Post-Restoration Monitoring (Year 1) of the Three Fathom Harbour Tidal Wetland Restoration Project

Prepared for:

Nova Scotia Department of Transportation and Infrastructure Renewal

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Executive Summary

Originally identified as a potential tidal wetland restoration site in 2004, restoration of a more natural hydrological regime to the Three Fathom Harbour (TFH) site was carried out in July 2015. The restoration design, which was developed by CBWES Inc. in collaboration with NS Transportation and Infrastructure Renewal (NSTIR), consisted of the installation of a 3.3 m x 3 m box culvert and upgrades to the associated road infrastructure.

The primary goals of the restoration efforts at the Three Fathom Harbour Tidal Wetland Restoration Project were to:

- Meet the terms and conditions of a wetland alteration approval from NS Environment (NSE; Approval 2013-085986) to compensate for damage to a nearby freshwater wetland following construction of the Porters Lake (Lakeview) Elementary School (Approval 2010-073464);
- Significantly reduce the tidal restriction caused by causeway-culvert highway crossing;
- Improve hydrological conditions upstream of the causeway (reduce ponding/flooding by freshwater; improved water quality);
- Facilitate natural colonization by halophytic vegetation and re-establishment of tidal wetland habitat conditions; and
- Improve fish passage to and within the wetland habitat upstream of the causeway.

To accomplish these goals, the restoration activities included the following components:

- Replacement of the existing buried, undersized culvert (0.82 m diameter) with a more appropriately sized box culvert (3.3 m x 3 m); and
- Conduct a pre- and post-restoration monitoring program to document habitat response.

A one-year pre-and five-year post-restoration monitoring program was developed for the project. The purpose of the monitoring program was to provide a scientific record of habitat conditions at the restoration site in order to quantify environmental change in response to restoration, to facilitate adaptive management actions if required, and to verify project success (restored marsh exhibits similar physical and biological characteristics and functional processes as a nearby reference site). Although a strong odour was reported by local residents during and after construction, specific sampling for odour was not part of the planned restoration monitoring program. To date, air quality has not been a formal part of the monitoring activities associated with any tidal wetland restoration in the province. However, because of the situation at TFH, consideration has been given to potential causes and the likelihood of the persistence of those conditions.

Pre-restoration monitoring was carried out in 2011 (Bowron et al. 2012). The first year of post-restoration ecological monitoring was conducted during the summer and fall of 2016 and winter of 2017. Data were collected for geospatial attributes, hydrology, soil and sediments, and vegetation and compared to both pre-restoration and reference conditions, the results of which are presented in this report and summarized below. The reference condition was drawn from the six years of monitoring data from the neighbouring Lawrencetown Lake Salt Marsh Restoration and Reference sites (Bowron et al. 2012a; Bowron et al. 2013b).

The results for the first year of post-restoration monitoring are detailed in the following report and summarized below.

Geospatial Attributes

The wetland boundary, as delineated by elevation, tree line and aerial photography, was determined to encompass a potential wetland area of approximately 2.21 ha. The elevation survey (digital elevation model and transect elevation profiles) showed in increase in mean surface elevation over that of 2011. A combination of sediment deposition, expansion of the below ground root zone, and improved site conditions (consolidation of soils) leading to improved accuracy of the survey contributed to the observed increase. Prior to restoration, the site was characterized as a poorly drained fresh water wetland consisting of mix of a shallow open water, marsh, fen and bog like habitat conditions, with highly variable water levels and periodic saltwater intrusion. Although the site is still very much in transition, the site now floods and drains daily with the tide, is experiencing consolidation of formerly waterlogged soils and the development of a channel network within the central pond area, and is seeing a shift in plant assemblage towards a more halophytic dominated community structure across the front portion of the site.

Hydrology

Hydroperiod and Tidal Signal:

Prior to the installation of the new crossing, water levels within the site fluctuated minimally with the recorded tidal conditions in the harbour and were predominantly driven by freshwater flows (precipitation; runoff). The new crossing resulted in the immediate drainage of the central pond and the re-introduction of regular tidal flow to the site. Water levels within the site are now directly tied to the tidal cycle, with peak high and low waters corresponding to those of broader Three Fathom Harbour tidal regime. The maximum recorded water level (high high tide) flooded a majority of the restoration site, whereas the mean tide line matched well with the edge of the former pond and the central bog area. Due to freshwater flow and the elevation gradient, a base flow of water is maintained within the sites re-establishing drainage and primary channel network. The new extent of tidal flooding is not yet reflected in the vegetation community, however it is showing significant signs of change (i.e., die back and colonization zones). The new tidal crossing does not represent a barrier to tidal flow, species or materials and the site is no longer considered tidal restricted.

Soils and Sediments

Sediment Accretion and Elevation:

Atlantic coastal waters tend to have low suspended sediment concentrations and the one year post-restoration depositional patterns at TFH reflect this. Sediment deposition at

TFH, as at the Lawrencetown reference and restoration site, appears to be largely during storm event driven. Accretion rates within the main tidal portion of the site were within the range of mean accretion measured at the reference site, particularly in the mid and high marsh areas. The change in surface elevation between 2011 and 2016 as measured by the RTK DGPS survey unit, was in all cases much greater than the net sediment accretion measured over the same period. This difference is likely the result of below ground processes such as expansion and contraction of the peat layer (water concentration) and the buildup of organic matter (production). The rates of accretion do suggest that both the reference and the restoration site are keeping up with sea level rise.

<u>Soil Characteristics</u>:

Prior to re-introduction of tidal flow, all of the cores were highly waterlogged, consisting mainly of peat and root fragments with low amounts of inorganic sediment. One year post-restoration, all stations save one (located adjacent to a developing freshwater drainage channel) experienced a decrease in water content. Samples taken closest to the tidal crossing and regularly flooded areas recorded the highest decrease in water content and organic matter content due to the improved hydrology and regular tidal flushing. Areas corresponding to the new high water line (wrack deposition zone) experienced a ~10% increase in organic matter content. Water content remains greater than at the reference site. Bulk density increased at most sampling locations corresponding to the decreased water and organic matter content. Where water and organic matter increased (i.e., mean high water), bulk density decreased. Water content, organic matter and bulk density values were lower, but within range, than those of the reference condition.

The majority of sediment cores were classified as being very close to 100% mud and were poorly sorted. Grain sizes found at TFH were similar to those of the reference, however, grain sizes at the reference were coarser reflecting the longer tidal history and storm driven depositional history. This situation is likely to continue as the TFH site also receives considerable seasonal inputs of wrack material, predominantly dead and dying seaweed, particularly during winter months. The deposition and decomposition of this material within the marsh, which previously occurred on the adjacent beach (Pett 2015), is anticipated to contribute to the continued accretion of fine organic soils (muds) as compared to the larger inputs of coarse, sandy sediments at the Lawrencetown reference sites.

Vegetation

The vegetation community at TFH one year following restoration more closely resembles that of the reference condition then it did prior to the reintroduction of tidal flow. The vegetation community has begun a shift toward the halophytic dominated plant community found at the reference site with a number of salt marsh species now present within the site and in areas not previously vegetated. Although a statistically significant difference remains between the two sites, the difference is less following restoration. Average species richness of TFH in 2016 was lower than that of 2011 and is closer to that of the reference site.

Structured Winter Walk and Community Concerns

Of note from the structured winter walk in February 2017 was the presence of a significant quantity of tidally-deposited seaweed within the site. Although the deposition of this wrack material is a natural part of tidal marsh ecology, the quantity and extent observed during the winter walk mirrored the large quantities observed the previous winter and on the adjacent beach prior to culvert replacement in summer 2015. Decomposition of this material had previously generated periodic foul odours, particularly during warm summer months, and one such event coincided with the construction period in 2015.

Summary

Prior to restoration, TFH was characterized as a poorly-drained freshwater wetland complex consisting of a shallow open water zone, marsh, fen and bog-like habitat conditions, with highly variable water levels and limited tidal (salt water) influence. A mix of freshwater plant species dominated the vegetation community and soils were highly waterlogged and consisted of mainly peat and root fragments and very little inorganic material.

The installation of the new tidal crossing in 2015 resulted in the elimination of the hydrological restriction and the restoration of a more natural, tidally driven, hydrological regime to the site. In addition to the increased frequency, extent and duration of tidal flooding, the new crossing also re-established fish and waterfowl passage and the transport of materials (i.e., seaweed/wrack) into and out of the site; reduced flood risk (by freshwater); initiated a transition in the vegetation community structure (i.e., re-colonization by halophytic species); reconnected the site to the broader estuarine system; and the general long-term improvement in the ecological integrity and resilience of the site. Although at this early stage in the recovery process much of the documented changes in physical and biological conditions are concentrated in the “front” portion of the site, the restored hydrology should ultimately be to the benefit of the entire 2.21 ha wetland area, as well as surrounding upland habitats and downstream marine environment.

Acknowledgements

This work would not have been able to be completed without the assistance of the In_CoaST, MP_SpARC and EPIC research teams at Saint Mary's University. Financial support for this project was provided by the Nova Scotia Department of Transportation and Infrastructure Renewal.

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1.0 Introduction

1.1 Background

CBWES Inc. was commissioned in May 2011 by the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR) to complete a restoration feasibility and design study for the Three Fathom Harbour Tidal Wetland Restoration site (Bowron et al. 2011a). It was determined that replacement of the existing tidally restrictive culvert with a more appropriately-sized structure would result in a significant reduction in the hydrological barrier. The replacement of the crossing would result in the restoration of a more natural hydrological regime to the site, the enhancement of existing wetland habitat conditions and an increase in the amount of tidal wetland habitat. In addition, the project would:

- Re-establish a more natural connection between the restoration site and the Three Fathom Harbour estuary;
- Reduce pooling of freshwater on the marsh;
- restore fish passage to the site and access to the marsh surfaces (an increase in fish habitat);
- Improve productivity and transport of materials (nutrients); and
- Allow native coastal wetland-dependent species (i.e. fish, invertebrates, water birds, shorebirds, wading birds, waterfowl) to be reestablished and/or to increase in number.

Determining the restoration potential was the first step in the process to fulfill NSTIR's compensation requirements for the Nova Scotia Environment (NSE) wetland approval associated with the Porters Lake (Lakeview) Elementary School (Approval 2010-073464). This was followed by the development of a tidal wetland restoration monitoring program and the implementation of the pre-restoration (baseline) portion of the program that same year (Bowron et al. 2012). The monitoring program, presented in Chapter 2, was developed based on the experience with similar projects in the region (Bowron et al. 2011a; Neckles et al. 2002; van Proosdij et al. 2011) and was approved by NSE (Approval 2013-085986) and Fisheries and Oceans Canada (DFO; File 13-HMAR-MA1-00199.

Restoration (earthworks) was carried out in July 2015 and consisted of the replacement of the existing undersized and failing culvert (0.82 m diameter) with a significantly larger box culvert (3.3 m x 3 m) and upgrades to the associated causeway (increased elevation, new guard rails, new pavement, shoreline armouring). The new culvert and causeway were designed to meet the restoration goals of the project and with an eye towards potential future hydrological and weather conditions resulting from climate change and sea level rise.

All aspects of this project were conducted or supervised by CBWES staff and project partners, under contract to NSTIR. Field and laboratory work was carried out by: Tony M. Bowron, Jennie M. Graham and Katie Porter with CBWES, and Dr. Danika van Proosdij, Greg Baker, and Logan Horrocks with Saint Mary's University (SMU).

1.2 CBWES Inc.

Since 2005, CBWES has been involved in the restoration and monitoring of twelve major tidal wetland restoration projects within NS in collaboration with NSTIR[1]. These projects, in particular, the design and monitoring activities, have been presented by CBWES staff in poster and oral presentation formats at a number of regional, national and international scientific conferences[2]. Please contact CBWES for more information on these presentations. CBWES is committed to continuing to participate in important events such as these.

CBWES has a strong research partnership with SMU. Through this partnership, a number of undergraduate and graduate level research projects involving the restoration project sites have been supported. As a recognized Industrial Partner with the Natural Sciences and Engineering Research Council of Canada (NSERC), CBWES Inc. received NSERC grants for six of these projects (four undergraduate and two graduate). The resulting theses are available from the SMU library. Summaries of these salt marsh restoration research projects, as well as the non-NSERC funded current and completed projects are provided in Appendix A.

To date, three peer-reviewed papers have been published focusing on separate restoration projects. One was published in *Restoration Ecology* on the Cheverie Creek Restoration Project titled “*Macro-Tidal Salt Marsh Ecosystem Response to Culvert Expansion*” (Bowron et al. 2011b); the second appeared in the journal *Ecological Engineering* on the Walton River Restoration Project titled *Ecological Re-engineering of a Freshwater Impoundment for Salt Marsh Restoration in a Hypertidal System* (van Proosdij et al. 2010); while the third “*Classification and environmental correlates of tidal wetland*

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[1] Cheverie Creek (Bowron et al. 2011b; 2013a), Walton River (Neatt et al. 2013; van Proosdij et al. 2010), Lawrencetown Lake (Bowron et al. 2013b), Smith Gut (Bowron et al. 2012b), St. Croix River (Bowron et al. 2015b), Cogmagun River (Bowron et al. 2015a), Antigonish Landing (in collaboration with CBCL Ltd.) (CBCL 2011), Three Fathom Harbour (Bowron et al. 2012a), Tennycape (Bowron et al. 2011b), Morris Island (Bowron et al. 2014); Mavillette (Bowron et al. 2016). CBWES reports available for download at www.gov.ns.ca/tran/enviroservices/enviroSaltMarsh.asp)

[2] Restore Americans Estuaries 9th National Conference (RAE 2016); Adaptation Canada Conference (2016); CLRA-Atlantic Reclamation Conference (ARC 2015); Coastal and Estuarine Research Federation 23rd International Conference (CERF 2015); EC Gulf of Maine HOTO Project Results & Collaborative Opportunities Workshop (HOTO 2015); Atlantic Flood Management Conference (AFMC 2015); Restore America’s Estuaries 7th National Conference (RAE 2014); 7th Annual Atlantic Reclamation Conference (ARC 2014); Atlantic Canada Coastal and Estuarine Science Society 2014 Conference (ACCESS 2014); 6th Annual Atlantic Reclamation Conference (ARC 2013); Coastal and Estuarine Research Federation 22nd International Conference (CERF 2013); 2013 Mid-Atlantic Living Shorelines Summit (RAE 2013); Canadian Land Reclamation 37th National Conference (CLRA 2012); Atlantic Canada Coastal and Estuarine Science Society 2012 (ACCESS 2012); BoFEP’s 9th Bay of Fundy Science Workshop (BoFEP 2011); Coastal and Estuarine Research Federation’s 21st International Conference (CERF 2011); Restore America’s Estuaries 5th National Conference on Coastal and Estuarine Habitat Restoration (RAE 2010); Atlantic Reclamation Conference (ARC 2008; 2009, 2010); Coastal and Estuarine Research Federation’s 2009 International Conference (CERF 2009); BoFEP’s 8th Bay of Fundy Science Workshop (BoFEP 2009); Canadian Water Resources Association - Maritime Water Resources Symposium (CWRA 2008); Atlantic Canada Coastal and Estuarine Science Societies’ 2008 conference (ACCESS 2008); Estuarine Research Federations’ 2007 International Conference (ERF 2007); Canadian Land Reclamation Associations National Conference (CLRA 2007); Ecology Action Centre’s “Six Years in the Mud – Restoring Maritime Salt Marshes: Lessons Learned and Moving Forward” workshop (EAC 2007).

vegetation: implications for ecological restoration and monitoring" (Porter et al. 2015) appeared in the journal *Botany*. A book chapter has also been published titled "Chapter 13 – Salt Marsh Tidal Restoration in Canada's Maritime Provinces" in *Tidal Marsh Restoration: A Synthesis of Science and Management* (Roman and Burdick 2012). Abstracts for each of these publications appear in Appendix A.

An article looking back over 10 years of tidal wetland restoration projects in NS, written by Tony Bowron, was featured in the Canadian Society of Landscape Architects' national magazine *Landscapes/Paysage* (Lord et al. 2016). Tony was also a quest editor on the issue, the central theme of which was wetlands.

On January 26, 2017, CBWES received the Bronze Award for Innovative Business of the Year 2017 at the Halifax Business Awards for our work with NSTIR and SMU on the study and restoration of tidal wetlands in NS.

2.0 Three Fathom Harbour and Monitoring Program

2.1 Three Fathom Harbour Restoration Site

The Three Fathom Harbour restoration site (TFH) is a 2.26 ha (5.5 acre; 22,600 m^2) former tidal wetland in Three Fathom Harbour, adjacent to the Three Fathom Harbour Road just off Highway 207 (Halifax Regional Municipality, NS) (Figure 1). The site was originally identified as a potential tidal wetland restoration project by T. Bowron (CBWES Inc.) and Dr. Bob Pett (NSTIR) in 2004 during an inventory of tidally restricted coastal wetland systems conducted in the area for NSTIR.

Prior to the construction of the former Musquodoboit Railway (now the Trans Canada Trail), Route 207 and the Three Fathom Harbour Road, TFH acted as a wetland corridor connecting Porters Lake to Three Fathom Harbour (Figure 2). The sequential construction of the three transportation routes resulted in the isolation of the wetland from both Porters Lake and Three Fathom Harbour and its conversion from a tidal wetland system to a brackish-freshwater system (Figure 3). Each of the transportation causeways was constructed with extremely undersized culverts in order to facilitate freshwater drainage. The culvert within the Three Fathom Harbour Causeway originally allowed limited hydrological exchange with the Three Fathom Harbour tidal system (Figure 4). However, subsequent rock armouring of the seaward side of the causeway and the deposition of sand, flotsam and seaweed detritus (wrack) resulted in the blockage of the downstream end of the culvert and further restriction (approaching complete) of the hydrological exchange.

The pre-restoration structure, a concrete culvert, had a diameter of 0.82 m and an upstream invert elevation of 0.042 m. The length of the culvert and elevation of the downstream invert was not known due to the presence of the armour stone and sand. Due to its size and blockage on the downstream end by displaced armour stone and tidally deposited sand and wrack material, tidal flow and fish passage into the site was extremely limited. More significant was the retention and pooling of brackish water within the site.

Communication with local residents prior to restoration indicated that drainage rarely occurred and typically would only occur following a major rain event causing enough hydrologic pressure to partially clear the downstream blockage (sand) (Figure 5).

The new tidal crossing structure and upgrades to the causeway (increased elevation of the road, new guard rails and armour stone) were completed in July 2015 (Figure 6; Figure 7). The installation of the new crossing had the immediate effect of improving the hydrology of the site by draining the head pond, enabling the unrestricted flow of tidal waters into and out of the site, and over the subsequent year the re-activation of the primary tide channel and remnant creek network within the site (Figure 7).

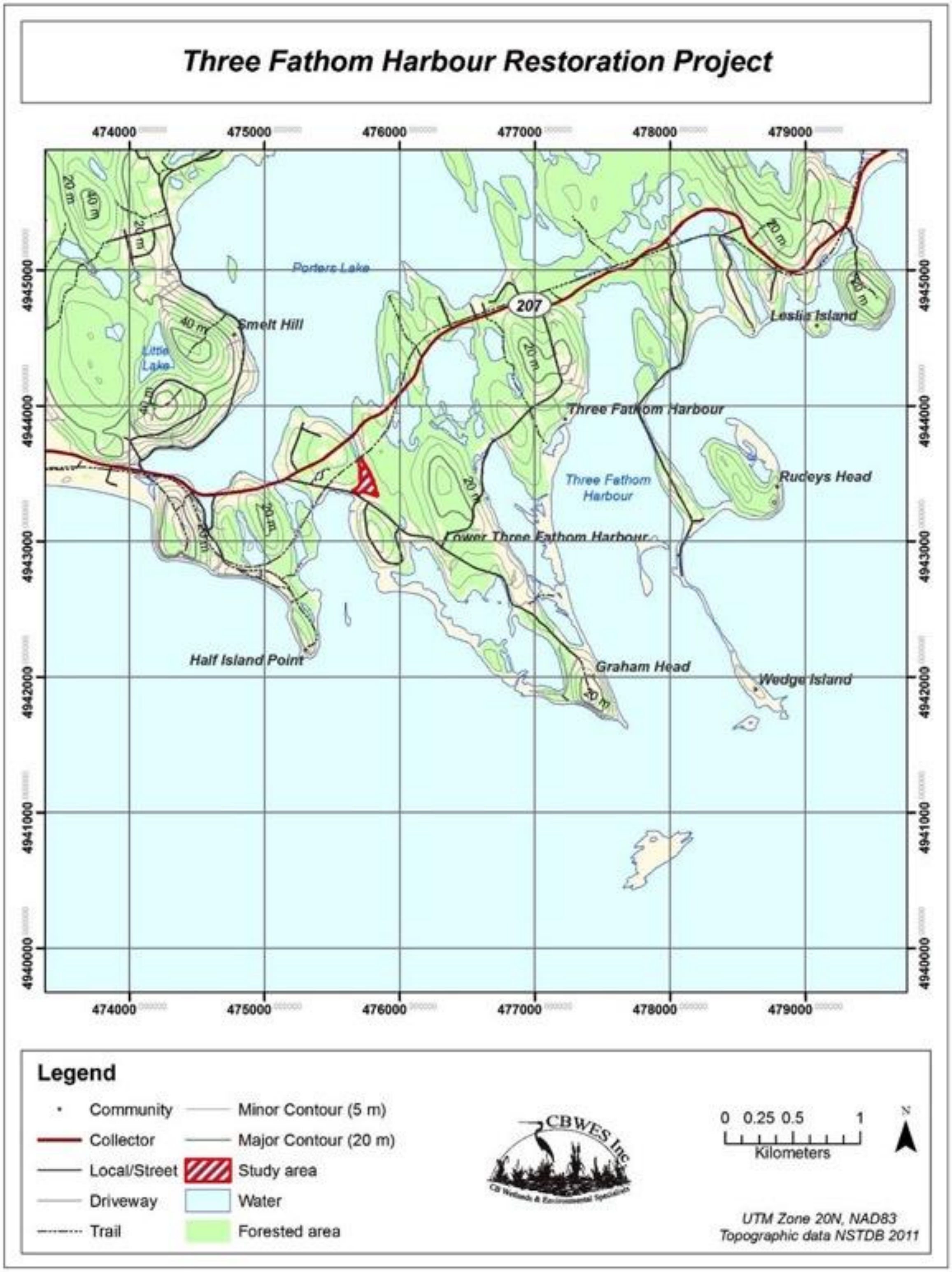

Figure 1 Location of TFH.

Figure 2 Three transportation routes separating the study site from Three Fathom Harbour and Porters Lake.

Figure 3 Landscape photograph of TFH from roadway above crossing. Photograph by T. Bowron, 12/8/11.

Figure 4 Upstream side of Three Fathom Harbour causeway and culvert shortly after a natural, storm blowout of the buried/plugged culvert. Photographs by T. Bowron, 12/8/11.

Figure 5 Adjacent beach with accumulated seaweed wrack downstream of the buried culvert. A temporary enlarged channel was created by a rainfall event shortly before the June 25, 2011 photograph.

Figure 6 New tidal crossing installed July 2015. Photography by CBWES, July 16, 2015.

Figure 7 New tidal crossing, causeway upgrades and incoming tide flowing into the site via the re-established primary channel. Water can be seen in the re-activated network or smaller channels within the site. Aerial image by CBWES, September 22, 2016.

2.2 Reference Condition

A comparable (size, hydrology, vegetation community structure) unrestricted wetland suitable for use as a reference site for direct comparison was not available in the area. Although not an ideal comparison, the neighbouring Lawrencetown Lake Salt Marsh Restoration and Reference sites (Bowron et al. 2012a; Bowron et al. 2013b) (Figure 8) were used as a general habitat reference condition.

The Lawrencetown Lake Salt Marsh Restoration (LT) and Reference (LTR) sites are located approximately 4 km west of TFH along NS Route 207 (Marine Drive) in Lawrencetown (Halifax County), and are part of the Lawrencetown Lake tidal wetland system (Figure 9). The restoration site is a 26,354 m^2 (6.51 acres, 2.6 ha) tidal wetland that was restored (culvert installation) in 2007, and has been extensively monitored between 2006 and 2011. The reference site, located on the lake side of the Trans Canada Trail, is an 8,305 m^2 (2.0 acres; 0.8 ha) unrestricted tidal wetland (Figure 8). Both of these sites are part of a tidal marsh system extending around much of the perimeter of the Lawrencetown Lake tidal system. Although both sites were used in the comparison to TFH, the Lawrencetown Lake Reference site (LTR) in particular was the focus of the comparison for this report. Both LT and LTR follow a typical zonation pattern, hydrology and species composition expected of a salt marsh with low, mid and high marsh zones.

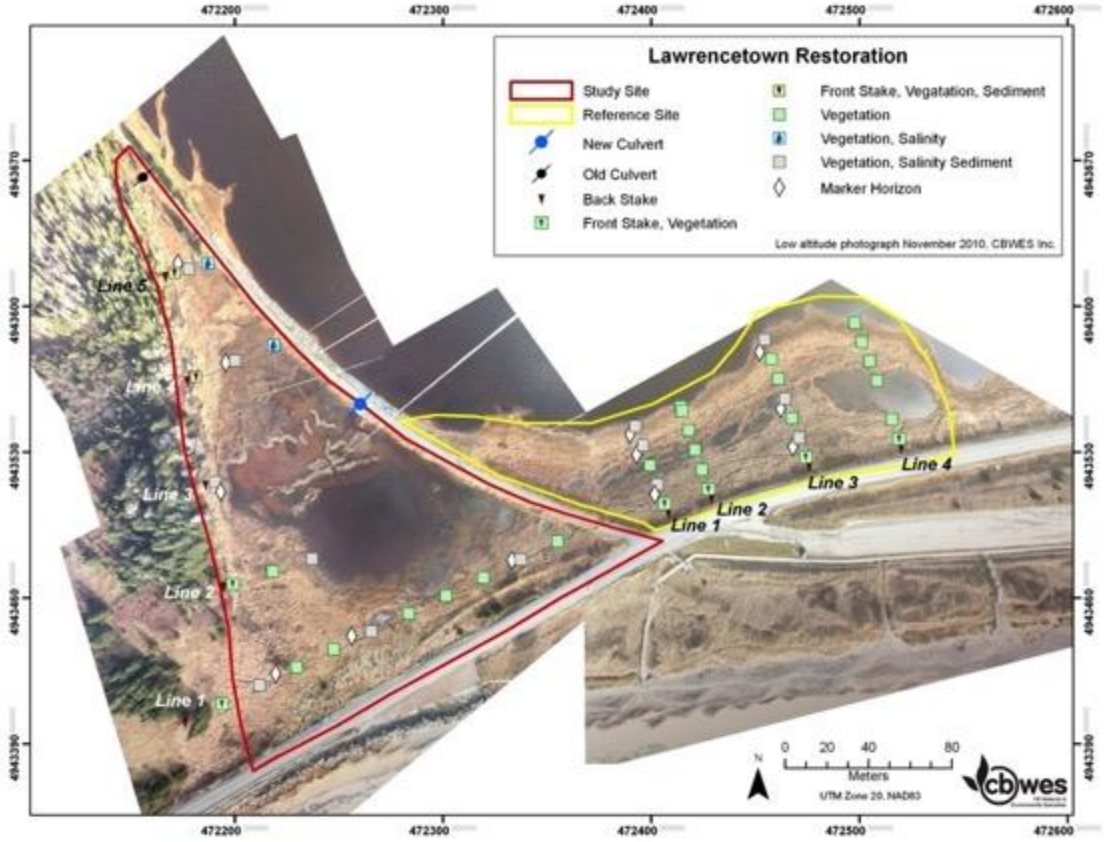

Figure 8 Lawrencetown Lake Restoration (red) and Reference site (yellow).

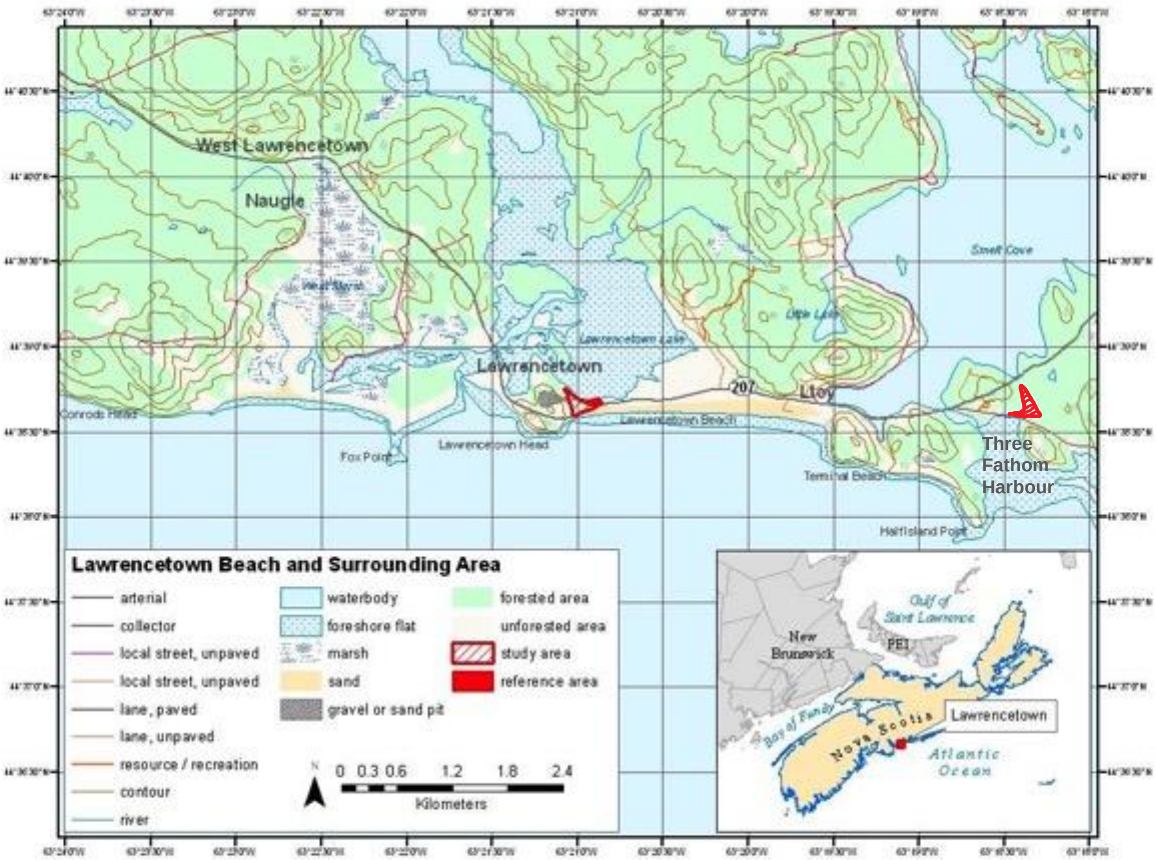

Figure 9 Location of Lawrencetown Lake restoration and reference sites, Halifax County, NS relative to Three Fathom Harbour (TFH) (base map downloaded from: www.geogratis.ca/geogratis/en/product/search.do?id=28954).

2.3 Monitoring Program

The monitoring program for the TFH project was developed based on experience with similar restoration projects in the region (Bowron et al. 2011a; Neckles et al. 2002; van Proosdij et al. 2010; http://novascotia.ca/tran/works/enviroservices/enviroSaltMarsh.asp). The monitoring program is intended to document the changing habitat conditions following restoration; to evaluate the impacts of restored tidal flow; to indicate whether additional intervention was required; and to determine the ecological benefits of restoration (project success).

Annual monitoring during the first three years following restoration is critical because it is during these initial years following restoration that the greatest and most rapid changes are likely to occur. Monitoring of other tidal wetland restoration projects in the region have shown that although physical change can occur quite quickly and that the biological communities can be highly responsive, it can take many years (highly varied between sites) for conditions at restoration sites to approach those of reference sites (van Proosdij et al. 2010; Neatt et al. 2013). Monitoring beyond the first three years following restoration allows a greater period of time for change to occur, for the documentation of the longer term, often more gradual, changes in response to restoration and for conditions (e.g., vegetation species composition, marsh surface elevation, hybrid creek network) to develop and begin to show indications of parity with reference conditions (Able et al. 2008; Burden et al. 2013; Garbutt and Wolters 2008; Mitsch et al. 2012; Perry et al. 2001).

The monitoring program utilizes a suite of wetland indicators and data collection methods tailored to this project, and seeks to characterize a broader range of coastal wetland ecosystem components. These indicators (geospatial attributes, hydrology, soils and sediments, and vegetation) are measures of wetland structure and function, and when applied pre- and post-restoration, collectively provide information on ecosystem status and response to restoration. The physical and biological parameters within each of these indicator categories and the timeline and frequency for the monitoring activities are identified in Table 1.

An adaptive management approach is integrated into the monitoring framework. For instance, if an indicator(s) appears to be developing as expected, the frequency at which the indicator is monitored can be decreased. Alternatively, if an indicator(s) is not progressing as expected, additional studies may need to be undertaken and/or the sampling frequency altered to better understand and quantify change in the indicator(s). In this way, the monitoring program will contribute to the overall management of the restoration site by identifying when the project is, or is not, reaching the expected outcome.

Table 1 The TFH Tidal Wetland Restoration Monitoring Program, including core and additional ecological indicators, methodologies, and sampling frequency (X - completed sampling; Y – scheduled future sampling) (LT-R sampling schedule not included).

Category	Parameters	Sampling Method	Annual Sampling Frequency	Monitoring Year					
				Pre	Post-Restoration				
				Design & Baseline (2011)	Year 1 (2016)	Year 2	Year 3	Year 4	Year 5
Hydrology	Tidal signal	Automated water level recorders (5 minute intervals)	Minimum 29 day period during sampling year 11/8/16-13/10/16	X	X				X
Soils & Sediments	Marsh surface elevation	Digital Elevation Model (DEM); G8 GNSS RTK surveying unit (or equivalent)	Once per required sampling year. 11/8/16	X	X		X		X
	Sediment accretion	Sediment pins; Marker Horizons**	Annually 13/10/16	X	X		X		X
	Sediment characteristics***	(bulk density, organic matter content, sediment type, water content)	Once per required sampling year 13/10/16	X	X				X
Vegetation	Composition Abundance Height	Transect based, Point Intercept Method (1 m^2 plots)	Once per sampling year 8/8/16	X	X				X
	Habitat map	Aerial photograph, DGPS/GIS, Low-altitude aerial photography	Low-altitude; Once per sampling year 22/9/16	X	X		X		X
Evaluation of Restoration Progress	Visual Assessment of habitat condition, restoration recovery rate, wildlife usage, etc.	Structured summer walks & photo-documentation	Once per sampling year		X	X	X	X	X

Category	Parameters	Sampling Method	Annual Sampling Frequency	Monitoring Year					
				Pre	Post-Restoration				
				Design & Baseline (2011)	Year 1 (2016)	Year 2	Year 3	Year 4	Year 5
Winter Conditions	Visual assessment of ice/snow, habitat conditions	Structured winter walk; photo-documentation	Once per sampling year 4/2/17		X	X	X	X	X

3.0 Methods

Sampling was conducted using a series of permanent transects and sampling stations that were established in a non-biased, systematic sampling design as part of the baseline monitoring activities in 2011 (Bowron et al. 2012a). Six transects were established, 50 m apart (as measured along the upland edge of the north-west side), running roughly perpendicular to the Three Fathom Harbour Road and marked along the upland edge with semi-permanent wooden stakes (Figure 10). Data collection was conducted at sampling stations established at equal intervals (20 m) along each transect. A Trimble R8 GNSS RTK (Real Time Kinematic) Differential Global Positioning System[3] (DGPS) was employed to relocated the transects and sampling stations.

3.1 Geospatial Attributes

Geospatial attributes are important in understanding the form and function of the salt marsh and serve as the basis for many other analysis. Geospatial data are monitored using 4 primary data sources: aerial photography, Digital Surface Models (DSM), Digital Elevation Models (DEM), and habitat maps. These products (excluding DSM) were developed as part of the baseline monitoring activities in 2011 and updated using the 2016 one year post-restoration monitoring data collection. Collectively they provide a foundation for the monitoring activities and a baseline against which changes in habitat conditions post-construction can be compared.

Aerial Photography and Digital Surface Model (DSM)

Georeferenced low-altitude aerial photography was collected for TFH on 22 September 2016 using the CBWES-Saint Mary’s University (SMU) DJI Phantom 3[4] drone and camera system. Orthophoto mosaics were generated using PIX- 4d software and used as base imagery throughout all mapping tasks (e.g., habitat mapping, DEM analysis; geomorphic and anthropogenic feature identification). A DSM was generated concurrently with mosaics using standard structure from motion algorithms. The use of ground control points (GCP) surveyed with RTK GPS ensured the horizontal and vertical accuracy of both the orthophoto and DSM. It is important to note the DSM captures the top of the vegetation canopy and bare ground only where it is visible. While a DEM (described below) is a bare-earth model and is critical to understanding hydrological conditions, a surface model can provide additional information such as vegetation height and can be very useful in modeling elevation for inaccessible areas or those not easily surveyed (i.e., unconsolidated sediments within the central pond).

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[3] www.trimble.com/index.aspx

[4] http://www.dji.com/product/phantom-3-pro

Digital Elevation Model (DEM)

The baseline DEM for TFH was developed utilizing the elevation survey data collected in 2011 using the Trimble RTK GPS receiver. The ArcGIS command TOPOGRID, which interpolates a model of the marsh surface as a raster grid, was used to create the DEM. The inputs for this command are the surveyed points, as well as contours, from the 1:10,000 NS Topographic Database in the upland areas. The interpolation, a discretised thin plate spline technique, predicts the values for elevation between surveyed points and contour lines while allowing for abrupt changes in topographic slope. The 2011 DEM provided crucial information required for the hydrology modeling conducted as part of the feasibility and design phase of the project (i.e., flood modeling; Figure 11) (Bowron et al. 2011a; Section 3.2). When combined with the hydrological data, the DEM was used to determine the potential restoration area for the site.

To update the DEM for 2016, an elevation survey was conducted on 11 August (mean horizontal and vertical accuracy was reported as 0.012 m +/- 0.002 m and 0.017 m +/- 0.003 m respectively). The one year post-restoration DEM was generated using the elevation survey data and the DSM previously described. As discussed, the DSM captures the top of visible objects. At TFH this included bare earth in the former central pond, thick grass and sedge communities along the border of the former pond, and dense shrub communities. The DSM was up-sampled to 1 m resolution, smoothing the surface, and compared to surveyed points. The mean separation (representative of canopy height) was 0.46 m +/- 0.39 m, and ranged from -0.1 to 2.77 m. A TIN surface was created using the known elevation differences between survey points and contours generated from the DSM to preserve community structure and topographic continuity. This surface was subtracted from the DSM, essentially removing the canopy and creating a bare earth DEM. When the final surface was compared to the survey data, 92% of the points were within maximum possible error of the survey equipment (0.15 m), with a minimum error of 0 cm and maximum error of 40 cm. The lowest errors were found in the central pond and open bog areas, while the greatest deviations occurred in the high shrub zones. Although deviations between surveyed transects were not ground-truthed, vegetation communities were observed to have mostly homogenous canopy heights on site.

Habitat Map

Habitat maps (also known as surface cover maps) document vegetation community structure and other important habitat features at the landscape scale (e.g., channels, culverts, beaver damns). Baseline habitat maps were created for the site as part of the baseline monitoring program (2011) and updated in 2016 using vegetation survey plot data, RTK survey data and low-altitude aerial photography. Habitat community classes were identified by using vegetation analysis results to first identify larger community types (i.e., high marsh, low marsh, bog, etc.), and then using plot-level data (training points) to digitize surface cover classes from low-altitude imagery. For 2016 a model of vegetation height was created to aid in surface cover class delineation by subtracting the DEM from the DSM.

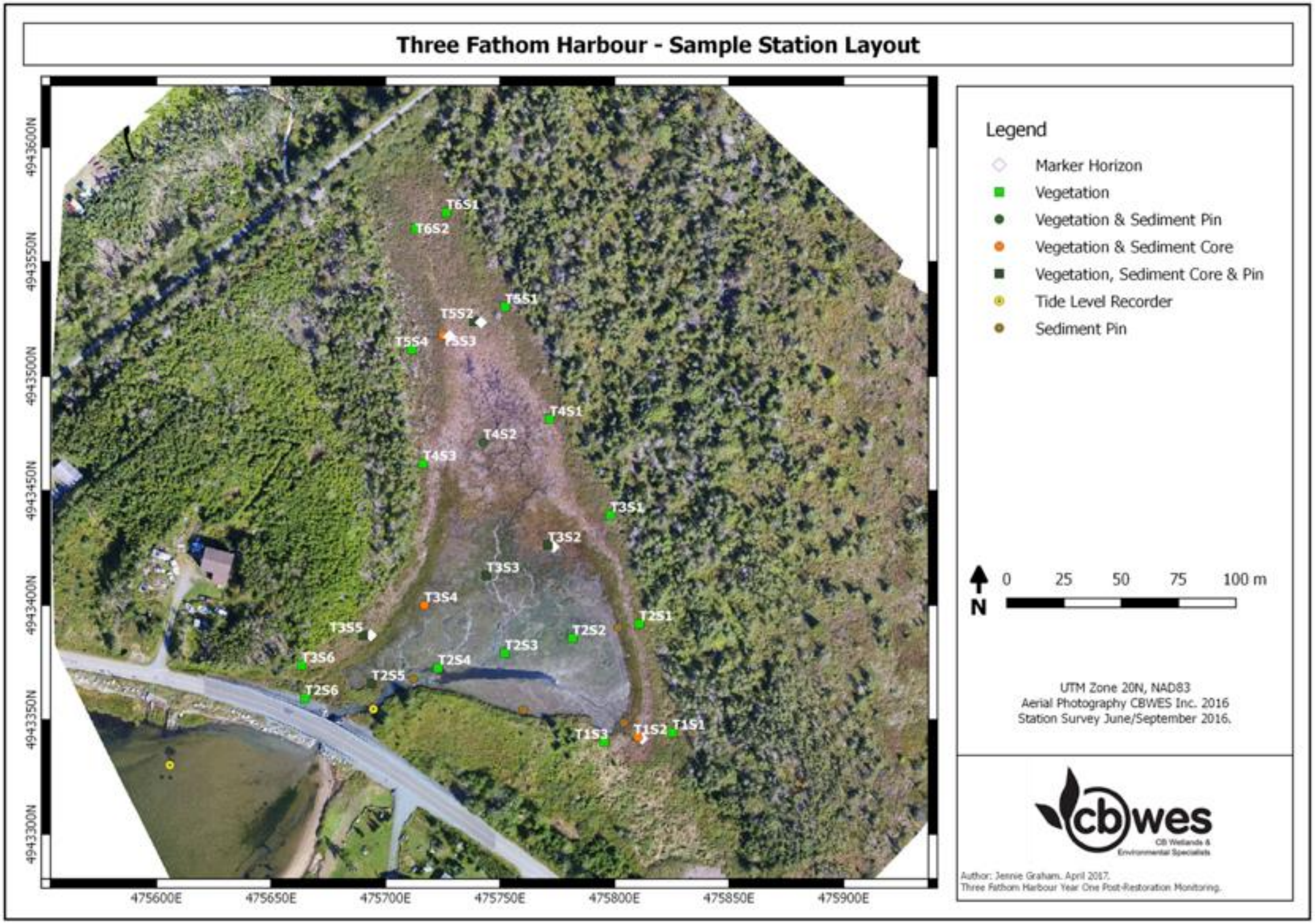

Figure 10 Sampling layout map for TFH depicting main marsh features, transects, and sampling locations.

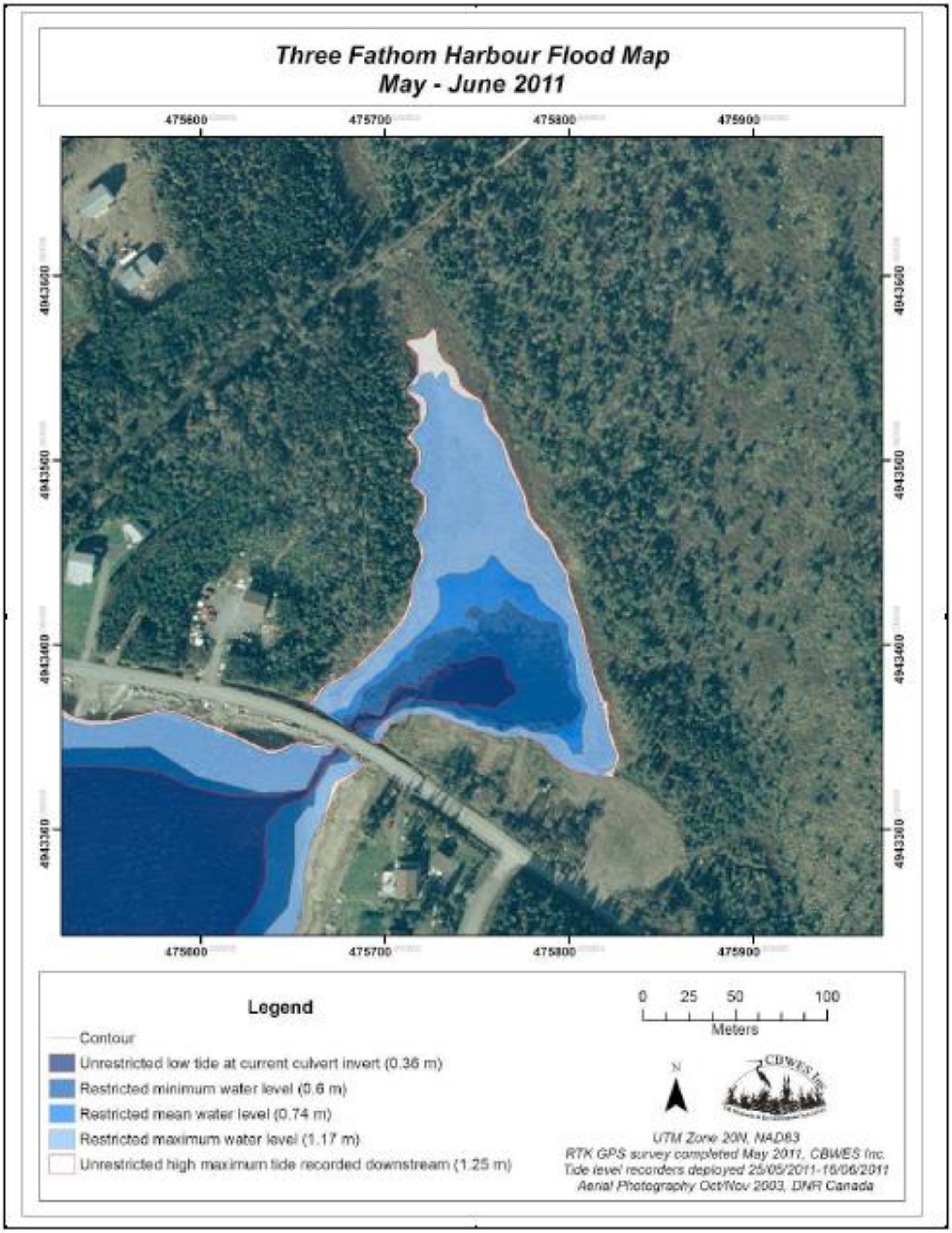

Figure 11 Flood map for TFH showing unrestricted flooding under low and high tide conditions and the restricted levels (min, mean, max) inside the site during the period 25 May to 16 June 2011.

3.2 Hydrology

The fundamental control on the structure and function of tidal wetland habitat is flooding with salt water (Mitsch and Gosselink 1986; Neckles and Dionne 2000). It is the hydroperiod (frequency and duration of tidal flooding) of a wetland that determines the area of marsh directly available as fish habitat. The hydroperiod is determined by the tidal signal (pattern of water level change with respect to a reference point) and marsh surface elevation.

Hydroperiod and Tidal Signal

The hydroperiod (frequency and duration of tidal flooding) of the restoration site following restoration was modeled using the tidal signal (pattern of water level change with respect to a reference point) and the marsh surface elevation (DEM). The tidal signal was measured in 2011 (pre-restoration) and in 2016 (Year 1 post-restoration) using a pair of Solinst Levelogger Gold (Model 3001[5]) automated water level recorders (water elevation and temperature at five-minute intervals) and a Solinst Barologger (atmospheric pressure and temperature). The tide level recorders were deployed (in still wells; Figure 12) for the period of 11 August to 13 October 2016. To capture a full range of tidal conditions at the site, one recorder was placed in the main tidal channel within the restoration site and the second was placed downstream of the site within the harbour (Figure 10).

The Barologger, which collects atmospheric pressure and temperature data required for post-processing of the Levelogger data, was installed in the upland above the restoration site (Figure 10). The positions of each of the units were surveyed using the GPS RTK. Upon retrieval, the data from the loggers were downloaded into the Solinst Software Version 3[6] for post-processing and analysis.

Using the tidal elevation information from the Leveloggers, a set of tide signal graphs were created in Microsoft Excel by creating line graphs, placing the date and time on the x-axis and tide height on the y-axis. The hypsometric curve for TFH was created using the hypsomtery extension in QGIS. The extension calculates the area of marsh flooded at a given tide height using a DEM provided by the user. In this case increments of 10 cm were used and a scatter plot was created in Excel with area on the x-axis and tide height on the y-axis.

Figure 12 Solinst Model 3001 Levelogger Gold and still well. Photographs by N. Neatt, 2008.

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[5] www.solinst.com/Prod/3001/3001d2.html
[6] www.solinst.com/Downloads/

3.3 Soils and Sediments

Monitoring marsh surface elevation, sediment accretion rates, and soil characteristics can provide insight into the processes controlling vegetation type, cover and productivity and the vertical growth of marsh following restoration (Neckles and Dionne 2000). Monitoring soil and sediment conditions before and after restoration can reveal insights regarding pre-restoration conditions of the marsh (subsidence due to oxidation of organic matter in sediments) and the process of recovery following restoration.

Accretion of inorganic and organic material deposited onto the marsh surface by flood waters and vegetation is one of the main processes that allow marshes to build vertically over time, offsetting increased tidal flooding resulting from restoration activities and/or sea level rise. Failure to keep pace with increased flooding could result in the loss of tidal wetland features and functions (i.e., loss of productivity and extent of habitat). Monitoring sediment accretion rates and elevation prior to engaging in restoration activities can provide an understanding of pre-restoration conditions on the marsh and the process of recovery following restoration. The GPAC Protocol recommends the use of Rod Surface Elevation Tables (RSET) and Marker Horizons (MH) (mm resolution) in combination to monitor/explain processes behind marsh elevation increases or decreases (i.e., sedimentation, subsidence) (Neckles et al. 2002). These methods have been used on a number of tidal wetland restoration projects in the region and have provided valuable information on the response of the systems to restoration activities. Other sediment monitoring methods (i.e., RTK, sediment pins) provide information on sediment gain or loss (change in elevation) (cm resolution), but not actual sedimentation rates or changes in below ground biomass.

Marsh soil characteristics are determined by the sediment source and tidal current patterns (Mitsch and Gosselink 1986). As tidal waters flow over the marsh surface, increasing elevation and vegetation slows the water allowing coarse-grained sediment to drop out of suspension close to the main channel edge while finer sediments drop further inland (Redfield 1972; Mitsch and Gosselink 1986). Sediment type and particle size greatly influences soil aeration and drainage (Packham and Willis 1997). Silt, clay and sand are the different soil textures typical of salt marshes. Silt and clay materials tend to retain more salt than sand, and clay is the most absorptive (Mitsch and Gosselink 1986). Clay and silt are expected to dominate high marsh soils, while the low marsh is expected to have a higher proportion of sand (Packham and Willis 1997), however, this will vary depending on the source material.

Sediment Accretion and Elevation

For larger salt marshes and marshes more directly exposed to tidal influence (i.e., Cheverie Creek, Walton River, St. Croix River, Cogmagun River), changes in marsh surface elevation and sediment accretion were monitored using a combination of DGPS survey (DEM), Rod Surface Elevation Tables (RSET) and marker horizons. Given the small size of TFH and its location within the Three Fathom Harbour system, it was originally decided that only elevation surveys and marker horizons (accretion) would be used (Figure 15). As part of the post-restoration monitoring program, eleven Sediment Pins[7] were installed at TFH on 13 October 2016. Sediment pins were matched with a subset of vegetation sampling stations as well as several discrete locations within the restoration site (Figure 10; Figure 13). Sediment pins were measured at the

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[7] http://www.tidalmarshmonitoring.org/monitoring-methods-sediment-pins.php

time of installation, surveyed with RTK unit on 5 December 2016, and will be measured once per sampling year at low tide during the neap tide cycle to minimize the influence of evapotranspiration (Paquette et al. 2004). Sediment accumulation (deposition) or loss (erosion) is determined by measuring the distance from the top of the sediment pin to the surface of the sediment with a meter stick (4 measurements per pin) and comparing to the previous year’s measurement. This is the third tidal wetland restoration project in NS, and the first on the Atlantic coast, to use sediment pins as part of the monitoring program. It remains to be seen how robust the sediment pins themselves will be in the region given the tide and winter conditions, or how the resulting data will compare to that of previously utilized methods (i.e., RSETs and marker horizons).

One immediate shortcoming of the sediment pin methodology was the inability to install a number of the pins to the desired 1.5 m depth due to the shallow nature of the marsh soils and the underlying geology of the site. Unlike tidal marshes in the Bay of Fundy in which wetland soils can be in greater than 10 m in depth, the underlying rock throughout much of the TFH site was around 0.5 m below the surface. It was noted during the structured winter walk in February that two of the pins had already been compromised (pins T1S2 and T2S2) (Figure 14).

Eight marker horizons were established at points throughout TFH that represent the different potential habitat zones (low, mid, high marsh) (Figure 15). The marker horizons were established according to the methods developed by Cahoon and Lynch (USGS 2005). Marker horizons were installed at TFH in October 2011. The marker horizons were measured approximately 15 months (13 October 2016) after tidal exchange was restored, using a cryogenic corer (Figure 16) and methods as described by Cahoon et al. (1996) on 13 October 2016. These were compared to the rates of accretion observed at LT(R). Seven markers were installed at LT and six markers at LTR. The markers at LT(R) were originally installed in November 2006 and measured annually for 5 years (2007-2012).

Of the 8 marker horizons established at TFH, only 5 could be re-located in 2016. The three stations that were ‘lost’ (T2S5, T3S3 and T3S4) were all located within the zone of greatest change in hydrodynamic conditions and increased frequency of flooding (Figure 10). A similar loss of stations closest to the ocean boundary was also observed at the Lawrencetown sites (Bowron et al. 2013b).

Figure 13 Example of a sediment pin installed at the Mavillette Tidal Wetland Restoration site (left image) in 2015, and two sediment pins installed along TFH's transect 2 (right image). Photographs by T. Bowron.

Figure 14 Sediment pin T1S2 compromised by winter conditions. Photograph by CBWES February 2017.

Figure 15 Example of a feldspar clay marker horizon. This is one of the markers established in 2005 at the Walton River Salt Marsh Restoration site. Photograph by T. Bowron, 2005.

Figure 16 Marker horizon sampling with the cryogenic corer at LT-R. Photograph taken by B. Lemieux, December 2011.

Soil Characteristics

Field Methods

Sediment samples (bulk density, organic matter (OM) and grain size) were collected on 13 October 2016 using a stratified random sampling procedure paired with a subset of vegetation sampling plots. Sediment sampling was conducted at eight locations at TFH (Figure 10). At each sampling station two sediment samples (cores) were taken. A small (30 ml) sample was taken using a 60 ml plastic syringe (1” diameter) and a larger sample taken with a metal tube (4” long and 1½ ” diameter). Samples were taken by pressing the syringe into the soil to the 30 ml depth and removed by cutting around the syringe with a knife and lifting out with a metal trowel. The metal tubes were pressed into the ground until the top of the tube was level with the marsh surface and removed using a knife and trowel.

The syringes were placed individually into Ziploc bags, sealed, labeled and transported in a cooler with ice back to the lab where they were placed in a freezer and kept frozen until processing. Some soil compaction did occur during the coring process, but every attempt was made to avoid further compaction of the samples during transport and storage prior to freezing. The metal tubes were capped on both ends using plastic caps and labeled directly. Some compaction did occur during the sampling process but no further compaction/disruption should have occurred prior to the samples freezing. All cores were carefully labeled and sealed using duct tape.

Laboratory Methods

Cores were processed at the In_CoaST research lab (SMU) for bulk density, water and organic matter content and grain size. Cores were analysed using a Coulter Multisizer 3^{tm} which is based on electrical resistance and is more accurate for the analysis of fine sediments (McCave et al. 2006). Grain size statistics were derived using Gradistat (Blott and Pye 2001; Figure 17).

Sample preparation and documentation:

The sediment cores were thawed before being extruded from their containers. The samples were photographed and split open to see the color, texture and composition of the core for a qualitative description. The top two 2 cm of each half were set aside for loss on ignition and Coulter multisizer grain size analysis.

Bulk density:

The soil samples were thawed and removed from the syringes. A known volume of sediment was placed in a crucible (known weight) and the weight was recorded. The samples were then oven-dried at 105 ˚C for sixteen hours. The weight of the oven dried sample and the crucible were then recorded again. From this, bulk density was calculated using the following equation:

$$\text{Bulk density (g/ml)} = \text{net dry weight (g)} / \text{volume (ml)}$$

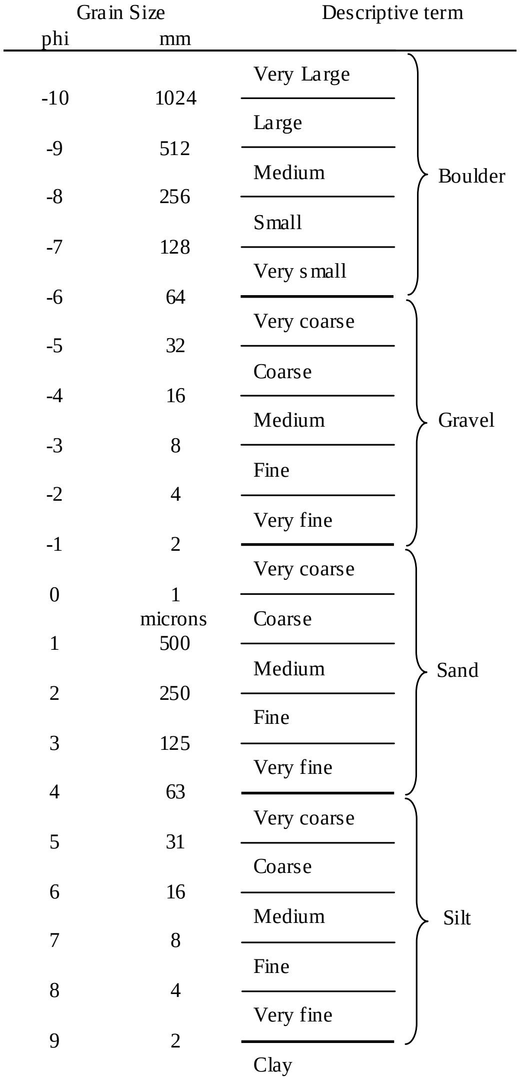
Organic content (using a loss-on-ignition technique):

The sediment cores were thawed and removed from the tubes and the top 2 cm of the core was removed, weighed and placed in a crucible for drying at 105 ˚C for twenty-four hours to determine water content. Once dried, each sample was weighed and placed in a muffle furnace for two hours at 550 ˚C. Samples were then cooled and weighed again to get loss on ignition (LOI) of organic material.

Sediment Type:

Sediment size (using laser diffraction):

Following the LOI process, each core sample was placed in water and gently manipulated to suspend all particles before being placed in the Coulter LS200 chamber. The particles were sonicated for four minutes at the start of three sixty-second runs. The average run data from the three run files were used to determine the statistical results. The grain size distributions were analyzed using the GRADISTAT program and size classes determined using a modified Udden-Wentworth scale (Blott and Pye 2001).



Grain Size phi	Grain Size mm	Descriptive term	
		Very Large	Boulder
-10	1024		
		Large	
-9	512		
		Medium	
-8	256		
		Small	
-7	128		
		Very small	
-6	64		
		Very coarse	Gravel
-5	32		
		Coarse	
-4	16		
		Medium	
-3	8		
		Fine	
-2	4		
		Very fine	
-1	2		
		Very coarse	Sand
0	1 microns		
		Coarse	
1	500		
		Medium	
2	250		
		Fine	
3	125		
		Very fine	
4	63		
		Very coarse	Silt
5	31		
		Coarse	
6	16		
		Medium	
7	8		
		Fine	
8	4		
		Very fine	
9	2		
		Clay	

Figure 17 Size scale adopted in the GRADISTAT program, modified from Udden (1914) and Wentworth (1922) (Blot and Pye 2001).

3.4 Vegetation

The primary food source in estuaries originates in the vegetation of salt marshes. The majority of this plant material is consumed indirectly as detritus (dead plant material) by decomposers and invertebrate consumers. It is through the production and export of detritus that salt marshes help to sustain commercial and non-commercial fish species by forming the base of coastal food webs. Salt marshes are characterized by their plant communities, with specific plants dominating the different salt marsh zones (high marsh, mid marsh, low marsh). It is the plants of a salt marsh, along with the physical conditions (hydrology, geology and chemical) that create the template for a self-sustaining coastal wetland system and which enable the biological components of the broader ecosystem (invertebrates, fish, birds and animals) to benefit from these habitats.

Field Methods

The marsh vegetation community was surveyed at TFH on 8 August 2016, using a modified point intercept method (Roman et al. 2002). The point intercept method utilizes permanent 1 m^2 plots positioned at intervals along each transect. The twenty-four plots were originally established at TFH as part of the baseline survey in 2011. Landscape photographs were taken along each transect, as well as close-up photographs of each plot.

Each 1 m^2 plot (quadrat) used was offset 1 m to the left of the transect (facing main tidal channel) and oriented towards the upland end of the transect. The quadrat was divided into a grid of 25 squares (20 cm x 20 cm) and the resulting twenty-five intercept points were used as sampling points. All plant species present in the quadrat were recorded and then a wooden dowel (3 mm in diameter) was held vertical to the first sampling point and lowered through the vegetation to the ground below. Any species that touched the rod (a “hit”) were recorded and this was repeated for all twenty-five intercept points. Other categories, such as water, bare ground, rock or debris, were also recorded if hit by the dowel.

Statistical Analysis

Plant species richness, halophytic species and abundance, and unvegetated area in 1 m^2 plots were compared between the study (TFH) and reference condition site using ANOVA. Halophytic species abundance was estimated as the total number of contact points by halophytic species per plot. Because the total number of hits was counted, this can result in a halophytic abundance of greater than 25 (the number of points sampled in each quadrat) when more than one halophytic species were present in the plot.

The species encountered at these sites that were classified as halophytes were: *Atriplex glabrisculata*, *Carex paleacea*, *Juncus gerardii*, *Limonium nashii*, *Potentilla anserina*, *Ruppia maritima*, *Salicornia europea*, *Spartina alterniflora*, *S. patens*, *S. pectinata*, and *Triglochin maritima*. Non-metric multidimensional scaling ordination was used to compare species composition and abundance between plots. Differences in overall vegetation composition and species abundance were assessed using non-parametric multivariate ANOVA.

3.5 Fish and Aquatic Invertebrates

Salt marshes support a wide range and abundance of organisms that swim collectively referred to as nekton, which include fish and many types of invertebrates. Fish and macrocrustaceans are an important ecological link between the primary producers of the marsh (plants) and near shore fisheries (Neckles and Dionne 2000). Their position in the upper levels of the coastal food webs and their dependence on a wide range of food and habitat resources serve to integrate ecosystem elements, processes and productivity (Kwak and Zedler 1997). Fish are a challenging group to quantify due to their mobility and temporal variability, as well as the difficulties of sampling in, what can be, a heavily vegetated environment with a varied hydrological regime.

Aquatic invertebrates, in association with benthic microbial communities, are largely responsible for providing the food resources that help fuel coastal and offshore marine ecosystems. In addition to directly being fish food, these organisms perform the important task of converting the rich productivity of salt marsh vegetation into a form (detritus) that is more palatable to other species such as fish. Benthic marine invertebrates and various freshwater and saltwater invertebrates such as insect larvae are well-known indicators of changes in hydrology, chemical characteristics and productivity (see the Canadian Aquatic Biomonitoring Network (CABIN) program website for more information on the use of aquatic invertebrates to monitor the health of aquatic ecosystems - www.ec.gc.ca/rcba-cabin/).

Fish and aquatic invertebrates were sampled as part of the baseline study (Bowron et al. 2012a) but were not sampled during the 2016 monitoring season. As conditions at the site recover, sampling of these parameters maybe revisited as part of the Year 3 and/or Year 5 monitoring activities.

3.6 Structured Winter Walk

On 3 February 2017, a structured winter site-walk was conducted at TFH. Landscape photographs were taken along each transect from the forested upland edge at TFH. Photographs were also taken of key features such as the crossing structure, former pond, seaweed deposits, downstream side of highway, ice, areas of erosion or deposition and other features of interest.

4.0 Results and Discussion

4.1 Geospatial Attributes

Habitat mapping and analysis of the DEM was carried out from the edge of the road to the upland edge, as delineated by the tree line. This encompassed the maximum extent of wetland vegetation including the freshwater bog which borders the main tidal portion of the wetland. Although the freshwater bog is not anticipated to transition to saltwater habitat at this time, it is a key part of the wetland complex and also represents the accommodation space of the tidal system (i.e., tidal wetland conditions will migrate into this space in response to sea level rise over the next century). The baseline and first year post-restoration survey and DEM statistics are shown in Table 2. Both the DEM and survey statistics show an increase in the mean elevation of 5 and 22 cm respectively. This increase could be the result of increased sedimentation within the site, however, the marker horizon data does not support elevation change being driven by sedimentation alone (section 4.3). A combination of sediment deposition and the expansion of the root zone due to waterlogged peat layer could explain the observed increase in elevation. In addition, some of the difference could be an artifact of the elevation survey itself, the improved conditions at the site and the inclusion of the DSM derived from the low-altitude aerial photography. In 2011, securing elevation data within the pond was challenging due to the highly unconsolidated sediment/bottom and the difficulty in clearly identifying the sediment surface. Whereas in 2016, there was a clearly defined sediment surface and the incorporation of the DSM, which required no disturbance of those sediments, improved accuracy throughout much of the site considerably.

DEM and DSM statistics are shown in Table 2. The 2016 DEM maximum elevation is considerably higher than the 2011 maximum, which is likely a result of changes to processing techniques rather than an actual real world change. Minimum elevations for both survey and DEM are within 10 cm of each other for 2011 and 2016, indicating little change in the total elevation range of the site (i.e., channel outlet elevations have remained stable). The 2016 DEM, DSM and survey elevation points are shown in Figure 18. When compared to the 2011 DEM, the 2016 DSM retains a great deal of information regarding the finer details of the exposed wetland surfaces, especially the mudflat and open bog wetland (Figure 18). However, it overestimates elevations in the shrub dominated bog habitat areas due to a less homogenous canopy which increases the probability of relicts in the DEM.

Comparisons between surveyed transects show an increase in elevation from the 2011 surface (Figure 19). This increase was most prominent on transect 2, which passes through the central mudflat/former pond. The increase in elevation decreases as you move toward the upstream end of the system (i.e., transect 4). This is in line with the expected spatial distribution of increased sedimentation due to tidal flooding (i.e., sedimentation decreases with distance from the tidal crossing) and the effect of tidal waters on subsurface peat layers.

Table 2 DEM and Survey statistics for TFH (m, CGVD28).

Year	Statistic	Survey	DSM	DEM
2016	*Mean elevation*	1.16	1.42	1.12
	Standard deviation	0.55	0.69	0.41
	Max elevation	3.49	10.42	8.99
	Min elevation	-0.4	0.38	0.23
2011	*Mean elevation*	0.94	--	1.08
	Standard deviation	0.50	--	0.77
	Max elevation	2.51	--	5.05
	Min elevation	0.04	--	0.12

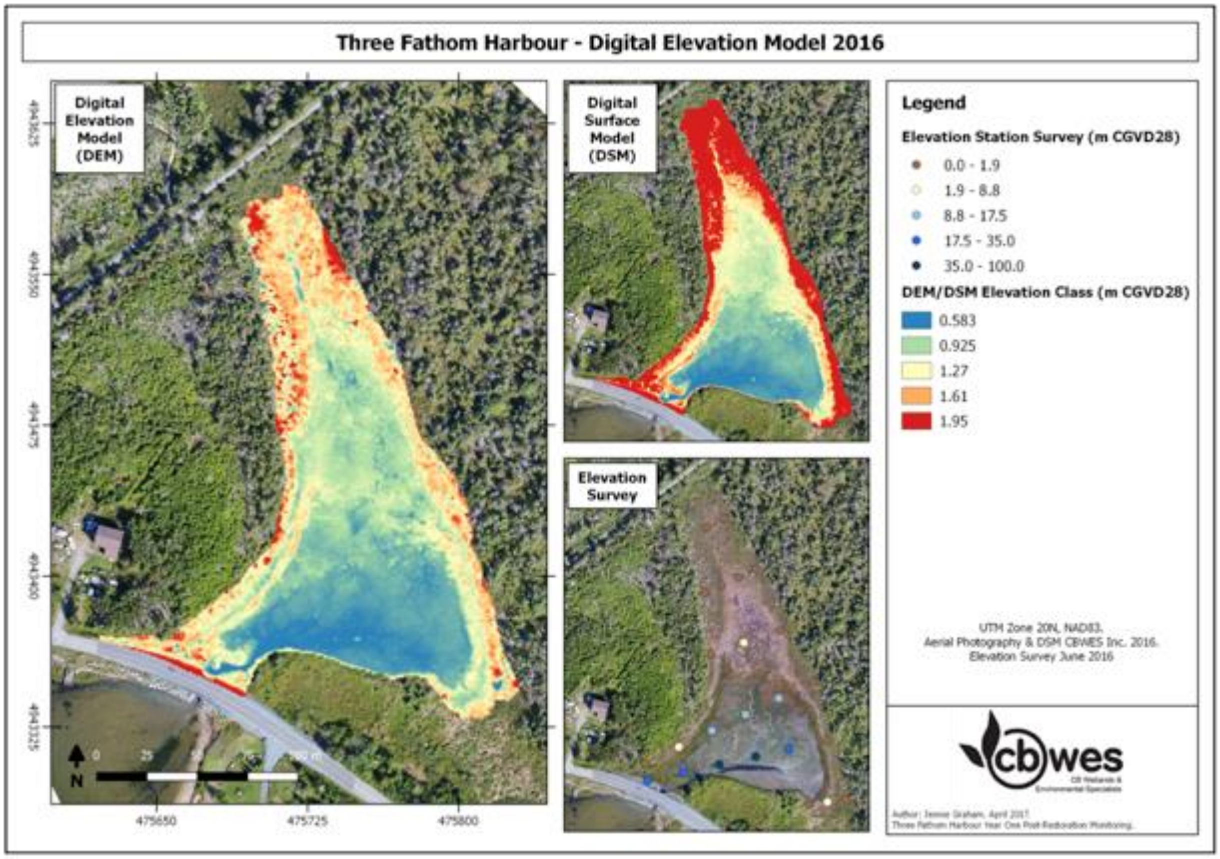


Figure 18 DEM, DSM and elevation survey points and class for TFH.

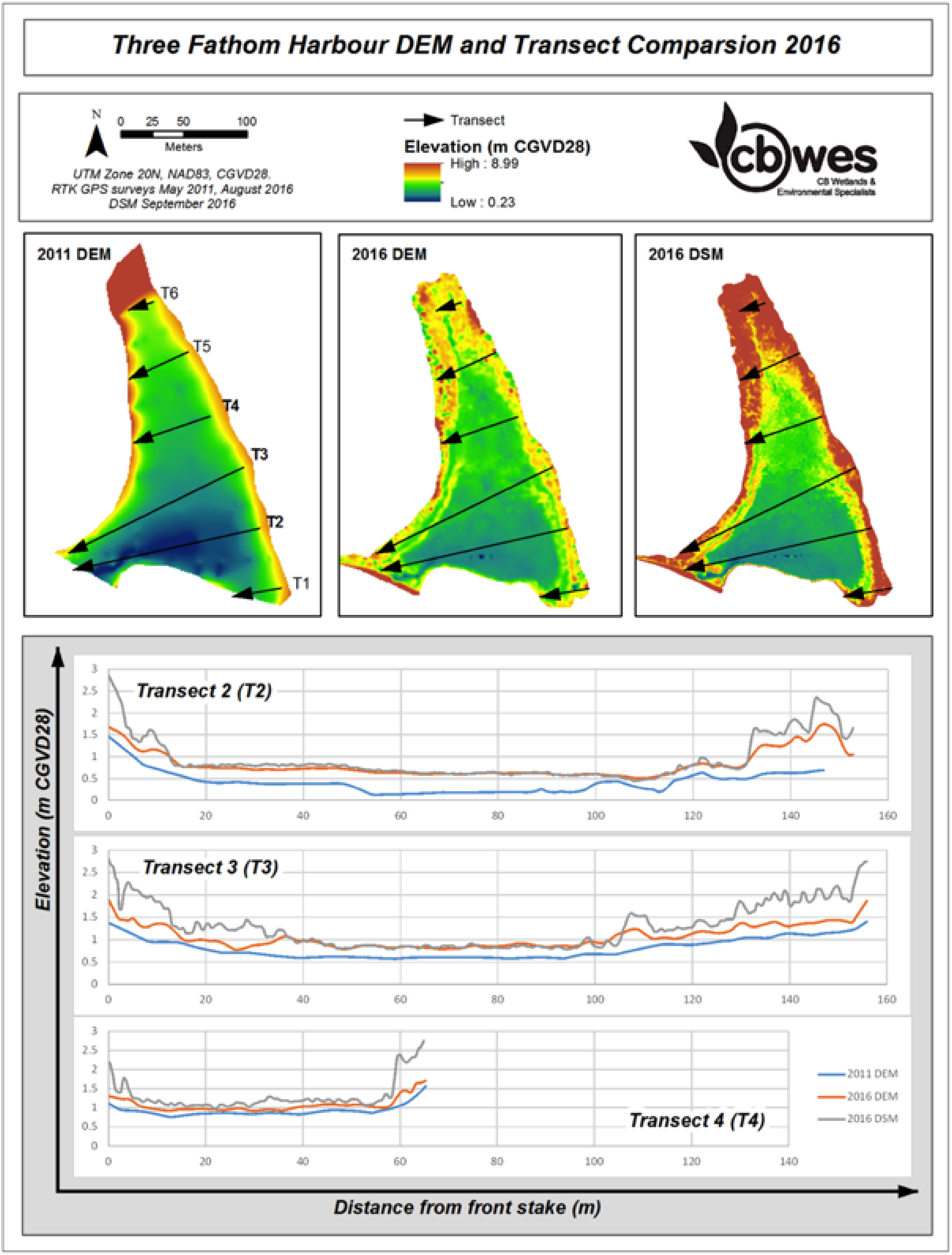


Figure 19 Elevation profiles along sampling transects.

Habitat mapping shows that the site is still very much in transition (Figure 20, Figure 21). Halophytic vegetation has established immediately upstream of the crossing and is showing evidence of expansion. The central ‘pond’ now floods and drains with the tide, and the resulting mudflat-like habitat is in the early stages of consolidation and is developing a distinct channel network. An area of dead vegetation previously dominated by freshwater sedges (die-off zone) now borders the unvegetated mudflat which corresponds closely to the extent of regular tidal flooding. The channel network that is developing as a series of runnels and small channels connecting to a central tidal channel extending into the site from the crossing, is similar to the process observed at other restoration sites in province (i.e., St. Croix, Cogmagun, Walton) in the first few years following restoration as the site dewaters (Figure 20) (Bowron et al. 2015b; Bowron et al. 2015b; Neatt et al. 2013). The border of the central pond, now mudflat, as well as the die-off zone, is being colonized by a mix of hardy brackish sedges, rushes and grasses (upper areas) and salt marsh species in the lower reaches. This mix of salt and brackish species is the same as those found at the nearby Lawrencetown reference site (Bowron et al. 2013b). Portions of the vegetation community within the bog zone appeared to be in very poor condition (i.e., large patches of dead or dying sphagnum), especially during the latter part of the summer. Given the extremely dry conditions that were experienced throughout the province during the monitoring period, it is difficult to determine whether this was the result of the restoration activity, the drought conditions or a combination of the two. Continued monitoring over the next one to two years will show whether the sphagnum recovers indicating that it was the drought, or continues to decline and transition to brackish communities (restoration).

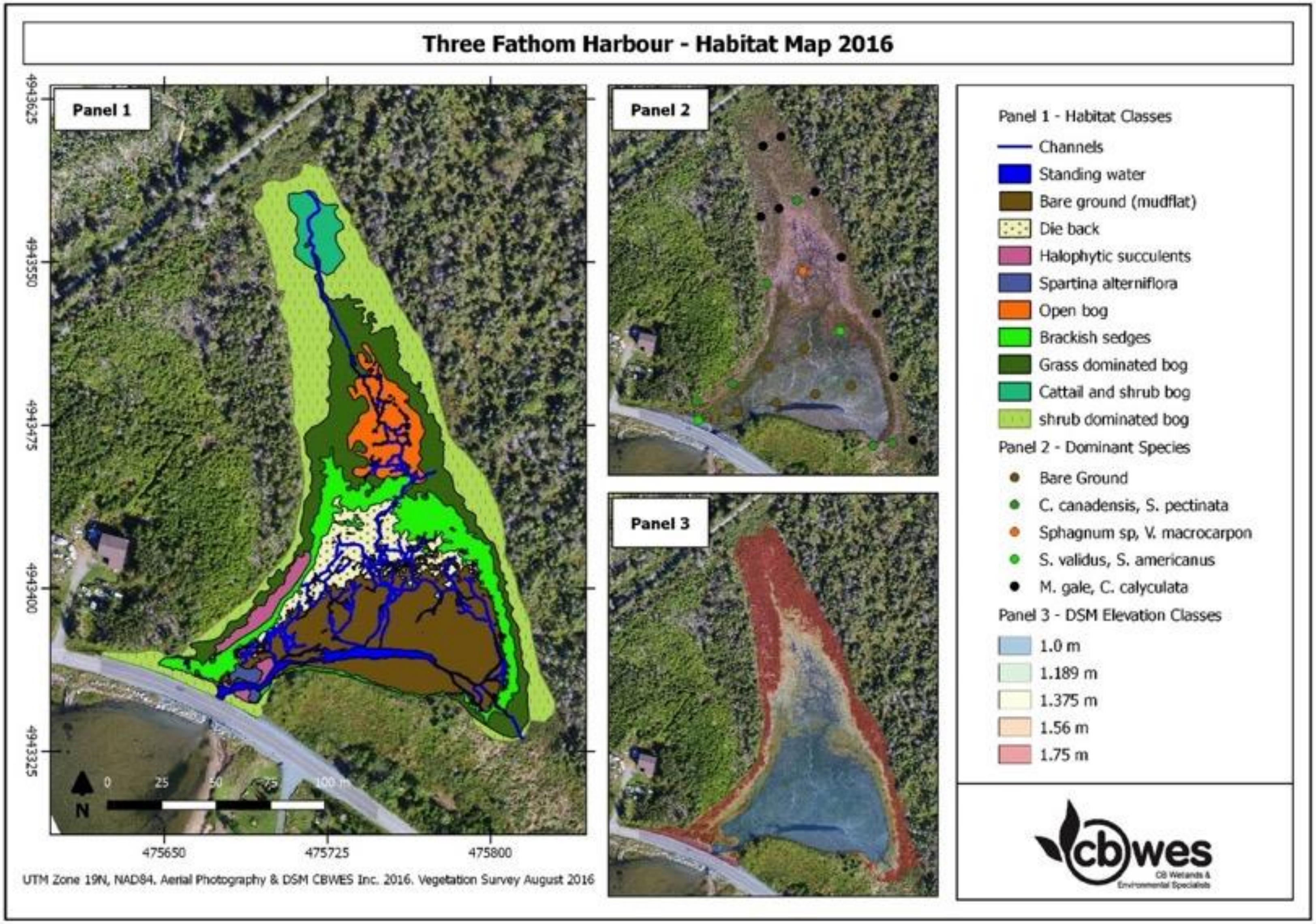
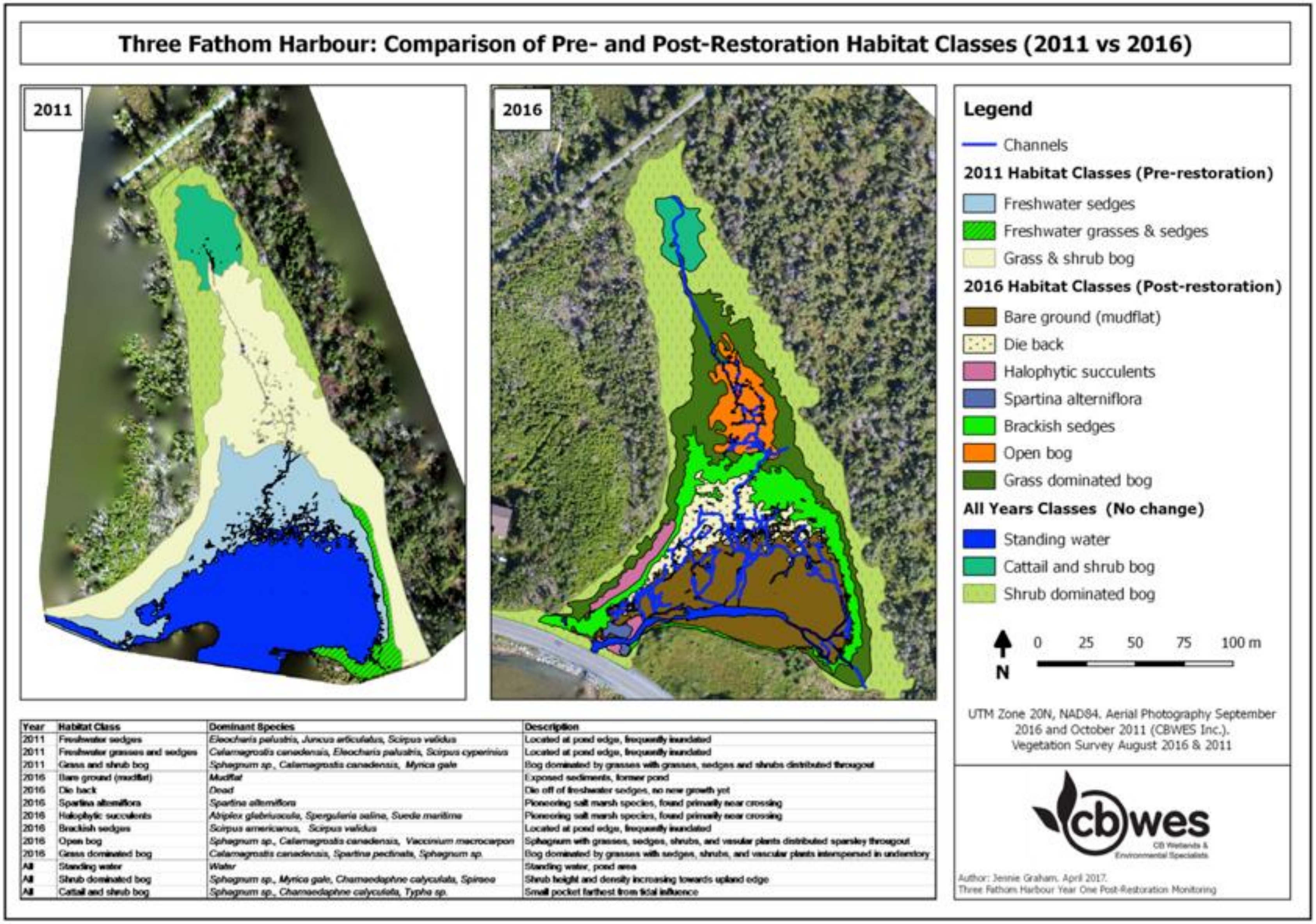


Figure 20 Habitat map for TFH one year post-restoration, showing habitat classes, dominant vegetation species, and elevation classes.



Year	Habitat Class	Dominant Species	Description
2011	Freshwater sedges	*Eleocharis palustris, Juncus articulatus, Scirpus validus*	Located at pond edge, frequently inundated
2011	Freshwater grasses and sedges	*Calamagrostis canadensis, Eleocharis palustris, Scirpus cyperinius*	Located at pond edge, frequently inundated
2011	Grass and shrub bog	*Sphagnum sp., Calamagrostis canadensis, Myrica gale*	Bog dominated by grasses with grasses, sedges and shrubs distributed throgout
2016	Bare ground (mudflat)	*Mudflat*	Exposed sediments, former pond
2016	Die back	*Dead*	Die off of freshwater sedges, no new growth yet
2016	Spartina alterniflora	*Spartina alterniflora*	Pioneering salt marsh species, found primarily near crossing
2016	Halophytic succulents	*Atriplex glabriuscula, Spergularia salina, Suede maritima*	Pioneering salt marsh species, found primarily near crossing
2016	Brackish sedges	*Scirpus americanus, Scirpus validus*	Located at pond edge, frequently inundated
2016	Open bog	*Sphagnum sp., Calamagrostis canadensis, Vaccinium macrocarpon*	Sphagnum with grasses, sedges, shrubs, and vasular plants distributed sparsley througout
2016	Grass dominated bog	*Calamagrostis canadensis, Spartina pectinata, Sphagnum sp.*	Bog dominated by grasses with sedges, shrubs, and vascular plants interspersed in understory
All	Standing water	*Water*	Standing water, pond area
All	Shrub dominated bog	*Sphagnum sp., Myrica gale, Chamaedaphne calyculata, Spiraea*	Shrub height and density increasing towards upland edge
All	Cattail and shrub bog	*Sphagnum sp., Chamaedaphne calyculata, Typha sp.*	Small pocket farthest from tidal influence

Figure 21: Comparison of habitat map for TFH pre-restoration (2011) and one year post-restoration (2016).

4.2 Hydrology

Hydroperiod and Tidal Signal

Tide level recorders were deployed for nine weeks and the observed tide signals are shown in Figure 22. Although peak tide (highest water level) did not always occur at the same time up and downstream, the mean difference in timing was less than five minutes and can be attributed in most cases to weather conditions such as strong onshore or offshore winds rather than a negative impact of the highway crossing. Important tide levels and flooded areas are shown in Table 3, and an updated flood map for the site is shown in Figure 23. At the maximum recorded water level, a majority of the restoration site is under water, however this extent of flooding is not yet reflected in the vegetation community structure along the upper ends of the elevation gradient. The mean tide line matches well with the edge of the former pond and the central bog area. Vegetation in this part of the site showed significant signs of stress and die off. The mean water line matched well with the lowest portion of the site, where water is retained at low tide. Hydroperiod ranged from 0 to 100%, with upland edge stations being flooded rarely if it all and central pond stations under water 100% of the recording period. Mean station hydroperiod was ~15 %, indicating much of the site will ultimately be colonized by higher marsh species. The revised hypsometric curve shows that the initial DEM overestimated the amount of marsh flooded at most water heights under current hydrological conditions (Figure 24). However, as sea level continues to rise, this percentage will increase which will drive a corresponding change in species composition. The 2016 hypsometric curve is moving towards the shape of hypsometric curves typically observed at tidal marshes in the region, where the floodplain flood rapidly due to its relative flatness and levels off as the upland boundary is approached.

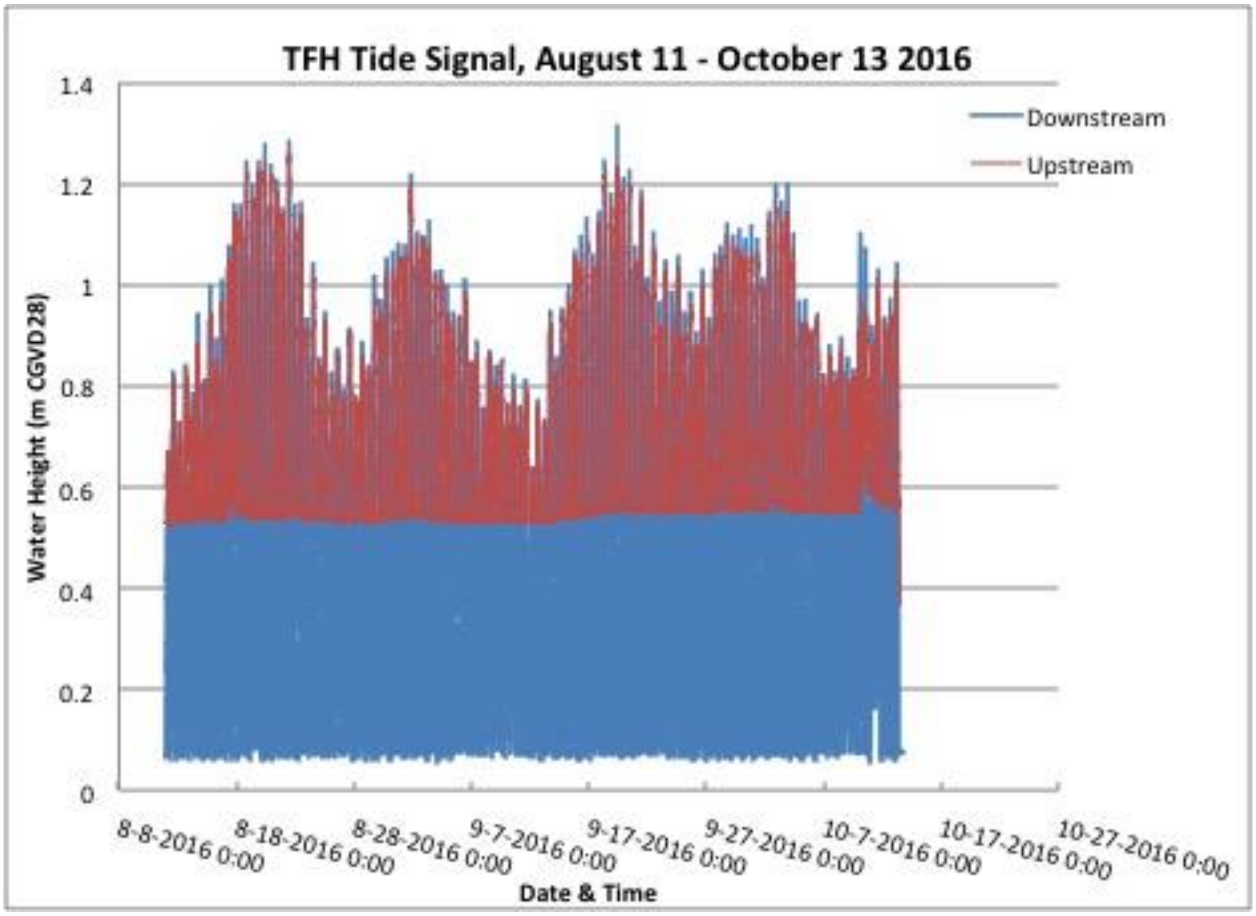


Figure 22 Tide signal for recording period of 11 August – 13 October 2016.

Table 3 Water levels (m; CGVD28) and flooded area (ha).

	Upstream (m CGVD28)	Area (ha) Upstream	Downstream (m CGVD28)
Max High Tide	1.27	1.2	1.32
Mean High Tide	0.98	0.51	1.00
Mean Water Level	0.65	0.01	0.41
Min High Tide	0.64	0.01	0.64
Min Water Level	0.37	0.0004	0.05

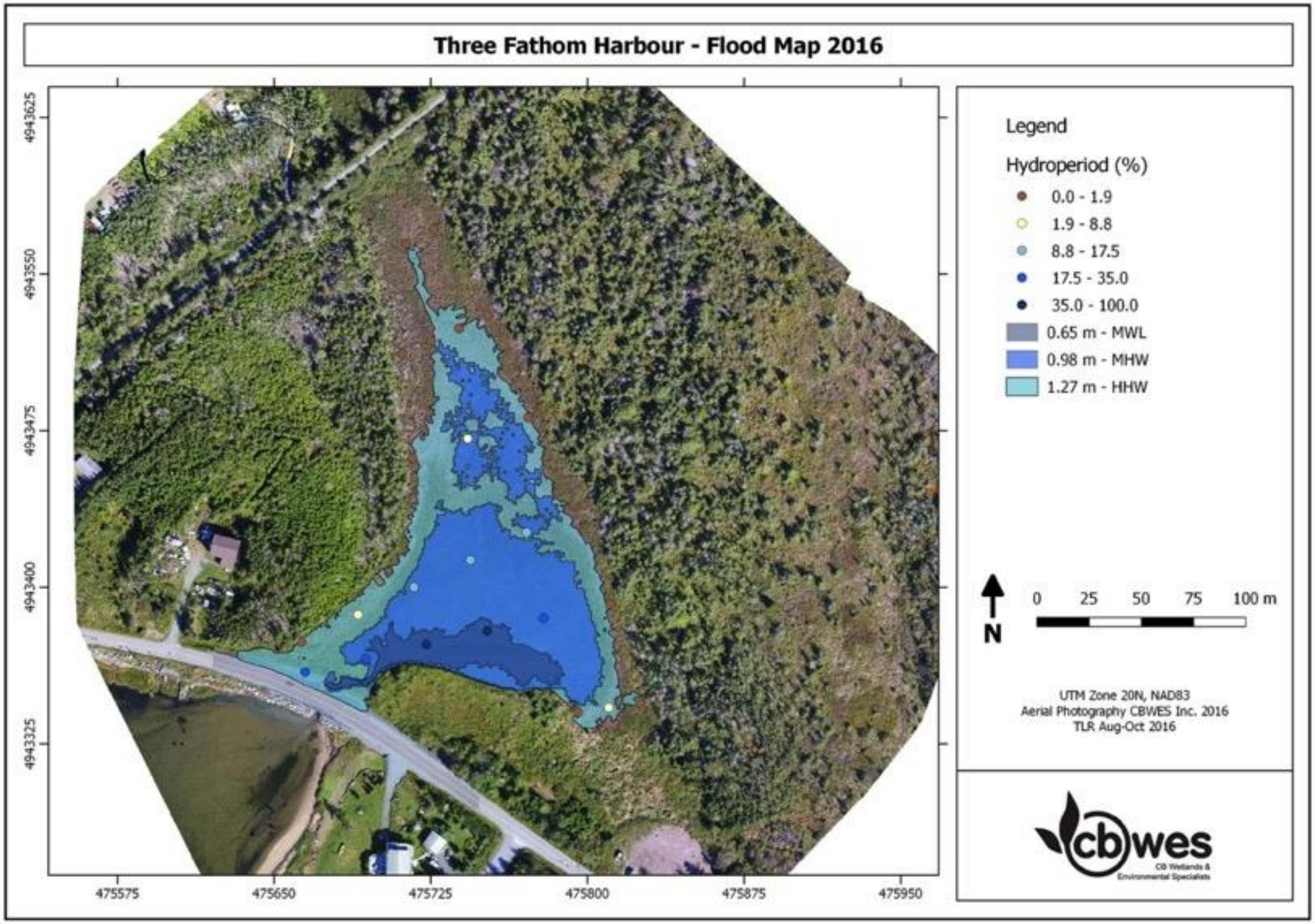


Figure 23 Flood map for TFH depicting recorded water levels under the new unrestricted hydrological regime. The updated flood map was produced using the results of the 2016 elevation and hydrological conditions.

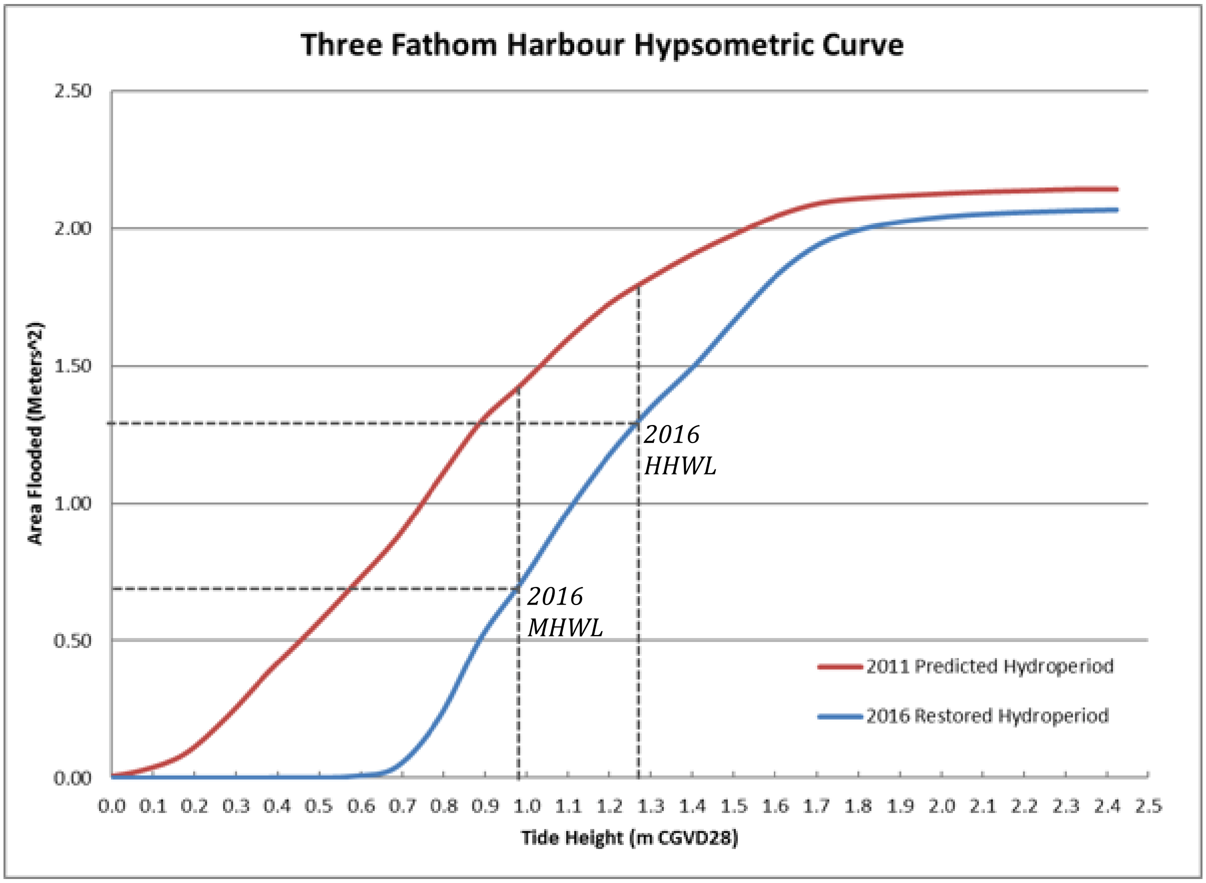


Figure 24 Updated hypsometric curve for TFH based on 2016 elevation survey and tide signal (blue line).

4.3 Soils and Sediments

Sediment Accretion and Elevation

The highest rate of sediment accretion (3.54 cm·yr^{-1}) at TFH was recorded at T1S2 (Table 4). This was anticipated given the configuration of the shoreline and most likely represents storm deposition given the low frequency of inundation at this station (Figure 23). As with the Lawrencetown sites, sediment is largely deposited during storm events given the relatively low suspended sediment concentration within Atlantic coastal waters (Bowron et al. 2012). It should be noted, however, that a clear storm lens of coarse sediment was not visually observed in sediment cores collected from the site. Stations T3S2 and L5S3 are located at the boundary of the change in flood frequency pre- and post-restoration and recorded 1.94 and 2.26 cm·yr^{-1} respectively (Table 4). These values are within the range of mean accretion measured at the Lawrencetown restoration site in the mid and high marsh (Table 5). The slowest rate of accretion at TFH (0.52 cm·yr^{-1}) was recorded in the grass and orach zone (mid marsh) at station T3S5 (Table 4; Figure 20). This value is slightly greater than the minimum rates recorded at either LT sites (0.34 and 0.43 cm·yr^{-1} at LT_L1S8 and LTR_L1MM respectively) (Table 5).

The change in surface elevation between 2011 and 2016 as measured by an RTK GPS, was in all cases much greater than the net sediment accretion measured over the same period (Table 4). However, with the exception of station T5S3, the relative difference between sites is similar. The most plausible explanation is the influence of expansion and contraction of the highly organic below-ground peat in response to evapotranspiration (Paquette et al. 2004). It is unlikely for the difference to be accounted for by below-ground production within the five year period. However, in the absence of Rod Surface Elevation Tables (RSETs) installed at the site recording changes in surface elevation, it is not known how the subsurface processes are behaving and how the surface as a whole is trending over time. The rates of accretion do suggest that both the reference and the restoration sites are keeping up with sea level rise as calculated for Halifax (0.32 cm per year from 1920-2009) (Forbes et al., 2009).

Table 4 Mean sediment accretion at TFH measured using feldspar marker horizons established in October 2011 relative to approximate date (July 2015) that tidal flow was restored. Elevation differences based on RTK surveys between 2011 and 2016. Stations T2S5, T3S3 and T3S4 could not be relocated in 2016.

2016	Station	Elev (m)	Habitat zone	# cores	quality	mean (cm)	rate (cm/yr)	rate (cm/mth)	survery elev 2011 (m)	variation in station elev (m)
	T1S2	1.061	sedge	1	Good	4.55	3.64	0.30	0.37	0.69
	T3S2	0.878	sedge	2	ok	2.43	1.94	0.16	0.64	0.24
	T3S5	1.077	grass & oracl	1	Great	0.65	0.52	0.04	0.94	0.14
	T5S2	1.254	bog	3	Ok	1.68	1.34	0.11	1.04	0.21
	T5S3	1.185	bog	2	Ok	2.83	2.26	0.19	1.09	0.10

Table 5 Mean sediment accretion measured by marker horizons at Lawrencetown restoration and reference sites from 2007 to 2012. *shorter measurement period.

Lawrencetown Restoration MH		Net annual accretion (cm/yr)					Annual average
Transect I	**Habitat Zone**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**cm/yr**
LT MH-1 L1S8	high marsh	0.05	0.98	-0.4	1.01	0.05	0.34
LT MH-2 L1S4	high marsh	0.05	0.73	1.15	1.13	0.35	0.68
LT MH-3 L1S2	high marsh	0.15	3.19	-1.44	4.03	4.60	2.11
Transect 3							
LT MH-4 L3FS	high marsh	NA	1.61*	NA	NA	NA	NA
Transect 4							
LT MH-5 L4S2	mid marsh	0.60	8.20	-0.08	2.71	-1.28	2.03
LT MH-6 L4S3	mid marsh	0.25	4.60	-0.43	1.06	0.65	1.23
Transect 5							
LT MH-7 L5S2	mid marsh	0.10	1.34	0.01	0.75	0.65	0.57
Lawrencetown Reference- MH		**Net accretion (cm/yr)**					**Annual average**
Transect 1	**Habitat Zone**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**cm/yr**
LTR MH-1 L1LM	low marsh	NA	NA	NA	NA	0	NA
LTR MH-2 L1MM	mid marsh	0.03	1.96	2.06	0.73	NA	1.20*
LTR MH-3 L1HM	high marsh	0.04	0.89	0.54	1.07	-0.46	0.42
Transect 3							
LTR MH-4 L3HM	high marsh	0.54	0.09	1.31	0.79	-0.33	0.48
LTR MH-5 L3MM	mid marsh	0.05	1.81	0.84	0.13	-0.71	0.43
LTR MH-6 L3LM	low marsh	NA	NA	NA	NA	NA	NA

The sediment pins installed throughout the site in 2016 were measured at the time of installation (Table 6). The pins will be re-measured annual for the remainder of the monitoring program. The difference (+/-) between the subsequent years measurements will provide insight into the deposition or erosion of material across the marsh surface.

Table 6: Baseline measurements of sediment pins installed and 13 October 2016, RTK survey 5 December 2016.

ID	Station	Top elevation (m CGVD28)	Bottom elevation (m CGVD28)	Measurement from GPS (m)	Field Measurement (meter stick)				
					1	2	3	4	Mean
SEDPIN1	T1S2	0.886	1.544	0.658	0.665	0.65	0.655	0.67	0.660
SEDPIN2	T2S1	0.839	1.676	0.837	0.85	0.85	0.855	0.86	0.854
SEDPIN3	T2S2	0.739	1.629	0.89	0.87	0.865	0.86	0.88	0.869
SEDPIN4	T3S2	0.899	1.726	0.827	0.815	0.815	0.81	0.81	0.813
SEDPIN5	T3S3	0.841	1.655	0.814	0.795	0.795	0.795	0.8	0.796
SEDPIN6	T4S2	1.001	1.769	0.768	0.77	0.765	0.76	0.765	0.765
SEDPIN7	T5S2	1.105	2.052	0.947	0.91	0.91	0.91	0.89	0.905
SEDPIN8	T3S5	0.967	1.806	0.839	0.815	0.79	0.81	0.815	0.808
SEDPIN9	T2S5	0.806	1.612	0.806	0.81	0.81	0.805	0.805	0.808
SEDPIN10	--	0.586	1.394	0.808	0.765	0.755	0.76	0.77	0.763
SEDPIN11	--	0.713	1.575	0.862	0.83	0.83	0.83	0.82	0.828

Soil Characteristics

Soil characteristics at each sample location are highly influenced by the site's elevation within the tidal frame, distance from the mouth of the estuary and distance from the creek bank. Bulk density, water content and organic matter content are influenced primarily by the sediment characteristics of the underlying substrate and presence or absence of vegetation. These characteristics will be discussed initially at the restoration site then compared to those observed at the reference site. A series of eight cores and associated syringes were collected pre-restoration (Oct. 7, 2011) and one-year post (Oct 13, 2016) for grain size analysis, organic matter, water content and bulk density determination (Table 7). Cores were portioned into two halves with the exception of the bulk density samples. Samples were extracted from top and mid core pre-restoration but only from the top 2 cm post-restoration since that is where anticipated change would occur. The locations of the samples are illustrated in Figure 10.

Prior to re-introduction of tidal flow, all of cores were highly waterlogged, consisting mainly of peat and root fragments with low amounts of inorganic sediment. Water content was very high, ranging from 84.6% at L2S5 to almost complete saturation with 94.9% at L5S2 (Table 7). It is interesting that the highest water content within the cores was recorded for the sampling locations furthest away from the pond and also at the highest elevation (Figure 10). This may potentially be explained by the very high organic matter content at the sampling stations along transect five, which contained greater than 85% organic matter (Table 7a). These soils can be fully classified as peat due to organic matter content greater than 80% (Mitsch and Gosselink 2007). The remaining samples were still classified as organic soils with organic matter content greater than 35%. The lowest organic matter (45.1%) was located at L2S5 at the edge of the pond. In general there was a decrease in both water content and organic matter content with depth within the cores, with the exception of L1S2 (water content) and L5S2, L5S3 (organic matter content) (Table 7a). Mean organic matter content at the reference site was markedly lower, ranging from 32.88% to 69.08%, likely associated with minerogenic inputs from regular tidal flooding (Table 7b). Water content was slightly higher at TFH compared to the reference site but still within the range of values recorded at LTR.

One year post-restoration, all stations at TFH experienced a decrease in water content with the exception of T1S2 (Table 7a), which increased and was close to fully saturated. Sites closest to the inlet (T2S5, T2S3) recorded decreases in water content between 10-20% as tidal exchange was restored and water drained effectively. Station T3S4 decreased by approximately 5% and water content at the remaining sites further into the system saw little change (Table 7a). In general the water content is still greater than at the reference site. Organic matter increased by approximately 10% at T1S2 and T5S2 (Table 7a), potentially as a result of the accumulation of wrack material. T1S2 recorded the highest sediment accretion based on the marker horizon data (Table 5). Similarly, to the trend with water content, those areas closest to the inlet (T2S5 and T3S4) recorded marked decreases (~20%) in organic matter content (Table 7a). Stations T3S2 and T3S3 saw approximately a 10% decrease in organic matter content whereas stations T3S5 and T5S3 recorded minimal change (Table 7a).

Bulk density is a measure of soil compaction and reflects the soil's ability to function for structural support, movement of water and solutes and soil aeration. It is dependent on soil texture and the densities of soil minerals (sand, silt and clay) and organic particles, as well as their packing arrangement. In general, loose, porous soils and those rich in organic matter have lower bulk density. Bulk density values pre-restoration at TFH were low, ranging from 0.05 $g{\cdot}cm^{-3}$ at L5S2, L1S2 to 0.16 $g{\cdot}cm^{-3}$ at L3S2, L3S5 (Table 7a). Well decomposed organic soils typically range between 0.2 to 0.3 $g{\cdot}cm^{-3}$ and some peatland soils measure less than 0.05 $g{\cdot}cm^{-3}$ (Mitsch and Gosselink 2010), thereby supporting the findings of this study. Most of the bulk density values recorded at TFH (except L5S2, L5S3, L1S2) fall within the range of values recorded at the LTR (Table 7b). There was no clear relationship with elevation at TFH. One year post restoration bulk density increased three fold at T2S5 likely due to increased compaction as water content and organic matter content both decreased (Table 7a). Slight increases in bulk density were recorded at T1S2, T3S3, T5S2 and T5S3) and decreases at T3S2, T3S4, T3S5 (Table 7a). With the exception of T2S5 and SP10 bulk density values recorded at TFH are within the range of those recorded at the reference site (Table 7b). Organic matter decreased at most sites with the exception of T2S2, T3S5 and T5S2 which recorded values greater than 80% and reflect the fibrous nature of its contents (Table 7a, Figure 25b,d,f). The bulk density at SP10 (0.91 $g{\cdot}cm^{-3}$) suggests almost no pore space is available for water movement. This is supported by the very low water and organic matter contents and is consistent with its position on a newly formed sandy flood tidal delta bar (Table 7a).

Sediment type and particle size greatly influences soil aeration and drainage (Packham and Willis 1997). Silt, clay and sand are the different soil textures typical of salt marshes. Silt and clay materials tend to retain more salt than sand, and clay is the most absorptive (Mitsch and Gosselink 2007). Clay and silt are expected to dominate high marsh soils, while the low marsh is expected to have a higher proportion of sand (Packham and Willis 1997), however, this will vary depending on the source material. Samples from TFH were processed using a Coulter Multisizer 3 and grain size statistics calculated using Gradistat (Blott and Pye 2001) and described using

Folk statistics. In general, pre-restoration, the top portion of the cores contained finer inorganic material (e.g. fine silt – 4-8 µm) than the lower portion (e.g. med silt – 8-16 µm) with the exception of L3S3 (Table 8a). All cores were classified as very close to 100% mud and were poorly sorted (Table 8a). Skewness is a measure of spread of the distribution relative to the mean and was mostly symmetrical for the top section of the cores, which is unusual for natural sediments (Table 8a). Otherwise the remaining cores exhibit a tail of fines suggesting a winnowing effect (Table 8a). The bottom section of L1S2, however, was the exception and was coarsely skewed (Table 8a). Grain sizes found at TFH are consistent with those found at the reference site in 2010 (Table 8b). Grain sizes reported in 2012 at the reference site are coarser (Table 8b), reflecting significant storm deposits during that year.

Re-introduction of tidal exchange one year post-restoration resulted in a coarsening of material at all stations except T3S5 (Table 8a, Table 10). Sediments remained poorly sorted and shifted to very fine skewed or symmetrical, reflecting the addition of coarser sediments within the top 2 cm. The additional core collected in 2016 (SP10) was classified as very poorly sorted coarse sand and coarse skewed as fine sediments are winnowed out of the sample (Table 9). A deposit of coarse sand reflects the re-introduction of tidal flow and higher velocities associated with a larger volume of water moving through the channel. The source of this material is likely the beach and intertidal flats located on the seaward side of the road.

A significant advantage of the Coulter Multisizer is the ability to perform disaggregated grain size analysis and plot grain size versus normalized volumetric concentration (Figure 26). The shape of the curve is an indication of both source material and transport mechanism (Krank and Milligan 1985). The shape of the curves suggests that different transport mechanisms were responsible for sediment transport. Some of the pre-restoration samples showed clear single ‘round’ settling (Krank and Milligan 1985) (e.g. L1S2 and T3S2) which suggests one single settling event. Other samples pre-restoration showed bimodality with the sample or ‘two-round’ distributions indicating multiple transport events or forces and were mostly located within the top 5 cm of the core. This was most pronounced at L5S2 and L5S3 (Figure 26). Post-restoration sediment samples collected at T2S5, T3S3 and T3S4 showed the introduced coarser sediment component (addition of coarse and very coarse silt) very clearly (Figure 26, Table 10). The slope of their curves also suggests a similar sediment source. Samples T3S2, T3S5, T5S3 and T5S2 also have similar source material and a higher proportion of clay size particles (Figure 26, Table 10). Higher clay content may increase the ability of suspended sediments to flocculate and be deposited, however, the limited accretion data available does not allow this to be verified. No sedimentary horizons were observed within the cores (Figure 25).

Table 7 Comparison of sediment characteristics a) pre (2011) and 1 year post-restoration (2016) at TFH with b) reference site (LTR). Mean and standard deviation (stdev) at LTR derived from post restoration monitoring (2008-2011). Elevations in meters relative to CGVD28.

a) TFH Station	Elevation (m)		Water content (%)			Organic matter content (%)			Dry bulk density (g·cm^{-3})	
			2011		2016	2011		2016		
	2011	2016	top	mid	top	top	mid	top	2011	2016
T2S2	0.37	1.06	90.9	92.3	93.4	79.9	76.3	87.5	0.05	0.08
T2S5	0.59		84.6	85.9	64.8	45.1	45.5	26.4	0.14	0.34
T3S2	0.64	0.88	88.1	83.4	88.4	71.5	50.1	60.7	0.16	0.08
T3S3	0.60		88.9	80.0	79.3	64.6	36.1	51.9	0.11	0.16

T3S4	0.58		89.8	72.3	83.0	61.2	24.2	48.3	0.13	0.09
T3S5	0.94	1.08	85.7	79.4	86.2	81.3	42.1	83.0	0.16	0.12
T5S2	1.04	1.25	94.9	93.7	93.7	85.3	90.1	97.5	0.05	0.09
T5S3	1.09	1.19	93.8	93.2	92.6	86.1	88.5	85.7	0.07	0.10
SP10					23.0			2.1		0.91

b) LTR Station	**Elev (m)**	**Water content (%)**		**Organic matter content (%)**		**Dry bulk density ($g{\cdot}cm^{-3}$)**	
		mean	**stdev**	**mean**	**stdev**	**mean**	**stdev**
LTR-L1S1	0.71	82.3	4.7	52.4	12.5	0.14	0.06
LTR-L1S3	0.49	79.7	13.6	59.6	23.8	0.11	0.03
LTR-L1S4	0.64	74.4	6.7	46.8	21.1	0.16	0.15
LTR-L3S1	0.77	81.7	6.0	65.4	12.3	0.12	0.03
LTR-L3S3	0.67	85.0	5.3	59.5	14.2	0.10	0.02
LTR-L3S6	0.63	68.0	6.1	32.7	9.0	0.24	0.03

Table 8 Comparison of sediment grain statistics a) pre (2011) and 1 year post-restoration (2016) at TFH with b) reference sites (LTR). Data from LTR represent mean 2010 and 2012 based on cores analyzed using the Coulter Multisizer 3^{tm} within In_CoaST. Samples from prior years were not utilized since they were processed using a Coulter Laser instrument and are not comparable. Size = mean grain size; Folk = folk classification, mod= modality f.silt = fine silt, m.silt = medium silt, c.silt = coarse silt, vc.silt = very coarse silt, vf.sand = very fine sand, f.sand = fine sand. Uni = unimodal; bi = bimodal, poly= polymodal. Sym = symmetrical, fine = fine skewed, coarse = coarse skewed.

a) TFH station	**2011 (pre) top of core**				**2011 (pre) middle of core**				**2016 top (1-yr post) of core**			
	Mean size (µm)	**Folk size class**	**Sort.**	**Skew.**	**Mean size (µm)**	**Folk size class**	**Sort.**	**Skew.**	**Mean size (µm)**	**Folk size class**	**Sort.**	**Skew.**
T1S2									7.15	f.silt	poor	sym
T2S2	6.85	f.silt	poor	Sym	5.58	f.silt	poor	Coarse	15.40	m.silt	poor	v.fine
T2S5	7.02	f.silt	poor	Fine	7.05	f.silt	poor	Fine	11.56	m.silt	poor	v.fine
T3S2	7.23	f.silt	poor	Sym	7.97	m.silt	poor	sym	9.06	m.silt	poor	v.fine
T3S3	7.26	m.silt	poor	Sym	6.89	f.silt	poor	Sym	15.11	m.silt	poor	v.fine
T3S4	7.62	f.silt	poor	Fine	8.11	m.silt	poor	Fine	14.23	m.silt	poor	v.fine
T3S5	8.41	m.silt	poor	sym	7.68	m.silt	poor	Fine	7.56	f.silt	poor	sym
T5S2	6.23	f.silt	poor	sym	10.44	m.silt	poor	Fine	8.14	m. silt	poor	sym
T5S3	7.23	f.silt	poor	sym	9.08	m.silt	poor	sym	6.57	f.silt	poor	sym
SP10									852.9	c.sand	v.poor	coarse

b) LTR station	**2010**				**2012**			
	Mean size (µm)	**Folk size class**	**Sort.**	**Skew.**	**Mean size (µm)**	**Folk size class**	**Sort.**	**Skew.**
LTR-L1S1	8.00	m.silt	poor	Fine	9.41	m.silt	v.poor	coarse
LTR-L1S3	6.45	F. silt	poor	Sym	8.59	m.silt	v.poor	coarse
LTR-L1S4	10.62	m. silt	poor	Fine	10.39	m.silt	v.poor	coarse
LTR-L3S1	7.15	f. silt	poor	Sym	9.53	m.silt	v.poor	coarse
LTR-L3S3	7.84	f.silt	poor	Fine	8.33	m.silt	v.poor	coarse
LTR-L3S6	9.40	m. silt	poor	fine	11.53	m.silt	v.poor	coarse

Table 9 Sediment Characteristics based on Coulter Laser Particle Size Analysis from the top 2 cm of core samples SP10, T1S2, T2S2 and T2S5 at TFH; Sediment characterization determined using Folk and Ward method in GRADISTAT (Blott and Pye 2001).

		TFN	TFN	TFN	TFN
	ANALYST AND DATE:	SP10, MS3 + Sieve	T1S2	T2S2	T2S5
	SIEVING ERROR:				
	SAMPLE TYPE:	Trimodal, Very Poorly Sorted	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted
	TEXTURAL GROUP:	Gravelly Sand	Mud	Mud	Mud
	SEDIMENT NAME:	ine Gravelly Coarse San	Medium Silt	Coarse Silt	Coarse Silt
FOLK AND WARD METHOD (mm)	MEAN $(\bar{x}_a)$:	852.9	7.146	15.40	11.56
	SORTING (σ_G):	4.486	2.841	2.494	2.548
	SKEWNESS (Sk_G):	0.240	-0.020	-0.487	-0.342
	KURTOSIS (K_G):	2.716	0.939	1.138	0.970
FOLK AND WARD METHOD (Description)	MEAN:	Coarse Sand	Fine Silt	Medium Silt	Medium Silt
	SORTING:	Very Poorly Sorted	Poorly Sorted	Poorly Sorted	Poorly Sorted
	SKEWNESS:	Coarse Skewed	Symmetrical	Very Fine Skewed	Very Fine Skewed
	KURTOSIS:	Very Leptokurtic	Mesokurtic	Leptokurtic	Mesokurtic
	D_{10} (mm):	260.3	1.790	3.155	2.708
	D_{50} (mm):	523.7	7.344	20.37	14.08
	D_{90} (mm):	5479.1	27.77	38.92	29.90
	% GRAVEL:	21.7%	0.0%	0.0%	0.0%
	% SAND:	71.9%	0.0%	1.6%	0.0%
	% MUD:	6.4%	100.0%	98.4%	100.0%
	% V COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%
	% COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%
	% MEDIUM GRAVEL:	0.0%	0.0%	0.0%	0.0%
	% FINE GRAVEL:	18.2%	0.0%	0.0%	0.0%
	% V FINE GRAVEL:	3.5%	0.0%	0.0%	0.0%
	% V COARSE SAND:	11.5%	0.0%	0.0%	0.0%
	% COARSE SAND:	39.6%	0.0%	0.0%	0.0%
	% MEDIUM SAND:	19.1%	0.0%	0.0%	0.0%
	% FINE SAND:	0.3%	0.0%	0.0%	0.0%
	% V FINE SAND:	1.4%	0.0%	1.6%	0.0%
	% V COARSE SILT:	1.4%	7.5%	20.3%	9.7%
	% COARSE SILT:	1.5%	16.9%	39.9%	36.5%
	% MEDIUM SILT:	1.2%	24.9%	17.6%	25.8%
	% FINE SILT:	1.0%	22.1%	8.9%	12.5%
	% V FINE SILT:	0.8%	17.4%	6.8%	9.2%
	% CLAY:	0.5%	11.3%	5.0%	6.4%

Table 10 Sediment Characteristics based on Coulter Laser Particle Size Analysis from the top 2 cm of core samples T3S2 to T3S5 and T5S2, T5S3 at TFH; Sediment characterization determined using Folk and Ward method in GRADISTAT (Blott and Pye 2001).

	TFN	**TFN**	**TFN**	**TFN**	**TFN**	**TFN**
	T3S2	T3S3	T3S4	T3S5	T552	T553
	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted
	Mud	Mud	Mud	Mud	Mud	Mud
	Medium Silt	Coarse Silt	Coarse Silt	Medium Silt	Fine Silt	Fine Silt
MEAN	9.061	15.11	14.23	7.564	8.136	6.571
SORTING	2.840	2.523	2.621	2.853	3.149	2.742
SKEWNESS	-0.102	-0.477	-0.480	-0.067	0.024	0.087
KURTOSIS	0.852	1.183	1.053	0.845	0.811	0.843
MEAN:	Medium Silt	Medium Silt	Medium Silt	Fine Silt	Medium Silt	Fine Silt
SORTING:	Poorly Sorted	Poorly Sorted	Poorly Sorted	Poorly Sorted	Poorly Sorted	Poorly Sorted
SKEWNESS:	Fine Skewed	Very Fine Skewed	Very Fine Skewed	Symmetrical	Symmetrical	Symmetrical
KURTOSIS:	Platykurtic	Leptokurtic	Mesokurtic	Platykurtic	Platykurtic	Platykurtic
D_{10} (mm):	2.133	3.131	3.020	1.812	1.819	1.795
D_{50} (mm):	9.609	19.71	19.24	8.053	8.035	6.132
D_{90} (mm):	32.33	37.38	37.08	29.17	37.14	26.22
% GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% SAND:	0.0%	0.0%	0.9%	0.0%	1.2%	0.0%
% MUD:	100.0%	100.0%	99.1%	100.0%	98.8%	100.0%
% V COARSE GR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% COARSE GRA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% MEDIUM GRA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% FINE GRAVEL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% V FINE GRAV	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% V COARSE SA	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% COARSE SAN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% MEDIUM SAN	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% FINE SAND:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% V FINE SAND	0.0%	0.0%	0.9%	0.0%	1.2%	0.0%
% V COARSE SIL	11.2%	18.9%	16.9%	9.0%	12.6%	5.8%
% COARSE SILT:	21.2%	41.1%	39.9%	18.6%	17.2%	15.8%
% MEDIUM SILT	25.9%	18.7%	19.5%	24.2%	20.0%	22.5%
% FINE SILT:	19.3%	9.3%	10.1%	20.9%	20.3%	24.3%
% V FINE SILT:	13.9%	6.9%	7.5%	16.8%	18.3%	20.5%
% CLAY:	8.5%	5.0%	5.2%	10.6%	10.4%	11.2%

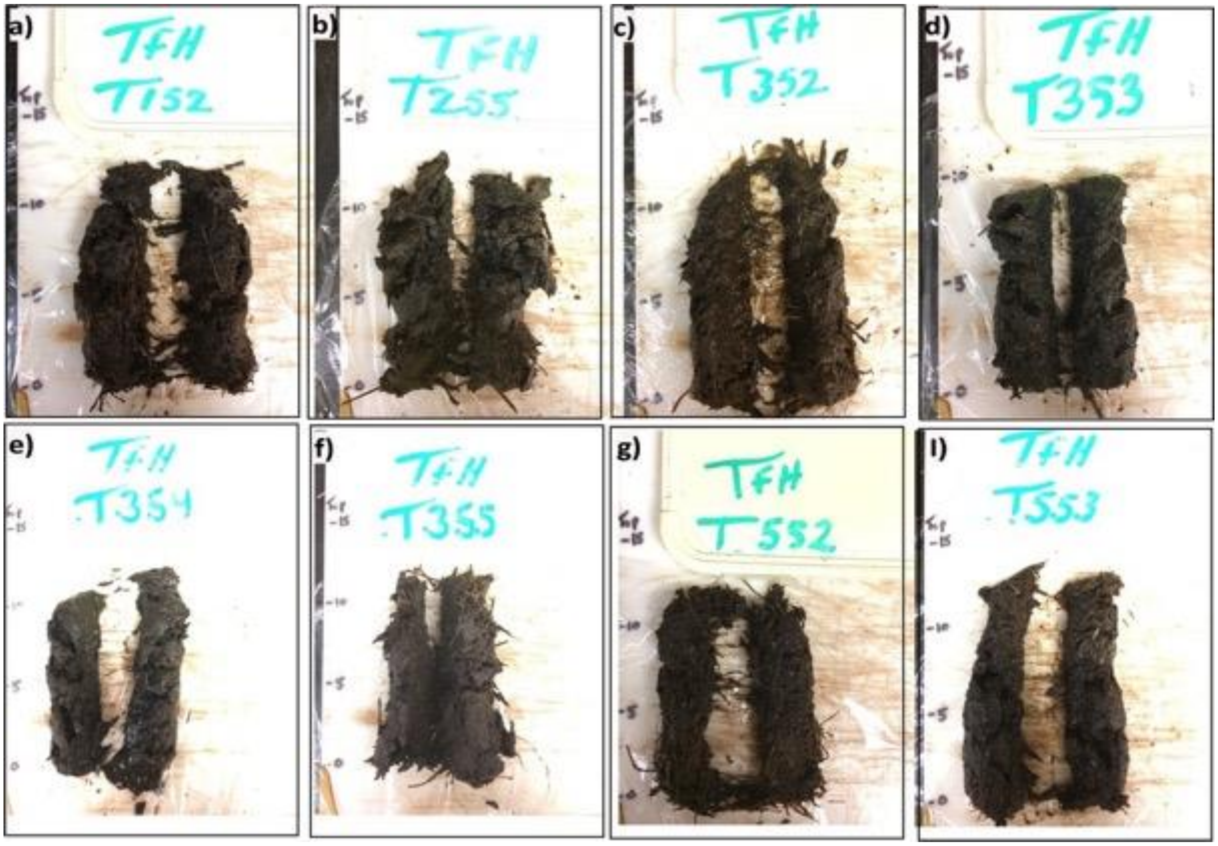
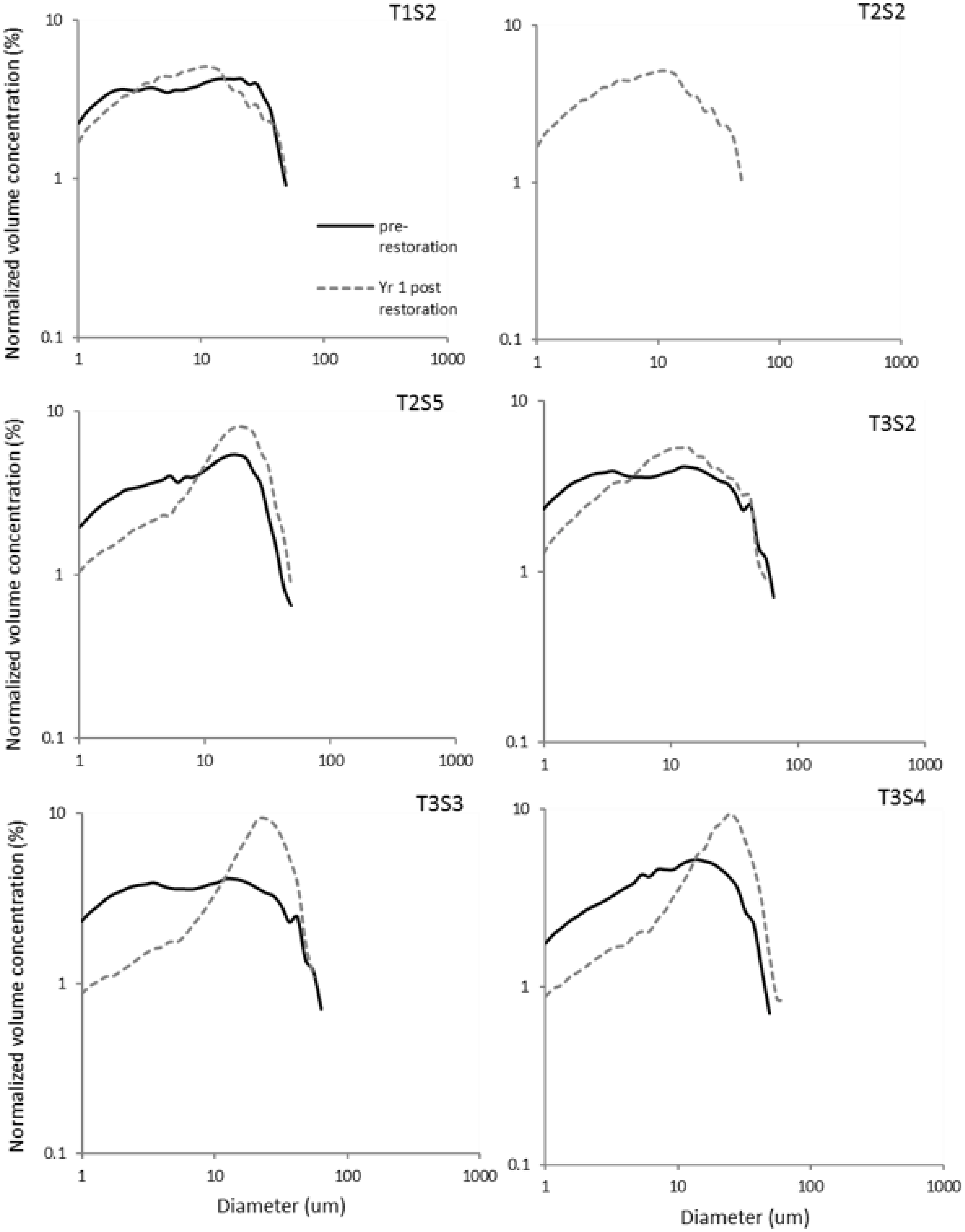


Figure 25 Split cores at TFH collected on 13 October 2016.


T1S2
T2S2
T2S5
T3S2
T3S3
T3S4
Normalized volume concentration (%)
10
1
0.1
1
10
100
1000
pre-restoration
Yr 1 post restoration
Diameter (um)

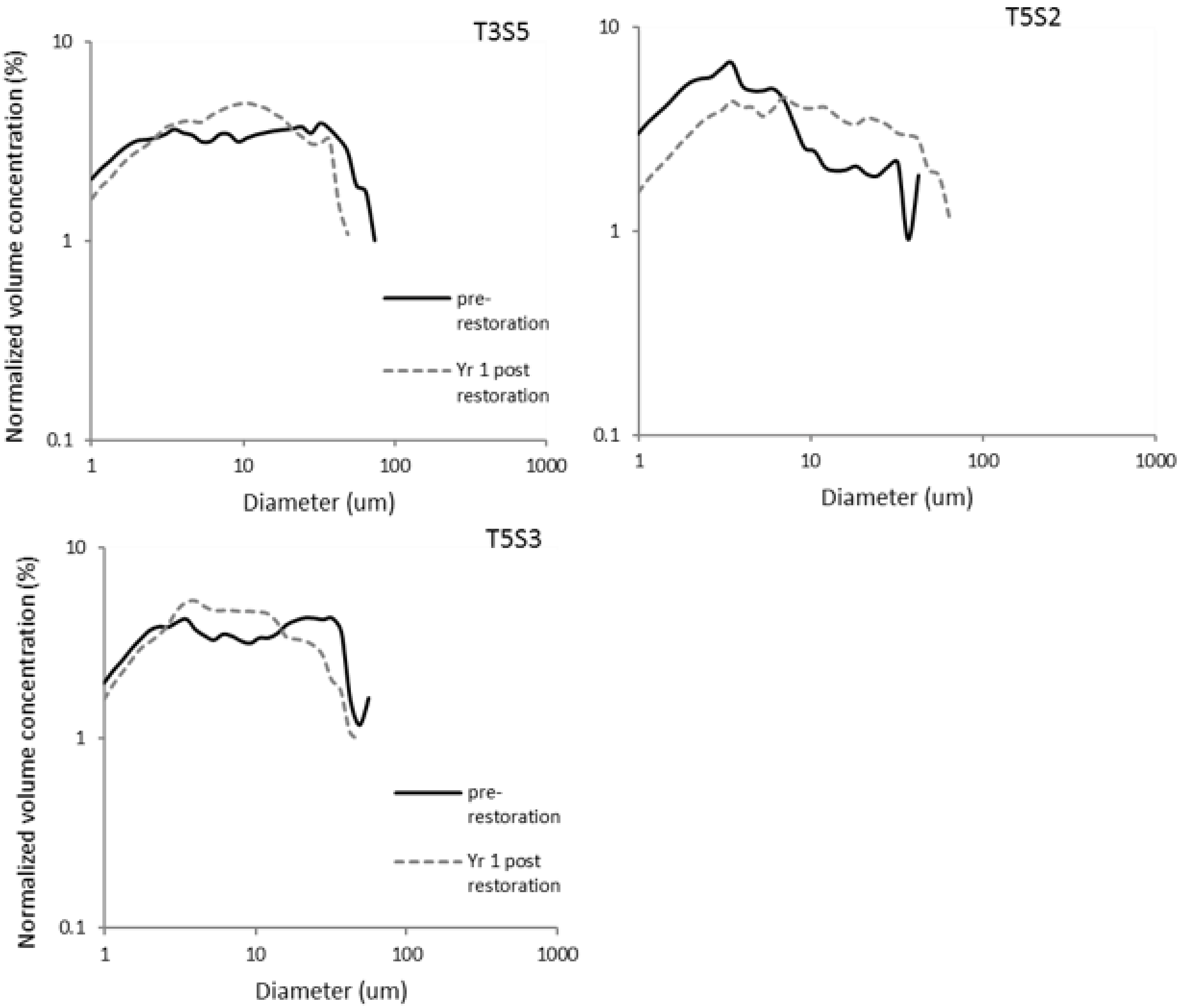


Figure 26 Merged (30 and 200 µm) grain size spectra from Coulter Multiziser 3 pre (2011) and 1-year post-restoration (2016) at TFH restoration site.

4.4 Vegetation

Since the 2011 pre-restoration vegetation sampling at TFH and one year following restoration, the vegetation community at the site has begun a shift toward the salt marsh plant communities found at the reference site (TFH-R). However, differences in vegetation community structure do remain between the sites.

Non-metric multidimensional scaling ordination (NMDS) revealed a change in vegetation communities at TFH between 2011 and 2016 (Figure 27). The vegetation community at TFH one year following restoration more closely resembles that of the reference condition then it did prior to the reintroduction of tidal flow. The wide separation apparent between plant community composition at TFH in 2011 and the reference has narrowed, marking a transition toward a more tidally influenced plant community.

Non-parametric multivariate ANOVA indicated, however, that a significant difference does remain in vegetation composition between the two sites (F=8.11; R^2=0.15; P<0.001). The magnitude of significance has slightly decreased since the 2011 baseline sampling period (2011: F=10.85; R^2=0.20; P=0.001). The restoration site continues to support an abundance of several freshwater wetland species including *Myrica gale* and *Calamagrostis canadensis*, *Carex magellanica* and *Maianthemum trifolium*. Table 11 compares species abundance and frequency for the TFH 2011 and 2016 sampling years and with reference site.

Average species richness of TFH in 2016 was lower than that of 2011. Although TFH continues to have greater average species richness than the reference site, the relative difference in their average species richness is now substantially smaller (Figure 28a; F=6.24; P=0.01).

Salt marsh species including *Hierochloe odorata* and *Atriplex glabriscula* have now become established at TFH. Though non-significant, halophytic species richness and abundance and their variability between plots increased, suggesting a trend toward a greater halophyte presence in the study site plant community. The reference site continues to host more halophytic species (Figure 28b; F=115; P<0.001) and much greater halophytic abundance than restoration site (Figure 2c; F=160; P<0.001).

Unvegetated area increased between 2011 and 2016 within the study site, although the difference was not statistically significant (Figure 28d; F=3; P=0.08). The location of the unvegetated areas was predominately in the zone surrounding the former central pond where increased tidal flooding has resulted in the dieback of non-halophytic species. This dieback is visually apparent on site and in the aerial imagery (Figure 29). What is not yet readily apparent in the vegetation survey data or the imagery is the early stages of colonization of this area by primary salt marsh colonizing species such as *Spartina alterniflora, Salicornea europea,* and *Atriplex glabriuscula* (Figure 30).

Table 11 Mean plot abundances (coverage: average # contacts/m2) and frequency (total # of plots at site containing the species) for TFH for 2016 and TFH and reference site (TFH-R) for 2011.

	TFH 2011	TFH 2011	TFH 2016	TFH 2016	TFH-R	TFH-R
Species	**Coverage**	**# Plots**	**Coverage**	**# Plots**	**Coverage**	**# Plots**
Agrostis stolonifera	0.17	2	0.35	1	1.89	7
Algae	0	0	0	0	1.67	2
Alnus sp.	0	0	0.04	1	0	0
Andromeda polifolia	0.08	1	1.04	2	0	0
Argentina anserina (formerly *Potentilla anserina)*	0	0	0	0	0.01	1
Aster sp.	0.05	2	0	0	0	0
Atriplex glabriuscula	0	0	0.57	2	0.06	3
Bidens cernua	0.04	1	0	0	0	0
Bidens frondosa	0.13	3	0	0	0	0
Calamagrostis canadensis	8.93	13	6.35	10	0	0
Calystegia sepia	0	0	0	0	0.17	2

Carex atlantica	3.14	10	2.35	7	0	0
Carex brunnescens	2.67	9	0	0	0	0
Carex exilis	0	0	0.74	1	0	0
Carex hormathodes	0	0	0	0	0.01	1
Carex magellanica	0	0	0.32	3	0	0
Carex nigra	0.01	1	0.35	1	0	0
Carex paleacea	0	0	0	0	5.34	9
Carex scoparia	1.25	9	0.24	4	0	0
Carex sp.	0.08	1	0	0	0	0
Carex stricta	0	0	0.27	3	0	0
Carex trisperma	0.04	1	0.09	1	0	0
Chamaedaphne calyculata	2.25	8	4.13	8	0	0
Comarum palustre (formerly *Potentilla palustre)*	0.04	1	0	0	1.18	4
Eleocharis palustris	3.5	6	0	0	0	0
Festuca rubra	0	0	0	0	6.54	7
Galium mollugo	0.04	1	0	0	0	0
Galium palustre	0.18	7	0	0	0.38	3
Glyceria laxa	0.11	5	0	0	0	0
Glyceria striata	0.08	1	0	0	0	0
Hierochloe odorata	0	0	1.52	4	2.97	6
Iris versicolor	0	0	0.13	1	0	0
Juncus balticus	0	0	0	0	4.63	5
Juncus brevicaudata	0.08	1	0	0	0	0
Juncus canadensis	0.08	2	0	0	0	0
Juncus effusus	1.89	7	0.49	3	0	0
Juncus gerardii	0	0	0	0	0.33	1
Juncus sp.	0.01	1	0	0	0	0
Limonium carolinianum (formerly *Limonium nashii)*	0	0	0	0	0.01	1
Lycopus americanus	0.13	1	0	0	0	0
Lycopus uniflora	0.34	4	0	0	0	0
Lysimachia terrestris	1.01	7	0.14	3	0	0
Maianthemum trifolium	0	0	0.09	1	0	0
Mentha arvensis	0	0	0.22	2	0	0
Myrica gale	5.29	10	5.78	11	0	0
Myrica pennsylvanica	0.02	2	0	0	0	0
Oclemena nemoralis	0	0	0.01	1	0	0
Onoclea sensibilis	0	0	0.01	1	0	0

Poa palustris	0	0	0	0	1.17	2
Polygonum hydropiper	0.01	1	0	0	0	0
Polygonum sagittatum	0.3	4	0	0	0	0
Ranunculus repens	0.01	1	0	0	0	0
Rubus hispidus	0	0	1.57	4	0	0
Rubus strigosus	0.01	1	0	0	0	0
Ruppia maritima	0	0	0	0	0.33	1
Salicornea europea	0	0	0	0	0.01	1
Sarracenia purpurea	0	0	0.04	1	0	0
Scirpus americanus	1.19	6	2.39	4	0	0
Scirpus cyperinus	2.38	6	0.05	2	0	0
Scirpus maritimum	0.04	1	0	0	0	0
Scirpus validus	2.39	5	1.61	2	0	0
Scutellaria galericulata	0.01	1	0	0	0.08	1
Solidago sempervirens	0	0	0	0	0.05	2
Spartina alterniflora	0	0	0	0	6.21	13
Spartina patens	0	0	0	0	8.19	12
Spartina pectinata	1.08	6	1.83	5	1.63	2
Sphagnum sp.	2.67	4	8.13	9	0	0
Spirea latifolia	2.43	12	2.13	7	0	0
Spirea tomentosa	0	0	0.13	1	0	0
Stellaria sp.	0	0	0.04	1	0	0
Symphotrichum lanceolata	0.01	1	0	0	0	0
Symphotrichum novi-belgii	0.08	1	0.58	6	0.58	3
Symphyotrichum novae-angliae	0	0	0	0	0.33	1
Taraxacum officinale	0	0	0	0	0.01	1
Thalictrum pubescens	0	0	0	0	0.01	1
Triadenum fraseri	0.8	11	0.1	2	0	0
Triglochin maritima	0	0	0	0	0.01	1
Typha angustifolia	0	0	0.17	1	0	0
Typha latifolium	0.5	3	0.52	1	0.04	1
Vaccinium macrocarpon	0.42	1	1.2	6	0.13	1
Vicia sp.	0	0	0.09	1	0.63	3
Viola macloskeyi ssp. pallens	0	0	0.09	1	0	0

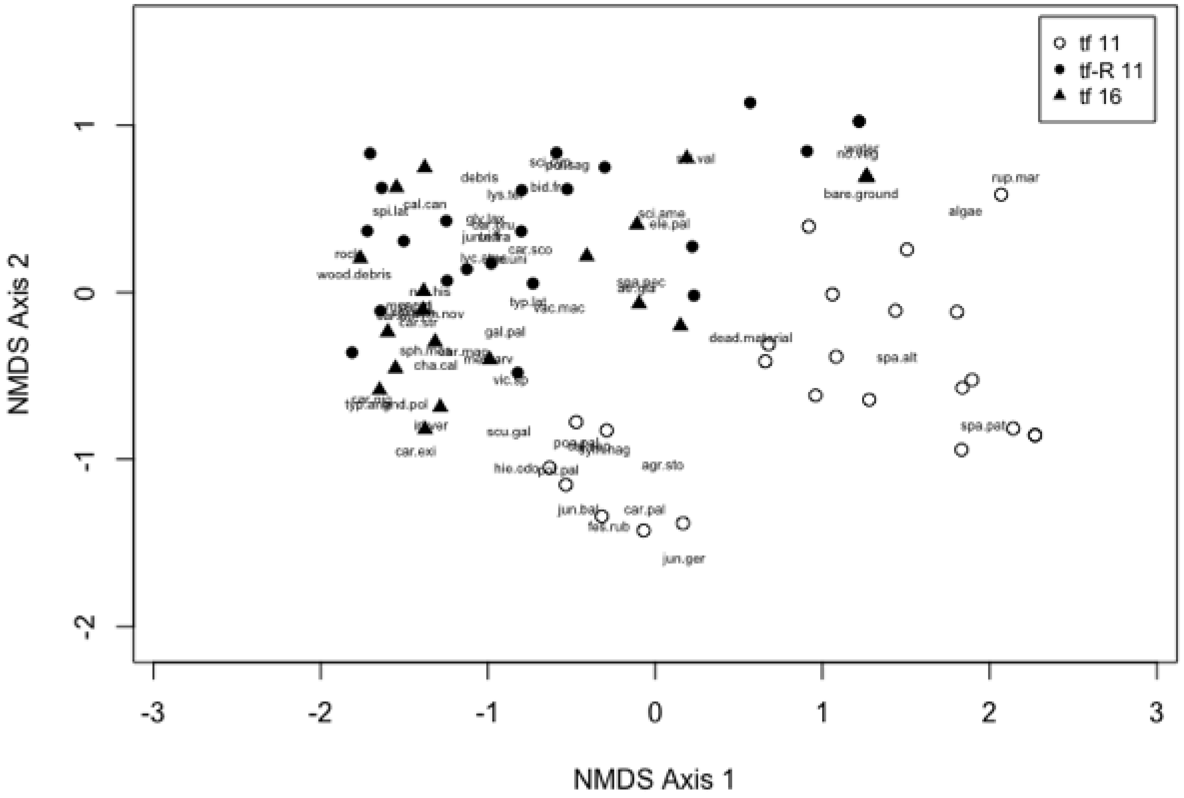


Figure 27 Non-metric multidimensional scaling ordination of vegetation plots comparing TFH (tf) in 2011 and 2016 with its reference site (tf-R).

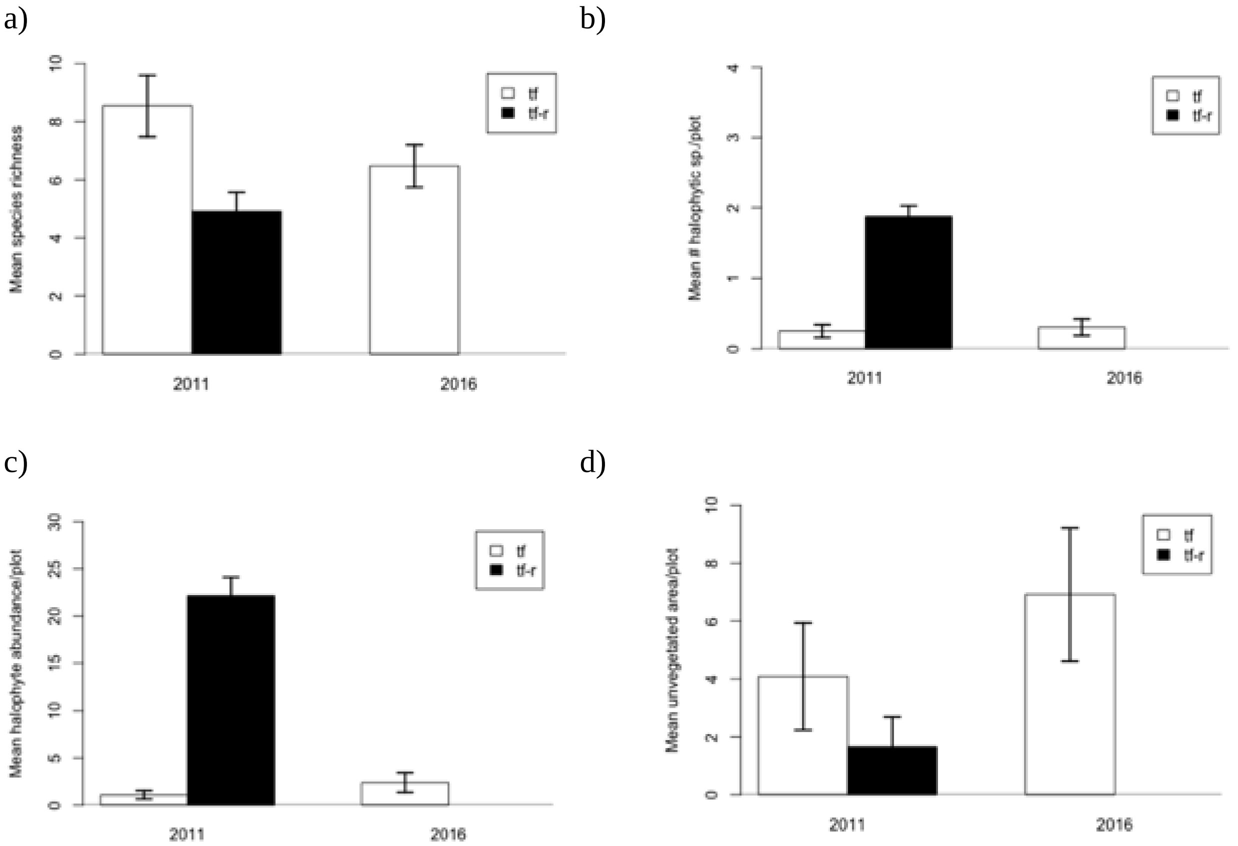


Figure 28 Comparisons of mean plot species richness (a), halophytic richness (b), halophytic abundance (c), and unvegetated area (d) between Three Fathom Harbour reference and study sites.

Figure 29 Aerial view of TFH at low tide showing the mudflat and dieback zone around much of the perimeter of the former pond. Photography by CBWES 2016.

Figure 30 Colonization of the die-back zone and mudflat of the former central pond by salt marsh species (pictured *S. alterniflora* and *Salicornea europea*). Photography by CBWES 2016.

4.5 Structured Winter Walk

The February 2017 winter was marked by unseasonably warm temperatures, with many of the daytime temperatures during the first three months of the season well above the freezing mark. Significant snowfall events were limited to one per month (mid December, early January, and mid February) and any accumulated snow did not persist due to the warm temperatures and rain events that followed. Snow and ice conditions on the marshes were low to non-existent for much of the winter, and what ice did form was localized and did not persist. A selection of landscape photographs from the structured winter walk is provided in Appendix B.

As a result of the fluctuating temperatures (warm days, cold nights) the marsh routinely went through periods of freezing and thawing. A small amount of snow and ice was present on the site at the time of the structured winter walk on 3 February 2017. Of particular note however, was the presence of a significant quantity of seaweed within the site. Much of the central panne/mudflat area was covered by tidally deposited seaweed (Figure 31 to Figure 33). This is consistent with reports from local residents of conditions within the site during the winter of 2016. Residents reported large amounts of seaweed deposited within the site over the winter months which persisted into the spring. When monitoring activities commenced in July, there was very little seaweed wrack remaining within the site (either decomposed, disaggregated or exported from the marsh back to Three Fathom Harbour).

The drifting and deposition of sea-borne materials such as seaweed (wrack) is a natural part of tidal marsh ecology. The deposition of seaweeds on shorelines and tidal marshes, particularly on the Atlantic coast of NS (e.g., Pett 2015 at TFH), tends to occur most heavily over the fall and winter months driven by the larger tides and storm events. Seasonal, storm-driven seaweed deposits on shorelines are often ephemeral, with the loose seaweed being pulled back out to sea by regular tidal action. When seaweed deposits do persist on a shoreline either because of location (beyond reach of regular tides) or quantity, it does start to decompose quickly. Decomposing seaweed blends with soils of beaches, dunes and marshes, aiding in the maintenance of habitat substrate and the addition of organic matter and nutrients to the ecosystem. Wrack can also serve as habitat for insects and invertebrates (i.e., amphipods (Crustacea) and seaweed flies (Diptera: Coelopidae), are forage habitat for ducks and shore birds and can support the transport and germination of wetland plant seeds and rhizomes.

In large amounts however, the deposition and decomposition of seaweed can repress plant cover and biomass, and in the case of a restoration site such as TFH, has the potential to hinder the rate of vegetation recovery. Large amounts of decomposing seaweed can also have a strong aroma, which was something also reported by local residents during construction and the spring of 2016.

Monthly site visits into spring and early summer of 2017 are recommended in order to determine if this cycle of winter deposition and spring/early summer re-suspension and export is a pattern for the site.

Figure 31 Seaweed wrack deposition within the restoration site. View is east to west across the site. Photography by CBWES Inc. 3 February 2016.

Figure 32 Seaweed wrack deposition within the restoration site. View is along the eastern edge of the site looking north across the site. Photography by CBWES Inc. 3 February 2016.

Figure 33 Primary tide channel with vegetated marsh surface in the foreground and wrack on the central mudflat within the site. View is from the upstream end of the tidal crossing looking north across the site. Photography by CBWES Inc. 3 February 2016.

5.0 Summary and Restorable Area

Pre- and post-restoration monitoring is an essential component of any habitat restoration project. Monitoring provides valuable information on the response of the physical and biological elements of the restoration site, the direction of change, the overall condition of the site and serves as a measure of the effectiveness of the restoration effort. In this way, a well-developed and implemented monitoring program can inform and support the management of a specific restoration project; identify the need for additional intervention (adaptive management); and help guide future management and restoration efforts throughout the region.

The monitoring program for TFH, based on the GPAC Regional Monitoring Protocol, is a six-year program with one year pre- and five years post-restoration. Monitoring during the first three years following restoration is critical because it is during these initial years that the greatest and most rapid changes are likely to occur. Monitoring beyond the first three years allows for the documentation of the longer term, often more gradual, changes in response to restoration and for conditions (e.g. soil chemistry, vegetation species composition) to begin to show, at least early, indications of parity with reference conditions (Able et al. 2008; Burden et al. 2013; Garbutt and Wolters 2008; Mitsch et al. 2012; Neatt et al. 2013). Depending on site conditions and the rate of change observed, it may be necessary to continue monitoring activities beyond the post five year point, as these types of habitats often require longer periods of time to achieve parity with the reference condition.

Prior to restoration, the vegetation community at TFH was dominated by a mix of freshwater species (i.e., *Calamagrostis canadensis, Eleocharis palustris, Myrica gale, Chamaedaphne calyculata*), and the soils were highly waterlogged and consisted of mainly peat and root fragments and very little inorganic material. The site could therefore be characterized as a poorly drained fresh water wetland consisting of a shallow open water, marsh, fen and bog-like habitat conditions, with highly variable water levels and periodic salt water intrusion.

The results of the 2016 year one post-restoration monitoring, as presented in this report, revealed that site is behaving hydrologically as the original modeling and design predicted and that a corresponding shift in habitat conditions, particularly in the front/main portion of the site, has been initiated. The vegetation community assemblage has begun the process of transitioning to a more halophytic species dominated one. A decrease in water and organic matter content and a corresponding increased bulk density were recorded for a majority of the soil cores and are consistent with improved drainage and regular tidal flow. That the sediment cores taken within the main tidally influenced portion of the site, which is also the part of the site where seaweed would have been most heavily deposited during the 2016 winter months, did not exhibit an increase in organic matter content suggests that much of the seaweed was transported out of the site rather than fully decomposing in-situ and incorporated into the site. As the soils within and immediately surrounding the former central pond continue to dewater and consolidate, it is expected that the colonization of these areas by halophytic plant species will increase. In the interim, the exposed mudflat is serving as valuable forage habitat for shorebirds and waterfowl (at least six different species were observed feeding within the site; three families of ducks were present at the site during the summer months) (Figure 34).

The installation of the new tidal crossing in 2015 resulted in the elimination of the hydrological restriction and the restoration of a more natural hydrological regime to the site. In addition to the increased frequency, extent and duration of tidal flooding, the new crossing also re-established fish and waterfowl passage[8] and the transport of materials (i.e., seaweed wrack) into and out of the site; reduced flood risk (by freshwater); initiated a transition in the vegetation community structure (i.e., re-colonization by halophytic species); reconnected the site to the broader estuarine system; and the general long-term improvement in the ecological integrity and resilience of the site. Although at this early stage in the recovery process much of the documented changes in physical and biological conditions are concentrated in the “front” portion of the site, the restored hydrology should ultimately be to the benefit of the entire wetland area, as well as surrounding upland habitats and downstream marine environment.

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[8] A variety of estuarine fish and waterfowl species were observed moving into and out of the restoration site through the new crossing across a range of water level conditions (i.e., mummichogs on leading edge of flood and ebb tide; adult & juvenile waterfowl at low tide)

Figure 34 One of the three families of ducks that were regularly seen at the site during the summer months. Photograph by CBWES, 10 August 2016.

Restored Area

The results of the first year of post-restoration monitoring, as discussed in this report, indicate that the hydrological and habitat conditions within the TFH system are responding in a positive manner to the original intervention. One unanticipated and undesirable development, from a local community perspective, that has resulted from the project is the deposition of large amounts of aquatic plant material (seaweed) during the winter months (as observed during 2017 winter walk), and the decomposition of which during the spring resulted in strong unpleasant odors.

Based on the 2011 DEM, hydrology, and geo-referenced low-altitude aerial photography, the estimated area of wetland habitat at TFH was 2.26 ha (Figure 35). Based on the 2016 data, the total wetland area has been revised to 2.21 ha (the 2016 DSM helped refine the wetland boundary). The new tidal crossing does allow for the regular flooding of approximately 0.9 ha (MHW) of the site by tidal waters and 1.5 ha under high water conditions (HWL). Although the portion of the site that is currently directly flooded by tidal waters is less than the total area, significant enhancement of form and function, as well as access for species and the transport of materials are anticipated across the entire site. The success of this project also means that as local sea level rises, the frequency duration and extent of tidal flooding will increase as will the amount of salt marsh habitat.

In summation, the TFH restoration site has begun to exhibit considerable evidence of returning to its former tidal wetland and salt marsh condition and that following the first year of recovery, the primary tidal wetland parameters are responding in a positive manner.

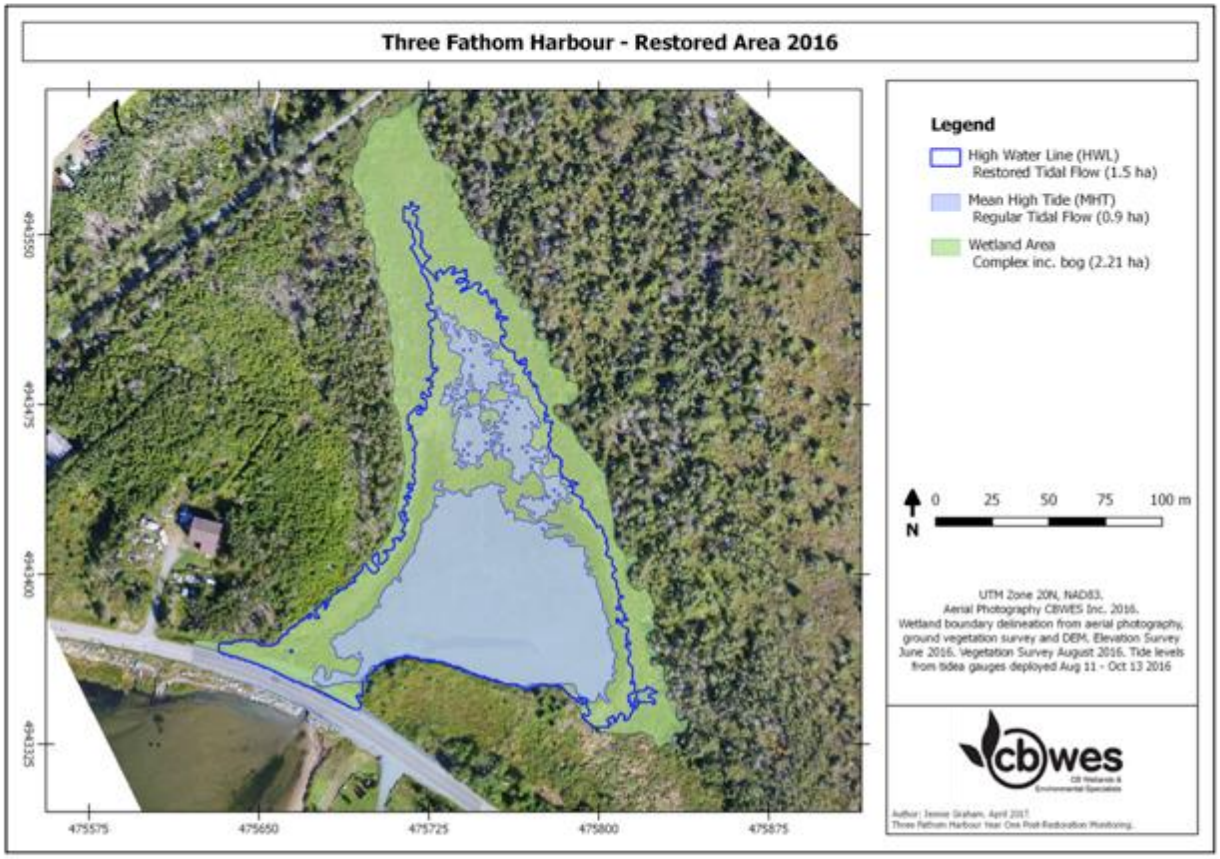

Figure 35 Estimated area of recovering tidal wetland habitat at COG based on 2011 hydrology, elevation and vegetation data.

6.0 Recommendations for Post-restoration Monitoring

It is recommended the post-restoration monitoring program as outlined in Table 1 (Section 2.3) and described in chapter 3, continue to be followed. This program will enable the continued documentation of the ecological conditions, changes and habitat/species responses to restoration and the determination of project success. Additional winter and spring site visits to monitoring the seaweed wrack situation are advised, given the concerns of local residents and the potential impact excessive deposition of wrack material could have on the rate (delayed) of revegetation at the site.

7.0 References

Able, K.W., T.M Grothues, S.M. Hagan, M.E. Kimball, D.M. Nemerson and G.L. Taghon. 2008. Long term response of fishes and other fauna to restoration of former salt hay farms: multiple measures of restoration success. Reviews in Fish Biology and Fisheries 18:65-97

Adaptation Canada. 2016. A National Symposium on Climate Change Adaptation. Ottawa, ON. 12-14 April 2016.

Atlantic Canada Coastal and Estuarine Science Society (ACCESS). 2014. Annual Conference. Halifax, NS. 12-14 June 2014.

Atlantic Canada Coastal and Estuarine Science Society (ACCESS). 2012. ACCESS 2012 Annual General Meeting. May 10 – 13, 2012. Halifax, NS

Atlantic Canada Coastal and Estuarine Science Society (ACCESS). 2008. ACCESS Conference 2008: Where the People Meet the Ocean: Nearshore Studies. Bedford Institute of Oceanography, May 14-15. Halifax, NS.

Atlantic Flood Management Conference (AFMC). 2015. Truro, NS. 5 March 2015.

Bay of Fundy Ecosystem Partnership (BoFEP). 2009. 8th BoFEP Science Workshop "Resource Development and its implication in the Bay of Fundy and Gulf of Maine". May 26-29. Acadia University, Wolfville, NS.

Bay of Fundy Ecosystem Partnership (BoFEP). 2011. Protecting the Watersheds and Estuaries of the Bay of Fundy: Issues, Science and Management. The 9th BoFEP Bay of Fundy Science Workshop. Saint John, New Brunswick. 27-30 September.

Blott, S.J. and K. Pye. 2001. Gradistat: A grain size distribution and statistics package for the analysis of unconsolidated sediment. Earth Surface Processes and Landforms 26: 1237-1248.

Bowron, T.M., N.C. Neatt, J.M. Graham and B. Lemieux. 2011a. Three Fathom Harbour Tidal Wetland Restoration Project: Feasibility and Design. Report prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Report No. 6. Halifax, NS.

Bowron, T.M., N.C. Neatt, J.M. Graham and B. Lemieux. 2011c. Tennycape River Tidal Wetland Restoration Project: Feasibility and Design. Report prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Report No. 7. Halifax, NS.

Bowron, T.M., N.C. Neatt, J.M. Graham, D. van Proosdij, and J. Lundholm. 2016. Mavillette Tidal Wetland Restoration Project: DEM, Hydrology and Design. Report prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Report No. 11. Halifax, NS.

Bowron, T.M., N.C. Neatt, J.M. Graham, D. van Proosdij, and J. Lundholm. 2014. Pre-restoration monitoring of the Morris Island salt marsh restoration project. Report prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Publication No. 40. Halifax, NS.

Bowron, T.M., N.C. Neatt, J.M. Graham, D. van Proosdij, J. Lundholm, and B. Lemieux. 2015a. Post-Construction Monitoring (Year 5) for the Cogmagun River Tidal Wetland Restoration Project. Report prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Publication No. 42. Halifax, NS.

Bowron, T.M., N.C. Neatt, J.M. Graham, D. van Proosdij, J. Lundholm, and B. Lemieux. 2015b. Post-Construction Monitoring (Year 5) for the St. Croix River High Salt Marsh and Floodplain Wetland Restoration Project. Report prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Publication No. 42. Halifax, NS

Bowron, T.M., N.C. Neatt, J.M. Graham, D. van Proosdij, J. Lundholm, and B. Lemieux. 2012b. Post-Restoration Monitoring (Year Five) of the Smith Gut Salt Marsh Restoration Project. Report prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Publication No. 29. Halifax, NS.

Bowron, T.M., N.C. Neatt, J.M. Graham, D. van Proosdij, J. Lundholm, and B. Lemieux. 2012a. Pre-Restoration Monitoring (Baseline) of the Three Fathom Harbour Tidal Wetland Restoration Project. Report prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Publication No. 32. Halifax, NS.

Bowron, T.M., N.C. Neatt, J.M. Graham, D. van Proosdij, J. Lundholm, and B. Lemieux. 2013a. Post-Restoration Monitoring (Year 7) of the Cheverie Creek Salt Marsh Restoration Site. Report prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Publication No. 33. Halifax, NS.

Bowron, T.M., N.C. Neatt, J.M. Graham, D. van Proosdij, J. Lundholm and B. Lemieux. 2013b. Post-Restoration Monitoring (Year 5) of the Lawrencetown Lake Salt Marsh Restoration Project. Report Prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Publication No. 35. Halifax, NS.

Bowron, T.M.; Neatt, N.C.; van Proosdij, D.; Lundholm, J. and J. Graham. 2011b. Macro-tidal Salt Marsh Ecosystem Response to Culvert Expansion. *Restoration Ecology*. Vol. 19. No. 3.

Burden, A.; Garbutt, R.A.; Evans, C.D.; Jones, D.L.; Cooper, D.M.. 2013 Carbon sequestration and biogeochemical cycling in a saltmarsh subject to coastal managed realignment. *Estuarine, Coastal & Shelf Science*, 120. 12-20. 10.1016/j.ecss.2013.01.014

Cahoon, D.R., J.C. Lynch, and R.M. Knaus. 1996. Improved cryogenic coring device for sampling wetland soils. Journal of Sedimentary Research 66: 1025 – 1027.

Canadian Land Reclamation Associate – Atlantic Chapter (ARC). 2015. 8th Annual Atlantic Reclamation Conference. Fredericton, NB. 29-31 October 2014.

Canadian Land Reclamation Associate – Atlantic Chapter (ARC). 2014. 7th Annual Atlantic Reclamation Conference. Wolfiville, NS. 20-21 October 2015.

Canadian Land Reclamation Association (CLRA). 2007. Land Reclamation & Environmental Stewardship AGM/Conference. Lord Nelson Hotel, August 25 – 31. Halifax, NS.

Canadian Land Reclamation Association (CLRA). 2012. 37th National Conference. September 25-28, 2012. Sydney, Nova Scotia.

Canadian Land Reclamation Association Atlantic Chapter (ARC). 2008. Atlantic Reclamation Conference 2008. Nova Scotia Museum of Industry, October 20 & 21. Stellarton, NS.

Canadian Land Reclamation Association Atlantic Chapter (ARC). 2009. “From the Ground Up” Atlantic Reclamation Conference 2009. November 3 – 5. Halifax, NS.

Canadian Land Reclamation Association Atlantic Chapter (ARC). 2010. Atlantic Reclamation Conference 2010. October 27-29. Halifax, NS.

Canadian Land Reclamation Association Atlantic Chapter (ARC). 2013. Atlantic Reclamation Conference. 3 October. Sackville, New Brunswick.

Canadian Water Resources Association (CWRA). 2008. Maritime Water Resources Symposium: Watershed Health, Planning and Management. Nova Scotia Community College Waterfront Campus. August 21 – 23. Dartmouth, NS.

CBCL Limited (CBCL). 2011. NSTIR – Antigonish Wetland Compensation Project: Wetland Compensation Proposal & Baseline Inventory Report (Addendum Report). Prepared for the Nova Scotia Department of Transportation and Infrastructure Renewal.

Coastal and Estuarine Research Federation (CERF). 2009. Estuaries and Coasts in a Changing World. International Conference, November 1 – 5. Portland, Oregon.

Coastal and Estuarine Research Federation (CERF). 2011. Societies, Estuaries & Coasts: Adapting to Change. 21st Biennial Conference of the Coastal and Estuarine Research Federation. Daytona Beach, Florida, USA, 6-10 November.

Coastal and Estuarine Research Federation (CERF). 2013. Toward Resilient Coasts and Estuaries, Science for Sustainable Solutions. 3-7 November. San Diego, California.

Coastal and Estuarine Research Federation (CERF). 2015. Grand Challenges in Coastal & Estuarine Science: Securing Our Future. Portland, Oregon. 8-12 November 2015.

Ecology Action Centre (EAC). 2007. Six Years in the Mud – Restoring Maritime Salt Marshes: Lessons Learned and Moving Forward. Bedford Institute of Oceanography, February 1 – 2. Halifax, NS.

Environment Canada Gulf of Maine HOTO Projects Results & Collaborative Opportunities Workshop (HOTO). 2015. Dartmouth, NS. 15 May 2015.

Estuarine Research Federation (ERF). 2007. 18th International Conference of The Estuarine Research Federation - Estuarine Interactions: Biological-Physical Feedbacks and Adaptations. Providence Place, November 4 – 8. Providence, Rhode Island.

Forbes, D.L., Manson, G.K., Charles, J., Thompson, K.R., Taylor, R.B. 2009: Halifax Harbour extreme water levels in the context of climate change: scenarios for a 100-year planning horizon, Geological Survey of Canada, Open File 6346, 21 p.

Garbutt, A. and Wolters, M. 2008. The natural regeneration of salt marsh on formerly reclaimed land. Applied Vegetation Science. Vol. 11. Pp. 335-344.

Kwak, T. and J.B. Zedler. 1997. Food Web Analysis of Southern California Coastal Wetlands Using Multiple Stable Isotopes. Oecologia. 110: 262-277.

Lord, J., T. Bowron, R, Wyma. (eds.) 2016. Landscapes/Paysages: Wet Places. The Canadian Society of Landscape Architects. Vol. 18. No. 1. Spring 2016.

McCave, I.N.; Hall, I.R. and G.G. Bianchi. 2006. Laser vs settling velocity differences in silt grain size measurements: estimation of palaeocurrent vigour. *Sedimentology* 53:919-928.

Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold Co., New York, N.Y.

Mitsch, W.J. and J.G. Gosselink. 2007. Wetlands 4th ed. John Wiley & Sons, New Jersey, USA.

Mitsch, W.J. and J.G. Gosselink. 2010. Wetlands 8th ed. John Wiley & Sons, New Jersey, USA.

Mitsch, W.J., L. Zhang, K.C. Stefanik, A.M. Nahlik, C.J. Anderson, B. Bernal, M. Hernandez, and K. Song. 2012. Creating Wetlands: Primary Succession, Water Quality Changes, and Self-Design over 15 Years BioScience. Vol. 62 No. 3. Pp. 237-250.

Neatt, N.C., T.M. Bowron, J.M. Graham, J. Lundholm, and D. van Proosdij. 2013. Post-Construction Monitoring (Year 7) of the Walton River Salt Marsh Restoration Project. Report Prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Publication No. 34. Halifax, NS.

Neckles, H. and M. Dionne. (eds.) 2000. Regional Standards to Identify and Evaluate Tidal Wetland Restoration in the Gulf of Maine. A GPAC Workshop. Wells National Estuarine Research Reserve, Wells, ME.

Neckles, H.A., M. Dionne, D.M. Burdick, C.T. Roman, R. Buchsbaum, and E. Hutchins. 2002. A Monitoring Protocol to Assess Tidal Restoration of Salt Marshes on Local and Regional Scales. Restoration Ecology 10(3): 556 – 563.

Packham, J.R. and A.J. Willis. 1997. Ecology of Dunes, Salt Marsh and Shingle. Chapman & Hall, New York, NY. pp. 87 – 118.

Perry, J. E; T.A. Barnard Jr.; J.G. Bradshaw; C.T. Friedrichs; K.J. Havens; P.A. Mason; W.I. Priest III; and G.M. Silberhorn. 2001. Creating Tidal Salt Marshes in the Chesapeake Bay. Journal of Coastal Research. Special Issue No. 27, 170 – 191.

Pett, R. 2015. What caused the stink in Three Fathom Harbour in the summer of 2015. Presentation prepared for the Nova Scotia Department of Internal Services. Halifax, NS.

Porter, C.; Lundholm, J.; Bowron, T.; Lemieux, B.; van Proosdij, D.; Neatt, Na.; Graham, J.. 2015. Classification and environmental correlates of tidal wetland vegetation in Nova Scotia, Canada. Botany. DOI: http://www.nrcresearchpress.com/doi/10.1139/cjb-2015-0066#.VgMAoo9Viko

Redfield, A.C. 1972. Development of a New England Salt Marsh. Ecological Monographs 42(2): 201 – 237.

Restore America's Estuaries (RAE). 2010. 5th National Conference on Coastal and Estuarine Habitat Restoration - Preparing for Climate Change: Science, Practice and Policy. Galveston, Texas. November 13 – 17.

Restore America's Estuaries (RAE). 2013. Mid-Atlantic Living Shorelines Summit. 9-11 December. Cambridge, Maryland.

Restore America's Estuaries 7th National Summit on Coastal and Estuarine Restoration (RAE). 2014. National Harbour, Maryland. 1-6 November 2014.

Roman, C.T., and D.M. Burdick. (eds.) 2012. Restoring Tidal Flow to Salt Marshes: A Synthesis of Science and Management. Island Press, Washington, DC.

Roman, C.T., K.B. Raposa, S.C. Adamowicz, M-J. James-Pirri, and J.G. Catena. 2002. Quantifying Vegetation and Nekton Response to Tidal Restoration of a New England Salt Marsh. Restoration Ecology 10(3): 450-460.

Roman, C.T., K.B. Raposa, S.C. Adamowicz, M-J. James-Pirri, and J.G. Catena. 2002. Quantifying Vegetation and Nekton Response to Tidal Restoration of a New England Salt Marsh. Restoration Ecology. Vol. 10(3): 450-460.

United States Geological Survey (USGS). 2005. Sediment Elevation Table (SET). U.S. Department of the Interior, U.S. Geological Survey, Patuxent Wildlife Research Center. http://www.pwrc.usgs.gov/ Last Updated: 16 February 2005.

van Proosdij, D., J. Lundholm, N.C. Neatt, T.M. Bowron, and J.M. Graham. 2010. Ecological Re-engineering of a Freshwater Impoundment for Salt Marsh Restoration in a Hypertidal System. Ecological Engineering 36(10): 1314-1332.

Appendix A - CBWES Supported Student/Research Projects

In addition to the undergraduate and graduate research projects described below, CBWES routinely collaborates with universities, community colleges, local elementary schools, and field naturalist groups to use the restoration sites as outdoor classrooms, provide student volunteers with valuable field experience, and supports student projects by providing research project ideas and access to data, information, expertise and supervision. CBWES has been a recognized NSERC Industrial Partner and multiple NSERC grant recipient since 2009. Through programs such as these, we are able to provide valuable internship opportunities to highly qualified undergraduate and graduate co-operative education students.

Current Projects

Environmental Science Honours

Department of Environmental Science
Saint Mary's University
Makeala MacIntyre
Comparing hydrodynamics in reference peatlands and the ditched Big Meadow Bog complex on Brier Island

Completed Projects

Masters of Applied Science

Department of Environmental Science
Saint Mary's University

Carly Wrathall
2014-2016
The Use of Spartina Species for Natural Shoreline Management

Christa Skinner
2013-2015
The biogeochemistry of a restoring macrotidal salt marsh: Cheverie Creek, Nova Scotia

Ben Lemieux
NSERC Industrial Postgraduate Scholarship
2010-2012
The influence of drainage network and morphological features on the vegetation recovery pattern of a macro-tidal wetland restoration project.

Jennie M. Graham
NSERC Industrial Postgraduate Scholarship
2010-2012
Tidal Creek Hydraulic Geometry for Salt Marsh Restoration in the Upper Bay of Fundy

Undergraduate Honours

Environmental Science
Saint Mary's University

Christa Skinner
2012-2013
Analysis of the Relationship Between Vegetative Community Structure and Geodetic Elevation for Salt Marsh Restoration in Hypertidal Systems

Alisha Glogowski
2012-2013
Information From the Wrack: Viability of Halophytic Vegetation within Tidal Wetland Wrack Mats

Alison Bijman
NSERC Industrial Undergraduate Student Research Awards
2011-2012
The Influence of Tidal Creek Networks on Wetland Vegetation Colonization in a Macro-tidal System

Rachel Deloughery (Dalhousie University)
2010
Contribution of seed hydrochory to re-colonization of vegetation in macro-tidal Bay of Fundy salt marsh restoration projects

Ben Lemieux
NSERC Industrial Undergraduate Student Research Awards
2009
The influence of soil seed bank on the colonization and restoration of a macro-tidal marsh

Emile Colpron
2008
The avian fauna of restored and natural salt marshes Minas Basin, Bay of Fundy, Nova Scotia

Directed Study Projects

Environmental Science
Saint Mary's University

Carly Wrathall
2014
Identification of the Challenges and Opportunities of Salt Marsh Creation as part of Shoreline Management Strategy

Carly Wrathall
2013

Vegetation Patterns and Primary Productivity of Natural and Restored Bay of Fundy Salt Marshes.

Undergraduate Class Research Projects

Department of Biology
Saint Mary's University

Shawn Adderley, Alison Bijman, Lydia Ephraim, Kristen Gallant, Robert Hicks, Sebastien Letourneau-Paci, Lori Miller, Chantal Pye, Benjamin Royal-Preyra, Shayna Weeks (Edited by Dr. Jeremy Lundholm)
Phragmites australis at Cogmagun Restoration Site

Appendix B - Structured Winter Walk

STRUCTURED WALK PHOTOGRAPHS TFH (3/2/17) (select images):

Figure 1 Transect one.

Figure 2 Transect two.

Figure 3 Transect three.

Figure 4 Transect four.

Figure 5 Transect five.

Figure 6 Upstream end of new tidal crossing and main tidal channel leading into site.