providing a visual record of each station (Table 10). At some stations, additional photos were taken showing views to the upland edge.

During vegetation surveys, photographs were taken from the 0' (creek channel) looking to the end of the transect (upland edge), and from the upland edge looking back at the creek channel. Many of the post-project photographs clearly show standing dead vegetation in the background, particularly white pine, cattails and alder (Table 11).

Table 9. Photo stations at the construction site, 2013 and 2018.

PRE-PROJECT (2013)	**2018**
View Downstream (North)	
	
View to Outlet (South)	
	
View to Inlet (North)	
	
View Upstream (South)	
	

Table 10. Photos stations at channel cross section transects, 2013 and 2018.

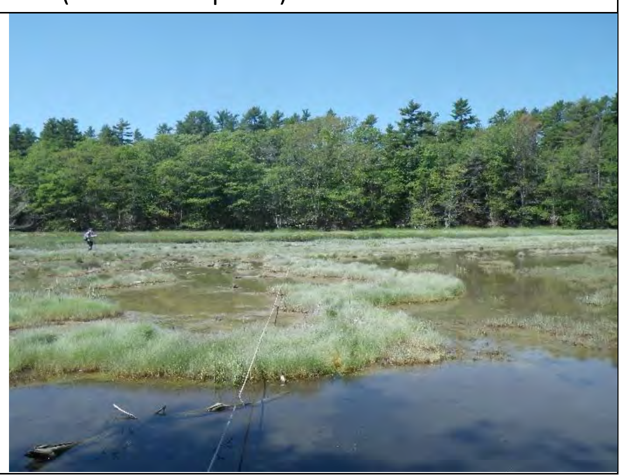
Pre-Project (2013)	**2018**
Station 1 Cross Section (view north)	
	
Station 2 Cross Section (view north)	
	
Station 3 Cross Section (view west)	
	

Pre-Project (2013)	**2018**
Station 4 Cross Section (view north)	
	
Station 5 Cross Section (view east)	
	
Station 6 Cross Section (view east/upstream)	
	

Pre-Project (2013)	**2018**
Station 7 Cross Section (view south)	
	
Station 8 Cross Section (view downstream)	
	
Station 9 Cross Section (view south)	
	

<table>
<tr><th>PRE-PROJECT (2013)</th><th>2018</th></tr>
<tr><td colspan="2">Station 10 Cross Section (view south; right photo from 2017)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 11 Cross Section (view upstream; left photo from 2014)</td></tr>
<tr><td></td><td></td></tr>
</table>

Table 11. Photo stations at vegetation transects, 2013 and 2018.

<table>
<tr><th>PRE-PROJECT (2013)</th><th>2018</th></tr>
<tr><td colspan="2">Station 1 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 2 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 2 Vegetation Transect (view from upland)</td></tr>
<tr><td></td><td></td></tr>
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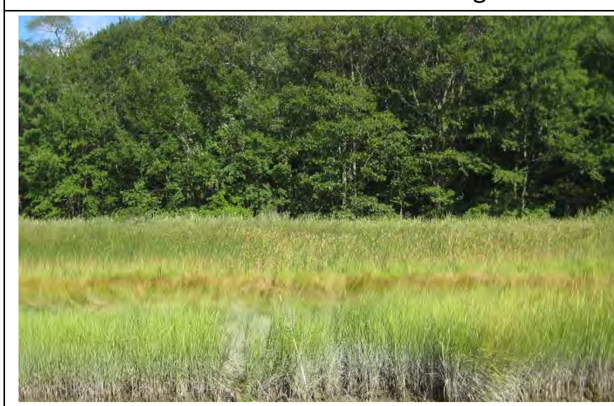
<table>
<tr><th>Pre-Project (2013)</th><th>2018</th></tr>
<tr><td colspan="2">Station 3 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 3 Vegetation Transect (view from upland)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 4 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
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Pre-Project (2013)	**2018**
Station 5 Vegetation Transect (view from channel)	
	
Station 6 Vegetation Transect (view from channel)	
	
Station 7 Vegetation Transect (view from channel)	
	

<table>
<tr><th>PRE-PROJECT (2013)</th><th>2018</th></tr>
<tr><td colspan="2">Station 7 Vegetation Transect (view from upland)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 8 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 9 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
</table>

<table>
<tr><th>2013</th><th>2018</th></tr>
<tr><td colspan="2">Station 10 Vegetation Transect (view from channel; left photo from 2014)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 11 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 12 Vegetation Transect (view from channel; left photo from 2014)</td></tr>
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3.8 Wildlife use

Although use of the Project Area by fish and wildlife was not a monitoring parameter specified in *The Plan*, CBEP noted incidental observations of fish and wildlife use in the marsh and the immediate upland edge. A partial list of species observed is provided in Table 12. The project appears to have benefited horseshoe crab (*Limulus polyphemus*). In 2016-7, extensive areas of the marsh adjacent to the tidal creek were used by mating horseshoe crabs, which were observed as far south as St. 8. Over 30 mating pairs were observed in an informal tally. Once again in 2018, particularly at the pool complex at St. 5- 6, the marsh was frequented by mating horseshoe crabs. Juvenile horseshoe crabs appeared common within pools later in the summer.

Table 12. Incidental observations of fish and wildlife during monitoring (2013 – 2018).

Common name	Scientific name	Notes
Great blue heron	*Ardea herodias*	Feeding in pools & pannes, at culvert outlet
Snowy egret	*Egretta thula*	Feeding in pools & pannes, at culvert outlet
Bald eagle	*Haliaeetus leucocephalus*	2013 nest in pine
Glossy ibis	*Plegadis falcinellus*	In flocks of 10-15, between St. 2-6, starting 2015
Osprey	*Pandion haliaetus*	Feeding in tidal creek
Greater yellowlegs	*Tringa melanoleuca*	Feeding in pools & pannes, at culvert outlet
Sandpipers	*Scolopacidae spp.*	Feeding in pannes
Black duck	*Anas rubripes*	2013, creek channel
Mallard	*Anas platyrhynchos*	2013, creek channel
Canada goose	*Branta canadensis*	2013, creek channel
Belted Kingfisher	*Megaceryle alcyon*	Feeding in channel; perching at upland edge
Black-crowned night heron	*Nycticorax nycticorax*	Feeding in pools & pannes
Mink	*Neovison vison*	
Fisher	*Martes pennanti*	Found dead in spring trap, St. 1
White-tailed deer	*Odocoileus virginianus*	
Coyote	*Canis latrans*	Sign
Black bear	*Ursus americanus*	Sign
Moose	*Alces alces*	Bones on marsh
Raccoon	*Procyon lotor*	Tracks in channel flats
Soft shell clam	*Mya arenaria*	Project Area tidal creek channel bottom
Quahog	*Mercenaria mercenaria*	Project Area tidal creek channel bottom
Ribbed mussel	*Geukensia demissa*	Abundant
Mud snail	*Hydrobiidae sp.*	Abundant in tidal creek channel
Macoma clams	*Macoma sp.*	Project Area tidal creek channel bottom
Horseshoe crab	*Limulus polyphemus*	Mating on high marsh, juveniles in pools, 2016-8
Silverside	*Menidia menidia*	Pools, pannes, tidal creek
Mummichog	*Fundulus heteroclitus*	Pools, pannes, tidal creek
Green crab	*Carcinus maenas*	
American eel	*Anguilla rostrate*	
Moon jelly	*Aurelia spp.*	High marsh, 2014
Striped bass	*Morone saxatilis*	Feeding in culvert, outgoing tides, 2018

4. MANAGEMENT RECOMMENDATIONS

Our analysis shows that changes to surface water hydrology, marsh vegetation, channel morphology, pore water salinity, and surface water salinity in the Project Area have met performance standards and align with mitigation goals. Based on monitoring for the presence of halophytic plants in the Project Area, we conclude that invasive species are being controlled through a combination elevated salinity levels and integrated pest management techniques, including application of herbicides. However, the ecosystem remains in a state of transition, leaving pockets of the marsh susceptible to colonization by *Phragmites*.

Recommendation: Continue to monitor for colonization by Phragmites australis within the Project Area for an additional 3 year period.

Evaluation of 2018 vegetation and channel data illustrate that these components of the marsh ecosystem remain in an ongoing state of adjustment to the new hydrological regime. This ongoing transition is particularly evident near the upland edge of the marsh (the end of vegetation transects), where the abrupt change in hydrology created an ecological disturbance that resulted in widespread mortality of freshwater and brackish vegetation, but has subsequently left standing dead wood, plant stems and associated root matter over sections of the marsh. This dead material, along with groundwater seeps into the marsh and other micro-topography, has slowed colonization by halophytic and brackish plants in some pockets of the marsh.

Generally, we have observed that the vegetative community in areas of the marsh that are further from the tidal creek, and/or further from the open ocean, have been slower to respond to the change in hydrology. In some pockets of the Project Area that are distant from open tidal water, colonization by any vegetation remains sparse (although halophytic volunteers are increasingly prevalent). As a result, conditions within these few pockets of the Project Area remain conducive to colonization by *Phragmites*.

The discovery of two clonal stands of invasive *Phragmites* within the Project Area in 2016, and subsequent observations of three clonal stands in 2018 coming at the end of the post-project monitoring period, reinforces the importance of monitoring for invasion by common reed. We therefore recommend continuing annual monitoring for *Phragmites australis*. In response to this recommendation, MaineDOT will commit to three years of Phragmites mapping and control from 2019-21. In 2021 MaineDOT will assess the need to continue treatment and address future control at that time.

5. REFERENCES

Abbott, A. Personal communication, 2/2015. Contractor with the US Fish and Wildlife Service, Gulf of Maine Coastal Program, Falmouth, Maine.

Achenbach, L., F. Eller, L.X. Nguyen and H. Brix. 2013. *Differences in salinity tolerance of genetically distinct Phragmites australis clones.* AoB Plants, 5: plt019. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4104622/.

CBEP 2015. *2014 Post-Construction Monitoring Report: Long Reach Lane at Long Marsh. Year 1 of 5.* Maine Department of Transportation.

Craig, M. and C. Bohlen. 2018. *Quality Assurance Project Plan for Tidal Marsh Monitoring and Assessment.* Casco Bay Estuary Partnership. Portland, Maine.

Gulf of Maine Council Climate Network. June 2016. *Quarterly Climate Impacts and Outlook, March-May 2016.* http://www.gulfofmaine.org/2/wp-content/uploads/2016/06/GOM-Spring-2016.pdf

Haines, A. and T.F. Vining. 1998. *Flora of Maine: A Manual for Identification of Native and Naturalized Vascular Plants of Maine.* V.F. Thomas Co., Bar Harbor.

Konisky, R., D.M. Burdick, M. Dionne, and H.A. Neckles. 2006. *A Regional Assessment of Salt Marsh Restoration and Monitoring in the Gulf of Maine.* Restoration Ecology, 14:4 (516-525).

Maine Department of Transportation, 2012. *Wetland Mitigation Plan: Martin's Point Bridge, Falmouth-Portland. PIN 16731.00.*

Mecklenburg, D., 2006. *The Reference Reach Spreadsheet: Version 4.3 L*. Ohio Department of Natural Resources.

Neckles, H., and M. Dionne, Eds., 1999. *Regional Standards to Identify and Evaluate Tidal Wetland Restoration in the Gulf of Maine.* Wells National Estuarine Research Reserve. https://www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf.

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

Verrill, S. 2017. *Pore Water Salinity Drives Brackish Vegetation Changes in Salt Marsh Tidal Restoration.* (Unpublished master's thesis). University of Southern Maine, Portland.

Wake, C., E. Burakowski, K. Hayhoe, C. Watson, E. Douglas, J. VanDorn, V. Naik, and C. Keating, 2009. *Climate Change in the Casco Bay Watershed: Past, Present, and Future.* Casco Bay Estuary Partnership. http://www.cascobayestuary.org/wp-content/uploads/2014/08/2009_cbep_climate_change_report.pdf

APPENDIX A – MONITORING STATION MAPS

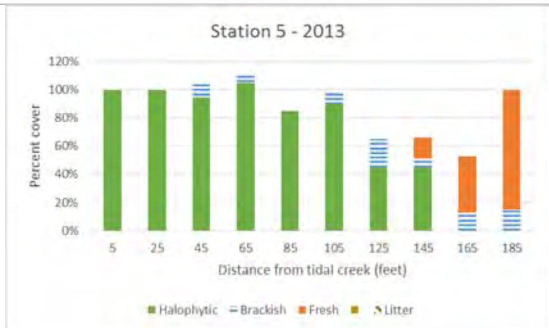
Vegetation
0 45 90 180 270 360
Meters
Transect Location
C = channel; U = upland
1C
1U
2C
2U
3C
3U
4C
4U
5U
5C
6C
6U
7C
7U
8U
8C
9C
9U
10C
10U

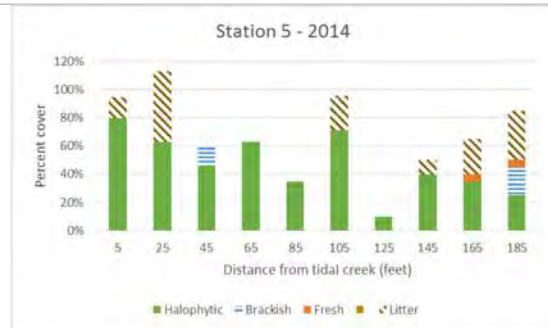

Channel Cross Sections
0 45 90 180 270 360
Meters
Stake
Casco Bay Estuary
PARTNERSHIP
XS1W
XS1E
XS2E
XS2W
XS3W
XS3E
XS4W
XS4E
XS5W
XS5E
XS6E
XS6W
XS7W
XS7E
XS8E
XS8W
XS9W
XS9E
XS10E
XS10W

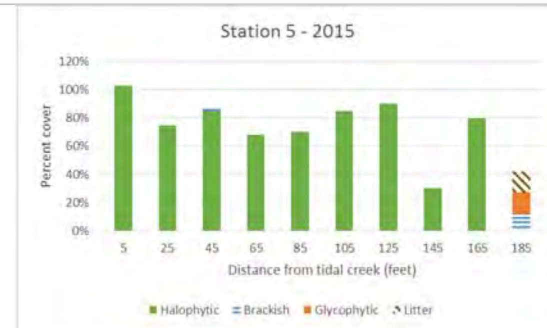

Pore Water Salinity
0 45 90 180 270 360
Meters
Well
Casco Bay Estuary
PARTNERSHIP
1S
2S
4S
6S
6aS
8S
10S

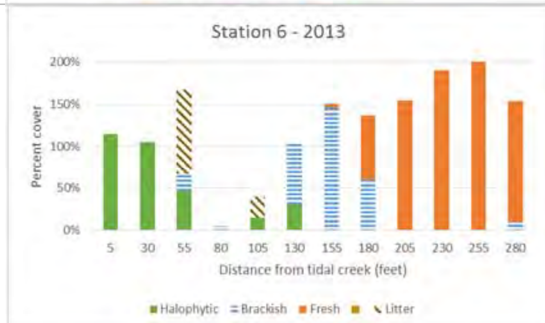
APPENDIX B – VEGETATION

Table 13. Bar graphs of community type (% cover) for Stations 1-10, by transect distance, 2013 - 2015.

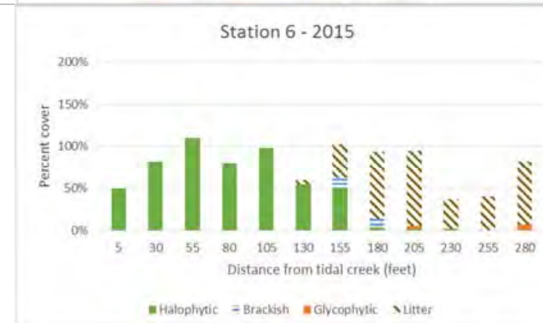

Station 5 - 2013
Percent cover
0% 20% 40% 60% 80% 100% 120%
5 25 45 65 85 105 125 145 165 185
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter

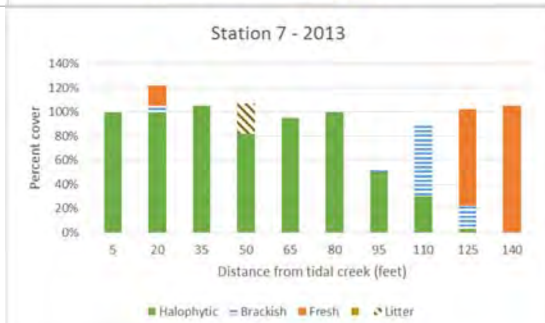

Station 5 - 2014
Percent cover
0% 20% 40% 60% 80% 100% 120%
5 25 45 65 85 105 125 145 165 185
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter

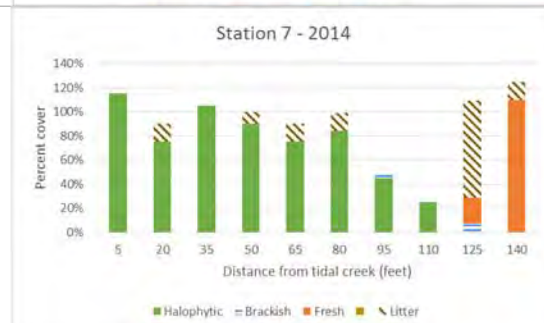

Station 5 - 2015
Percent cover
0% 20% 40% 60% 80% 100% 120%
5 25 45 65 85 105 125 145 165 185
Distance from tidal creek (feet)
Halophytic Brackish Glycophytic Litter

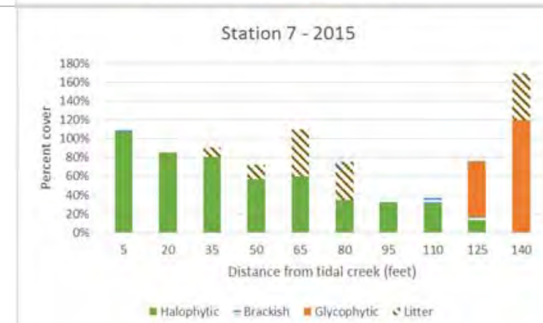

Station 6 - 2013
Percent cover
0% 50% 100% 150% 200%
5 30 55 80 105 130 155 180 205 230 255 280
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter

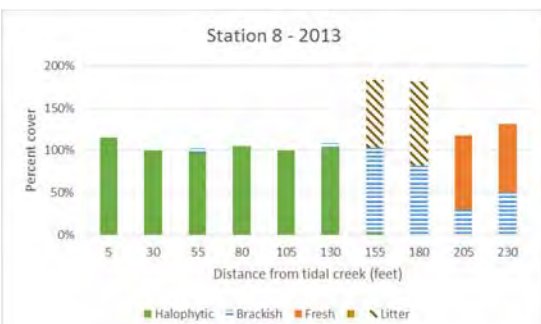

Station 6 - 2014
Percent cover
0% 50% 100% 150% 200%
5 30 55 80 105 130 155 180 205 230 255 280
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter


Station 6 - 2015
Percent cover
0% 50% 100% 150% 200%
5 30 55 80 105 130 155 180 205 230 255 280
Distance from tidal creek (feet)
Halophytic Brackish Glycophytic Litter

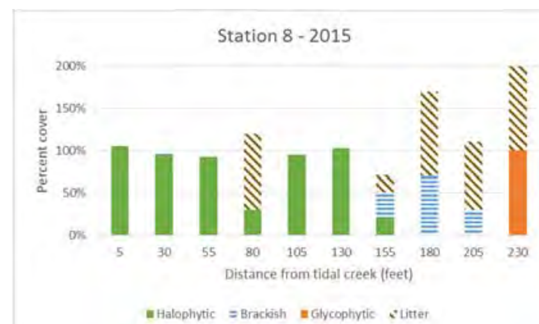

Station 7 - 2013
Percent cover
0% 20% 40% 60% 80% 100% 120% 140%
5 20 35 50 65 80 95 110 125 140
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter

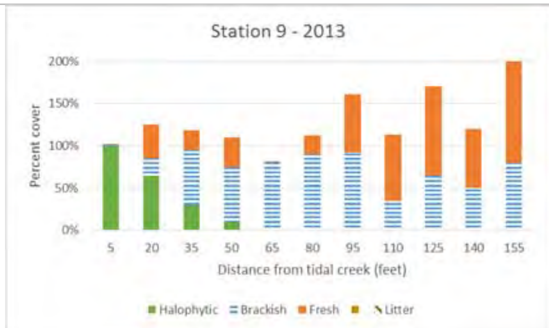

Station 7 - 2014
Percent cover
0% 20% 40% 60% 80% 100% 120% 140%
5 20 35 50 65 80 95 110 125 140
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter

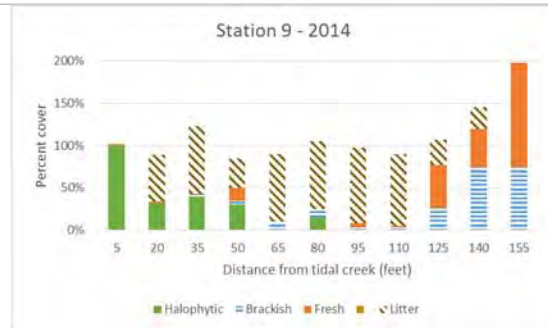

Station 7 - 2015
Percent cover
0% 20% 40% 60% 80% 100% 120% 140% 160% 180%
5 20 35 50 65 80 95 110 125 140
Distance from tidal creek (feet)
Halophytic Brackish Glycophytic Litter

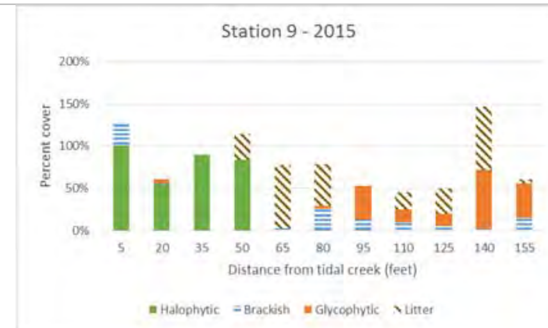

Station 8 - 2013
Percent cover
0% 50% 100% 150% 200%
5 30 55 80 105 130 155 180 205 230
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter

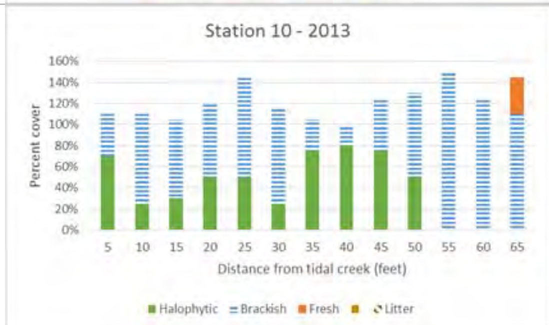

Station 8 - 2014
Percent cover
0% 50% 100% 150% 200%
5 30 55 80 105 130 155 180 205 230
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter

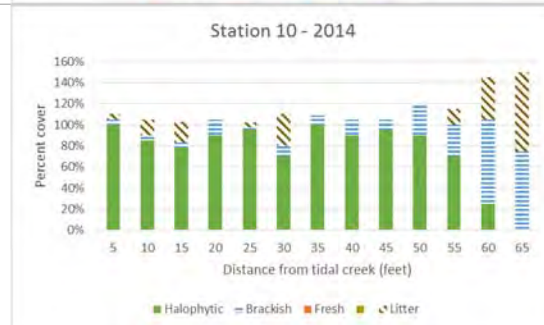

Station 8 - 2015
Percent cover
0% 50% 100% 150% 200%
5 30 55 80 105 130 155 180 205 230
Distance from tidal creek (feet)
Halophytic Brackish Glycophytic Litter

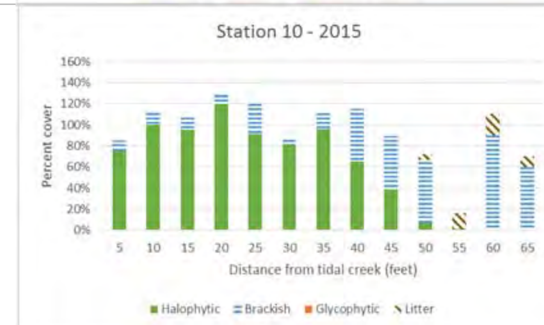

Station 9 - 2013
200%
150%
100%
50%
0%
Percent cover
5 20 35 50 65 80 95 110 125 140 155
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter


Station 9 - 2014
200%
150%
100%
50%
0%
Percent cover
5 20 35 50 65 80 95 110 125 140 155
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter


Station 9 - 2015
200%
150%
100%
50%
0%
Percent cover
5 20 35 50 65 80 95 110 125 140 155
Distance from tidal creek (feet)
Halophytic Brackish Glycophytic Litter


Station 10 - 2013
160%
140%
120%
100%
80%
60%
40%
20%
0%
Percent cover
5 10 15 20 25 30 35 40 45 50 55 60 65
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter


Station 10 - 2014
160%
140%
120%
100%
80%
60%
40%
20%
0%
Percent cover
5 10 15 20 25 30 35 40 45 50 55 60 65
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter


Station 10 - 2015
160%
140%
120%
100%
80%
60%
40%
20%
0%
Percent cover
5 10 15 20 25 30 35 40 45 50 55 60 65
Distance from tidal creek (feet)
Halophytic Brackish Glycophytic Litter