CB Wetlands & Environmental Specialists

A Report for:
Nova Scotia Department of Transportation and Infrastructure Renewal

Pre-Restoration Monitoring (Baseline) of the Three Fathom Harbour Tidal Wetland Restoration Project

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Executive Summary

The Three Fathom Harbour site was originally identified as a potential tidal wetland restoration project in 2004. In May 2011, the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR) commissioned CBWES Inc. to complete a restoration feasibility and design study for the site. It was determined that replacement of the existing tidally restrictive culvert with a more appropriated sized structure would result in a significant reduction in the hydrological barrier.

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

- 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 proposed restoration activities included the following components:

- Replacement of the existing buried, undersized culvert (0.82 m diameter) with a more appropriately sized culvert (3.5 to 4 m diameter) in order to restore a more natural tidal regime to the system and to improve fish passage; and
- Conduct a pre- and post-restoration monitoring program to ensure project success.

The purpose of the monitoring program, and this years' phase of it, was to:

- Document the efficacy of the compensation being undertaken to restore the Three Fathom Harbour tidal wetland system;
- Establish a baseline of physical, chemical and biological indicators against which to compare the nature, extent and direction of change, in habitat conditions, as a result of the restoration activity; and
- Document restoration progress and determine project success (restored marsh exhibits similar physical, chemical and biological characteristics as the reference site), by comparing the post-restoration habitat conditions to those which were present prior to restoration and to the reference condition.

Pre-restoration data were collected for geospatial attributes, hydrology, soils and sediments, vegetation, nekton (fish) and benthic invertebrates. The information collected will serve as a baseline against which to compare post-restoration habitat conditions and will provide insight into site changes as a result of the restoration activities. The monitoring conducted as part of this restoration project will also contribute to our

collective understanding of salt marsh ecology, and the effectiveness of restoration efforts in the region.

The results for the pre-restoration monitoring are detailed in the following report and summarized below.

Geospatial Attributes
The wetland boundary, as delineated by elevation and the tree line, was determined to encompass a potential wetland area of approximately 2.26 ha. The potential restorable area was found to be in the range of 1.71 ha (projected extent of flooding by largest recorded tide - 15 June 2011) and the 2.26 ha site boundary. Mean surface elevation was 1.08 m compared to 0.78 m (Lawrencetown reference site) and 0.88 m (Lawrencetown restoration site). The site could be 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. The site was historically connected hydrologically to Three Fathom Harbour and Porters Lake.

Hydrology
Hydroperiod and Tidal Signal:
Water levels within the site fluctuated minimally with the recorded tidal conditions in the harbour and appeared to be predominantly driven by freshwater flows (precipitation; runoff). With a larger and unobstructed culvert in place (3.5 to 4 m diameter), water levels within the site would rise and fall in relation to tidal conditions. By maintaining the current culvert invert elevation, water retention within the site at low tide would continue to flood an estimated 0.13 ha. Not considering storm (precipitation) events, 50% of recorded tides were sufficient to flood a portion of the site. Utilizing the maximum recorded tide, under unrestricted conditions, an area of approximately 1.71 ha would be flooded. This would represent an increase in area flooded, improved water quality (salinity, temperature, dissolved oxygen), increased frequency of inundation, and restoration of wetland vegetation community, fish passage and overall wetland productivity.

Soils and Sediments
Pore Water Salinity:
Interstitial pore water salinity levels over the majority of the site were zero. Salinity levels above 1 ppt (maximum 7 ppt) were recorded at the four stations closest to the culvert and bordering central pond and channel. Salinity readings indicated that aside from limited tidal (estuarine) intrusion through the culvert influencing the area immediately upstream of the causeway, the majority of the site could be characterized as freshwater habitat.

Soil Characteristics:
All of the cores were highly waterlogged, consisting mainly of peat and root fragments with low amounts of inorganic sediment, with many of the cores classified as peat. Water content and organic matter content were higher than typical of tidal wetlands. Bulk density values were low and within the range of peatland soils. All cores were classified

as very close to 100% mud and were poorly sorted. Given the highly organic nature of the soils found within the potential restoration site, careful attention will need to be given to below ground decomposition and redox potential. Such waterlogged soils may not support the desired vegetative communities. The site may require greater amount of time (than previous restoration projects) for suitable abiotic conditions to occur and hence restoration of wetland communities and productivity.

Vegetation
The vegetation survey identified no salt marsh (haloyphytic) vegetation of any kind. There is a complete separation between reference site plots which range from low marsh to high marsh, to brackish. The vegetation community structure is anticipated to continue to be highly divergent from that of the reference condition. Site is dominated by fen/freshwater wetland species including *Myrica gale*, *Typha latifolia, Scirpus validus, Calamagrostis canadensis*. The study site has greater average species richness than is typical of a halophytic species dominated salt or brackish marsh.

Nekton
Mummichog (*Fundulus heteroclitus*) was the only fish species encountered within the restoration site. Juveniles were captured in the invertebrate activity traps in August, and adults were captured in the fish traps later in the season. Access to the site for larger, non-resident species would be extremely limited due to the culvert and the hydrology/habitat conditions within the site being poor.

Aquatic Invertebrates
Activity trap samples contained a mix of estuarine and freshwater animals, and showed moderate diversity and abundance. Samples were typically dominated numerically by water boatmen (Corixidae) and small copepod crustaceans. Samples also included ostracods and a Hydrachnid (water mite), as well as occasional freshwater insects including Coleoptera (beetles), Odonata (dragonfly nymphs) and Hemiptera (water bugs), and one fish species (Banded Killifish—*Fundulus diaphanus*).

Summary
Pre-restoration monitoring confirmed TFH to be a freshwater wetland environment with a mix of open water, peat bog and fen conditions with limited salt water (tidal) influence. Characteristics of each wetland type were present within the soil, water and vegetation community. Hydrological modeling based on recorded water levels within Three Fathom Harbour and marsh surface elevations within the site indicate that the site would experience tidal flooding if the restriction was reduced/eliminated. This modeling also indicated that restoring a more natural hydrological regime to the site would facilitate the self re-organization of the abiotic and biotic conditions within the site and the eventual development of a more tidally influenced self-sustaining coastal wetland system.

While it is difficult to predict the exact nature of the site’s end state, the project goals are achievable, and the re-introduction of regular tidal flow and the reconnection of the site to the broader estuarine system are anticipated to re-establish a range of tidal wetland habitat conditions that are persistent and ecologically resilient. Post-construction monitoring over a ten-year period will enable the documentation of early stages of the wetland recovery process and verification of an acceptable restoration trajectory.

Acknowledgements

CBWES Inc. would like to thank Greg Baker (Saint Mary's University - SMU); Alison Bijman, Christa Skinner and Emma Poirier (SMU); and Patrick Stewart (Envirosphere Consultants Limited) for their assistance with data collection, sample processing, analysis and report preparation.

Financial and in-kind support for this project include: Nova Scotia Department of Transportation and Infrastructure Renewal; Natural Sciences and Engineering Research Council of Canada (NSERC); Nova Scotia Department of Economic and Rural Development; Human Resources and Skills Development Canada; Intertidal Coastal Sediment Transport Research Unit (SMU); Maritime Provinces Spatial Analysis Research Centre (SMU); and the Community-Based Environmental Monitoring Program (SMU).

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. 2011). 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 provincial wetland approval associated with the Lakeland Elementary School (Porters Lake). 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 (this report). The program (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).

The potential restoration site is currently a 2.26 ha wetland area that was cut off from the larger Three Fathom Harbour estuarine system by the Three Fathom Harbour Road. The Three Fathom Harbour Road crosses the mouth of the potential restoration site via a causeway-culvert structure, however, the culvert is largely buried by sand and rock and is significantly undersized (only 0.82 m) to allow for adequate tidal flushing of the upstream wetland area. This resulted in an almost complete restriction of tidal flow and fish passage to the upstream wetland area. Culvert replacement is scheduled to take place during the 2013 construction season.

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, Nancy C. Neatt, Jennie M. Graham, Ben Lemieux, Alison Bijman and Christa Skinner with CBWES; Dr. Jeremy Lundholm, Dr. Danika van Proosdij, Greg Baker, and Emma Poirier with Saint Mary's University (SMU); and Patrick Stewart and Heather Levy (Envirosphere Consultants Ltd., Windsor, NS).

1.2 CBWES Inc.

Since 2005, CBWES has been involved in the restoration and monitoring of nine salt marsh restoration projects in Nova Scotia (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 four of these projects. In 2009, an Industrial Undergraduate Student Research Award (IUSRA) enabled CBWES to hire a SMU undergraduate student to conduct a research project titled "The influence of soil seed bank on the colonization and restoration of a macro-tidal marsh". The resulting undergraduate thesis is available from the SMU library. In 2010, CBWES secured two two-year NSERC Industrial Postgraduate Scholarships to support post-graduate student research projects, that are examining how surface morphology contributes to vegetative re-colonization following restoration, and developing a GIS-based model and protocol for use in the design of tidal wetland restoration projects in macro-tidal environments. A second IUSRA was received in 2011 to support a project exploring the influence of tidal creek networks on wetland vegetation colonization in a macro-tidal system. Summaries of these salt marsh restoration research projects, as well as the non-NSERC funded current and completed projects are provided in Appendix A.

In 2009, a peer-reviewed paper on the Cheverie Creek Restoration Project titled "*Macro-Tidal Salt Marsh Ecosystem Response to Culvert Expansion*" was published in *Restoration Ecology* (Bowron et al. 2011a). A paper on the Walton River Restoration Project titled *Ecological Re-engineering of a Freshwater Impoundment for Salt Marsh*

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

[2]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). 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' 2007 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).

Restoration in a Hypertidal System appeared in the journal *Ecological Engineering* (van Proosdij et al. 2010). A book chapter titled "Chapter 14 – Salt Marsh Tidal Restoration in Canada's Maritime Provinces" has been submitted for peer-reviewed publication in the book *Restoring Tidal Flow to Salt Marshes: A Synthesis of Science and Management* (Roman and Burdick In Press). Plans are underway to produce additional peer-reviewed publications during the coming year to continue to share the lessons learned from these projects and contribute to the growing knowledgebase of coastal wetlands and restoration in the region.

2.0 Study Sites and Monitoring Program

2.1 Three Fathom Harbour Restoration Site

The Three Fathom Harbour restoration site (TFH) is a 2.26 ha (5.6 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 Trans Canada Railway line (now the Trans Canada Trail), Highway 107 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 has resulted in the blockage of the downstream end of the culvert and further restriction (approaching complete) of hydrological exchange.

The existing structure, a concrete culvert, has 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 is not known due to the presence of the armour stone and sand. A period of heavy rain prior to the monitoring period resulted in extensive flooding of the site by freshwater. The resulting hydrologic pressure was sufficient to partially clear the downstream blockage (sand), allowing the site to drain and the creation of a temporary channel (Figure 5). Communication with local residents indicated that this was an uncommon occurrence, while one resident indicated that this was the first time in fifteen years that the site drained and a channel formed.

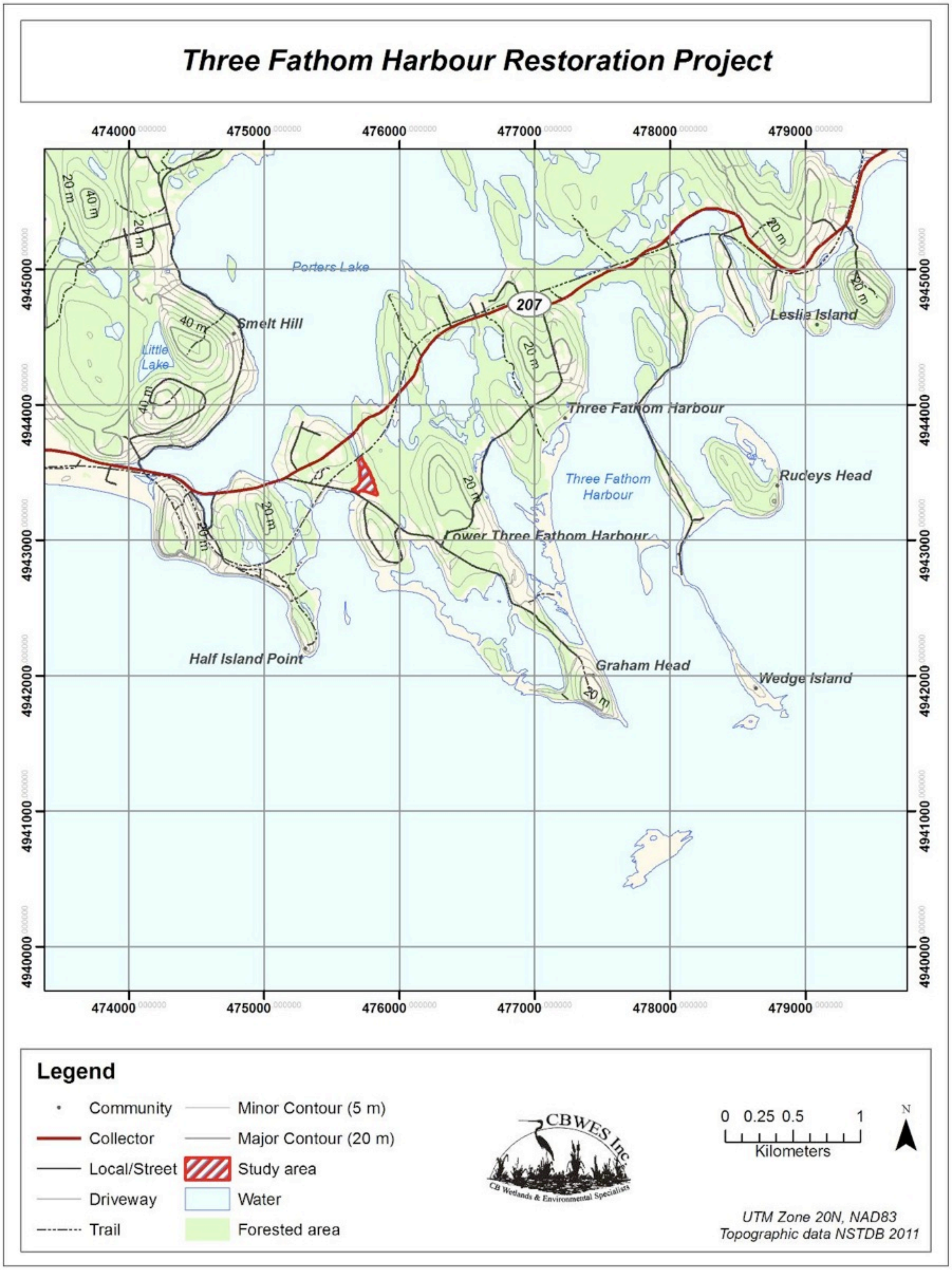

Figure 1 Location of TFH.

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

Figure 3 Landscape photograph of TFH. Photograph by T. Bowron, 25/6/11.

Figure 4 Upstream side of Three Fathom Harbour causeway and culvert. Photographs by T. Bowron, 25/6/11.

Figure 5 Downstream end of culvert buried by armour stone, and the temporary channel that was created by the spring freshet. Photograph by T. Bowron, 25/6/11.

2.2 Reference Site

A comparable (size, hydrology, vegetation community structure) unrestricted wetland suitable for use as a reference site could not be identified. Although not an ideal comparison, the neighbouring Lawrencetown Lake Salt Marsh Restoration and Reference sites (Bowron et al. 2012) (Figure 6) were used as a general habitat reference.

The Lawrencetown Lake Salt Marsh Restoration and Reference 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 7). 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 since 2006. 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 6). 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 (LT-R) in particular was the focus of the comparison for this report. LT-R follows a typical zonation expected of a salt marsh with low, mid and high marsh zones.

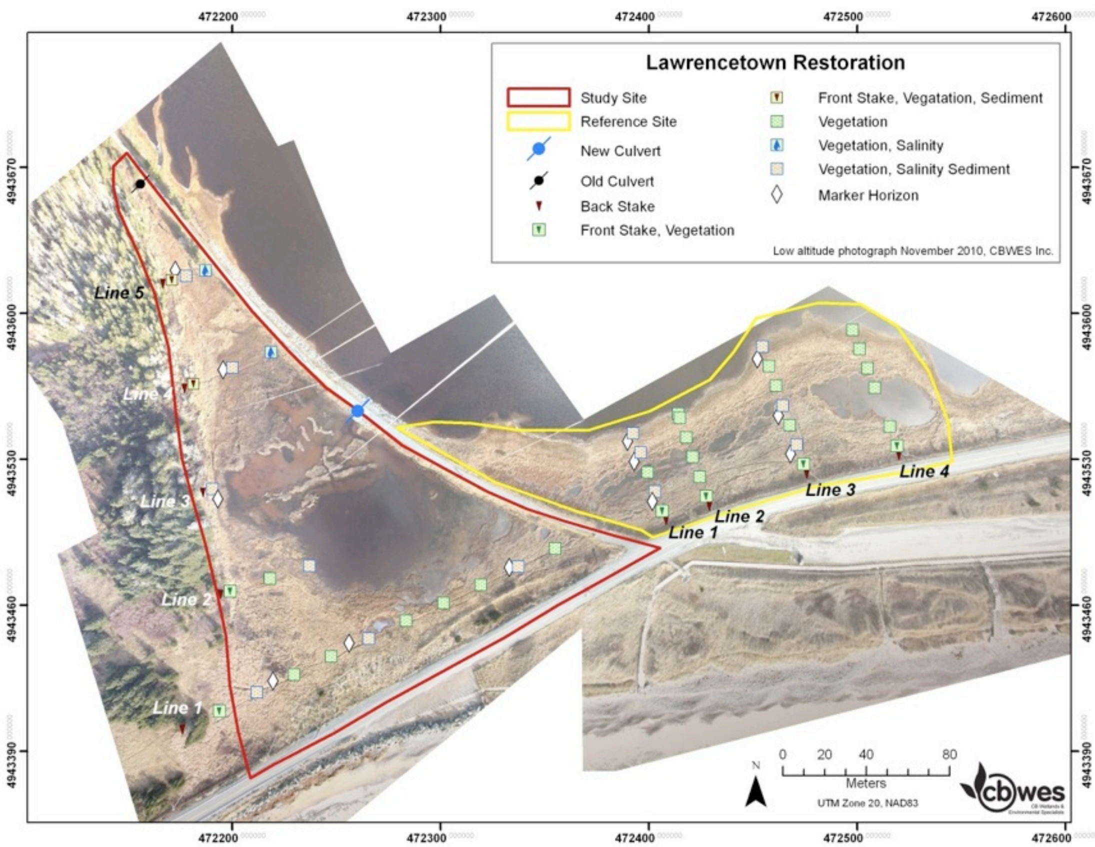

Figure 6 Lawrencetown Lake Restoration (red) and Reference site (yellow).

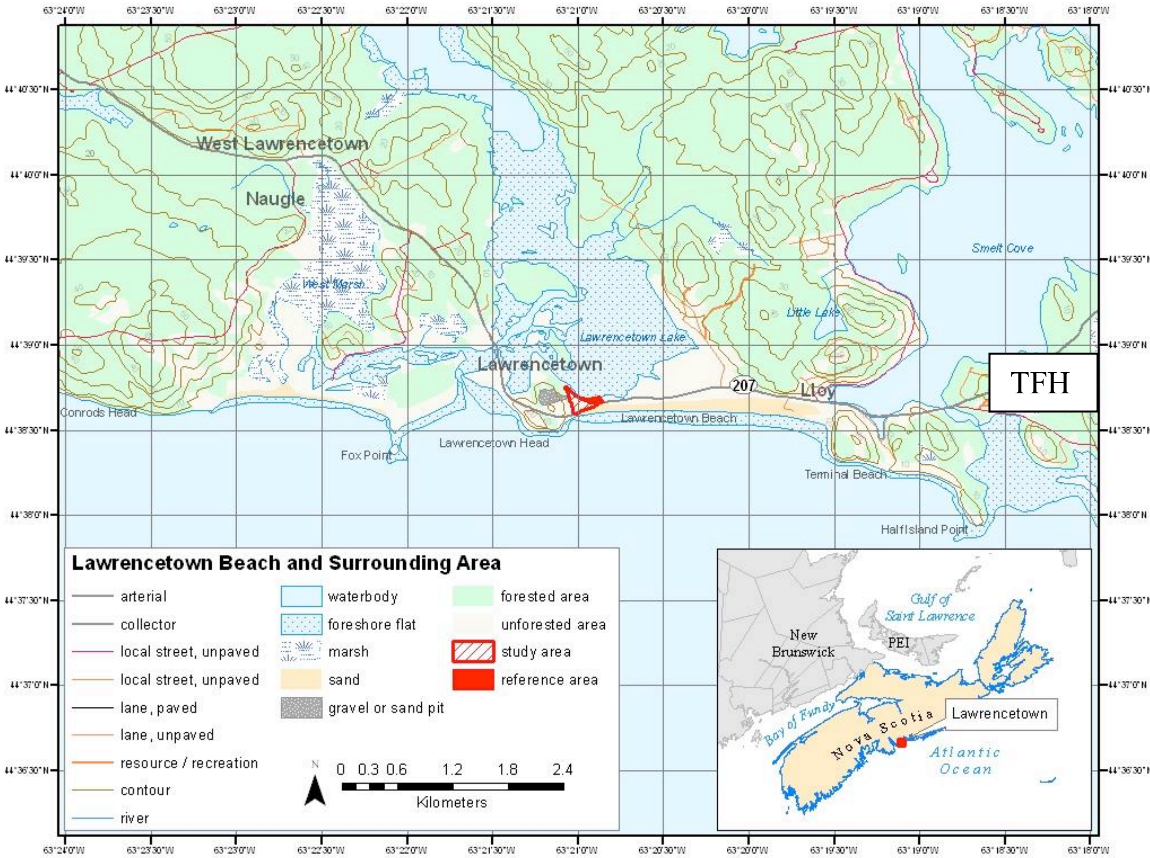

Figure 7 Location of Lawrencetown Lake restoration and reference sites, Halifax County, NS relative to Three Fathom Harbour (TFH) (base map downloaded from: www.geogratis.ca/geogratis/en/product/search.do?id=28954).

2.3 Monitoring Program

The TFH Tidal Wetland Restoration Monitoring Program was developed by CBWES based on experience with similar restoration projects in the region (Bowron et al. 2011a; Neckles et al. 2002; van Proosdij et al. 2010). The monitoring program will be used to document the changing habitat conditions following restoration; to evaluate the impacts of restored tidal flow; to indicate whether additional intervention is required; and to determine the ecological benefits of restoration (project success).

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, vegetation, fish and invertebrates) 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. Post-restoration monitoring activities are proposed for immediately following culvert replacement, as well as one, three, five and ten years post.

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	Sampling Frequency	Monitoring Year						
				Pre (2011)	Post-Restoration (2013-2023)					
					Post (2013)	1	3	5		10
Hydrology	Tidal signal	Automated water level recorders (5 minute intervals) (Solinst Levelogger (Model 3001)	Minimum 3 week period once per sampling season. 25/5/11 – 15/6/11 (Conducted as part of feasibility study)	S	Y	Y	Y	Y		Y
	Water quality (salinity, temperature, dissolved oxygen, pH)	YSI 650 MDS and YSI 600QS sonde Matched with nekton sampling events	Surface flood waters & pannes. Minimum 3 times per season, in conjunction with fish sampling events. 6/12/11	X	Y	Y	Y	Y		Y
Soils & Sediment	Marsh surface elevation	Digital elevation model (DEM). Total Station; Differential RTK GPS; LiDAR	Once per sampling year. Elevation survey: 27/5/11 (completed as part of feasibility study)	X		Y		Y		Y
	Interstitial pore water salinity	Electrical Conductivity Meter (FieldScout EC 110 Meter)	Once per month during field season 12/8/11; 30/9/11	X	Y	Y	Y	Y		Y
	Sediment accretion	Marker horizons & cryogenic corer	Installed during baseline; sampled once per year starting			Y		Y		Y

Category	Parameters	Sampling Method	Sampling Frequency	Monitoring Year						
				Pre (2011)	Post-Restoration (2013-2023)					
					Post (2013)	1	3	5		10
			in post-restoration year 1							
	Sediment Characteristics (bulk density, organic matter content, sediment type)	Sediment cores (soil samples) Paired samples: (30 ml syringe with base cut and 5 cm x 15 cm core).	Once per sampling year TFH – 8 cores 7/10/11	X		Y		Y		Y
	Redox potential	Oxidation Reduction Potential (ORP) meter 1 cm & 15 cm depth	Once per month during field season (minimum three sampling events); matched with pore water salinity sampling		Y	Y	Y	Y		Y
Vegetation	Composition Abundance Height	Point Intercept method (1 m^2 plots) Annually	30/8/11	X	Y	Y	Y	Y		Y
	Habitat/surface cover map(s)	Low-altitude aerial photography	Aerial photography conducted once per sampling year.	X		Y		Y		Y
Nekton	Composition Species richness Density Length	Minnow traps in pannes, tidal creeks and main channel (small fish); fyke net (30 m x 1 m; 6 mm mesh) on marsh surface (all sizes)	Minimum of two sampling events per sampling year following restoration of fish passage 6/12/11	X	Y	Y	Y	Y		Y

Category	Parameters	Sampling Method	Sampling Frequency	Monitoring Year						
				Pre (2011)	Post-Restoration (2013-2023)					
					Post (2013)	1	3	5		10
Aquatic Invertebrates	Abundance and species richness of aquatic invertebrates	Invertebrate Activity Traps (IAT)	Two traps per site per sampling event 12/8/11	X	Y	Y	Y	Y		Y
Winter Conditions	Ice/snow/wetland conditions	Structured winter walk; photographs along each transect	Once per year 7/3/12	X	Y	Y	Y	Y		Y

3.0 Methods

Pre-restoration sampling was initiated at TFH in May 2011 using a series of transects established in a non-biased, systematic sampling design. 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 8). Data collection was conducted at sampling stations established at equal intervals (20 m) along each transect. A combination of 100 m field tape, compass and Trimble R8 GNSS RTK (Real Time Kinematic) Global Positioning System[3] were employed to produce and digitally map, reproducible transects and sampling stations.

3.1 Habitat Map and Digital Elevation Model (DEM)

An elevation survey of TFH was conducted during the week of 23 May 2011 using a Trimble RTK GPS receiver, in order to create the DEM for the site. 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.

A habitat map and DEM were prepared in order to provide a foundation for monitoring activities and a benchmark against which changes in habitat conditions and marsh surface elevation could be compared post-construction (Figure 8). The DEM also provided crucial information required for the hydrology modeling conducted as part of the feasibility and design phase of the project (Figure 9; 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.

Habitat maps (surface cover) were also generated to document vegetation community structure and other important habitat features identified from low-altitude aerial photography, as well as data collected during the elevation and vegetation surveys.

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

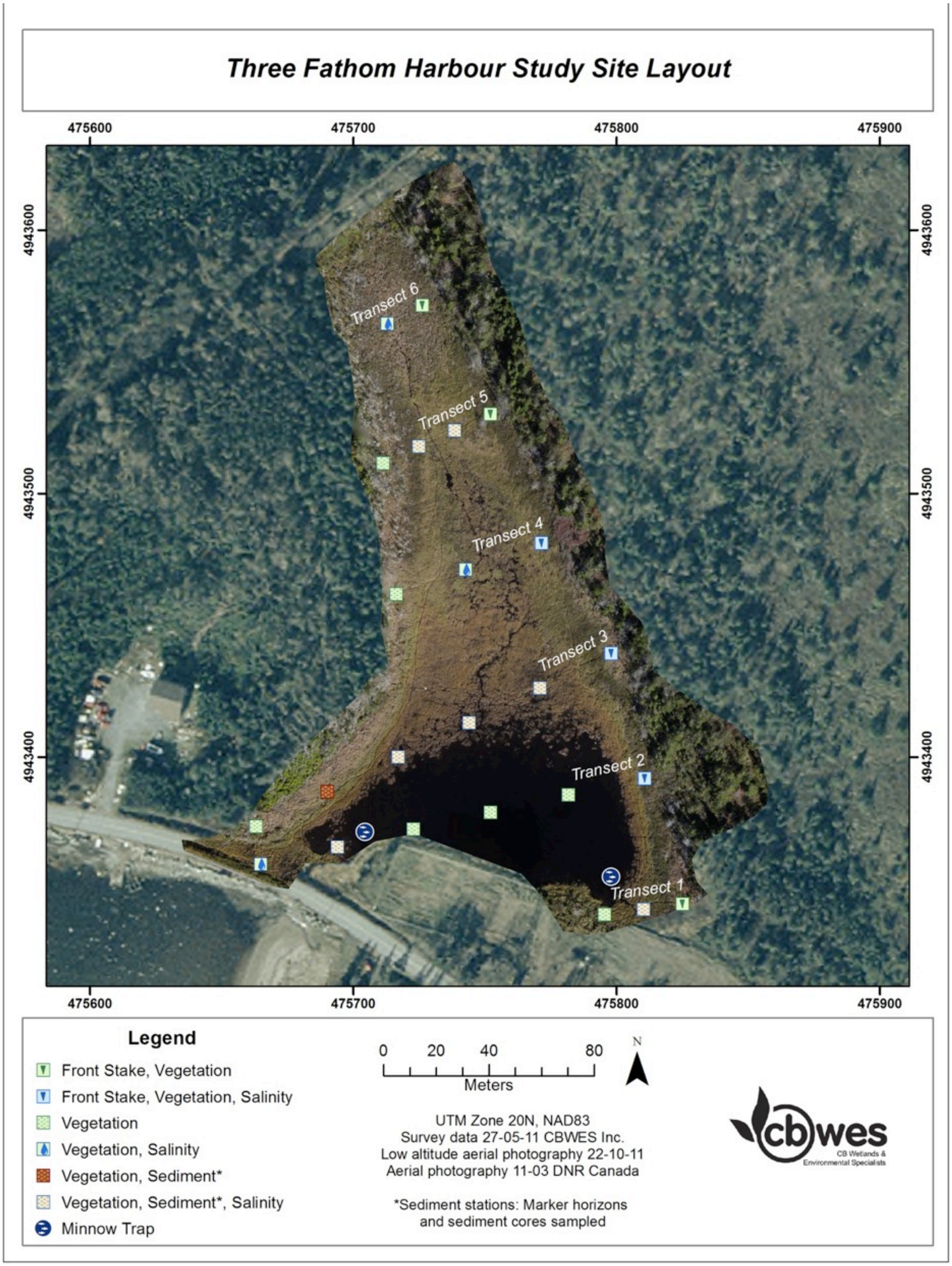

Figure 8 Sampling layout map for TFH depicting main marsh features, transects, and sampling locations.

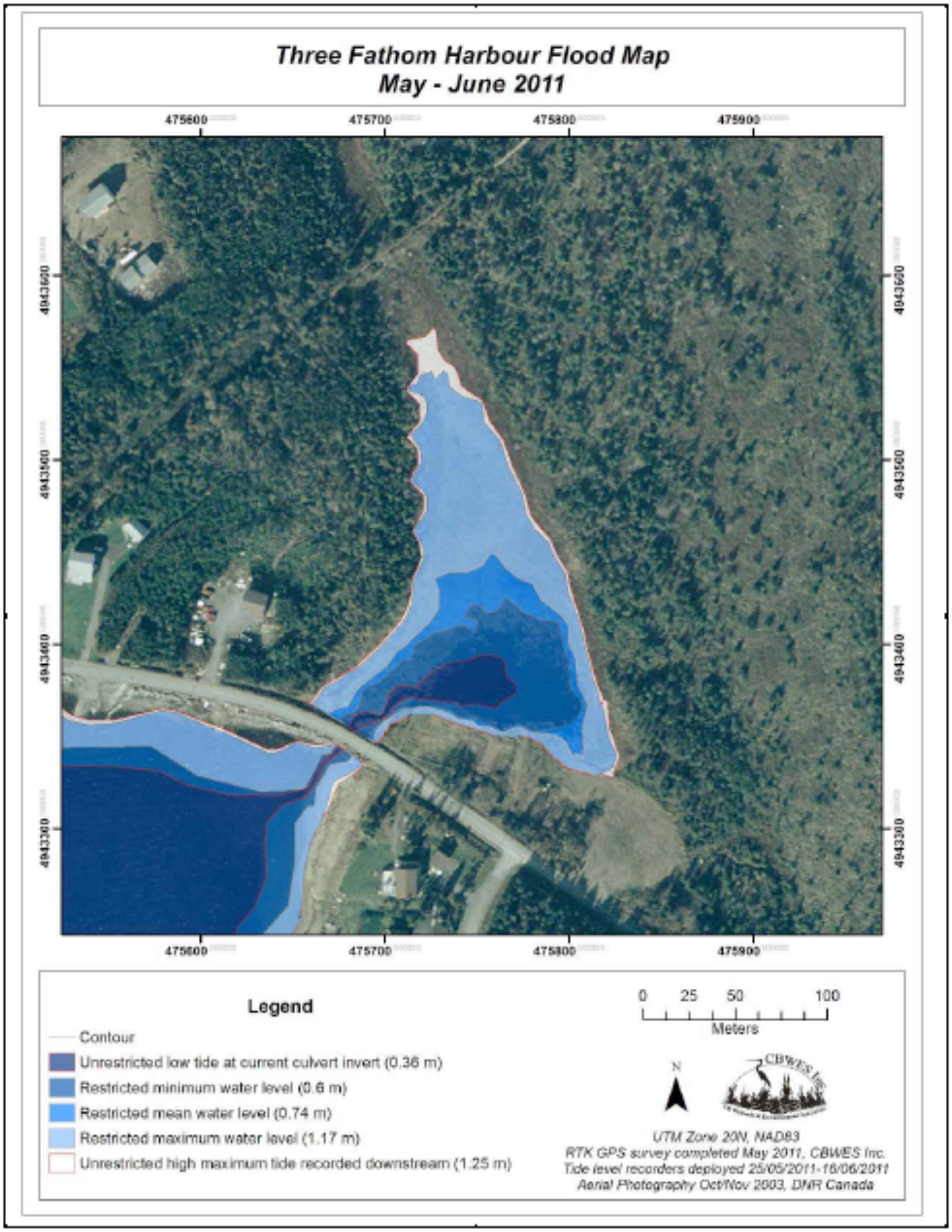

Figure 9 Flood map for TFH showing unrestricted flooding under low and high tide conditions and the restricted levels (min, mean, max) inside the site during the period 25 May to 16 June 2011.

3.2 Hydrology

The fundamental control on the structure and function of salt marsh 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 salt marsh that determines the area of marsh directly available as fish habitat. The hydroperiod of a salt marsh 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 pre-restoration hydroperiod (frequency and duration of tidal flooding) for TFH was modeled using the tidal signal data (pattern of water level change with reference to a fixed point) and the DEM. The tidal signal was measured using four Solinst Model 3001 Levelogger Golds (water elevation and temperature at five-minute intervals) and a Solinst Barologger[4] (atmospheric pressure and temperature). Automatic tide level recorders were deployed at three locations (in still wells; Figure 10) for the period of 27 May to 16 June 2011. To capture a full range of tidal conditions within Three Fathom Harbour (outside the site), one recorder was placed in channel leading from the culvert, while a second recorder was deployed below the low tide line within the Harbour. Two recorders were installed in the pond within the site (Figure 8).

The Barologger collects atmospheric pressure and temperature data, which is required for post-processing of the Levelogger data. The Barologger was installed in the upland adjacent to the restoration site. The instrument was installed in the upland above the restoration site to avoid submergence by water (Figure 8). The positions (elevation) of each of the units were surveyed using the GPS RTK. The data from the loggers were then downloaded into the Solinst Software Version 3[5] 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 flood metrics extension in ArcGIS. 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.

[4] Barologger is required for barometric compensation.
[5] www.solinst.com/Downloads/

Figure 10 Solinst Model 3001 Levelogger Gold and still well. Photographs by N. Neatt, 2008.

3.3 Soils and Sediments

Monitoring pore water salinity, sediment accretion rates, sediment elevation 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). Soil salinity (interstitial pore water salinity) is one of the main controls on the distribution and abundance of plant species in salt marshes (Niering and Warren 1980). Measuring pore water salinity throughout the early to mid growing season and in conjunction with water table depth monitoring can help explain changes in environmental conditions regulating plant growth, distribution and abundance and habitat responses to restoration activities.

Accretion of inorganic and organic material deposited onto the marsh surface by floodwaters and vegetation is one of the main processes that allow marshes to build vertically over time, offsetting increased tidal flooding. Failure to keep pace with increased flooding could result in the loss of salt marsh features and functions important to fish (loss of productivity and extent of habitat). Monitoring sediment accretion rates, elevation and determining organic content of marsh soils prior to engaging in restoration activities 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.

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.

Pore Water Salinity

Sampling locations for interstitial pore water salinity were matched with a subset of vegetation sampling stations at both sites (Figure 8 and Figure 6). At each of the fourteen sampling locations at TFH and nine at LT-R, both a shallow (15 cm) and a deep (45 cm) pore water salinity sample were taken *in situ* using a FieldScout EC 110 Meter[6]. Pore water salinity at both locations was conducted on 12 August and 30 September 2011.

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 decided that only elevation surveys and marker horizons (accretion) would be used (Figure 11). Replication of the DEM (years 3, 5, and 10 of the post-restoration monitoring program) and marker horizon measurements, should provide sufficient insight into any changes in overall marsh surface elevation and accretion rates following restoration.

Eight marker horizons were established at points throughout TFH that represent the different potential habitat zones (low, mid, high marsh) (Figure 11). 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 will be measured, in advance of culvert replacement in 2013, using a cryogenic corer (Figure 12) and methods as described by Cahoon et al. (1996). The markers will be sampled (cored) during years 3, 5, 7 and 10 following restoration in order to determine the mean rates of sediment accretion within the restoration site. This will be compared to the rates of accretion observed at LT(R). Seven markers were installed at LT and six markers at LTR (Figure 6). The markers at LT(R) were originally installed in November 2006 and measured annually.

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[6] http://www.specmeters.com/brands/field-scout/ec110/

Figure 11 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 12 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 7 October 2011 using a stratified random sampling procedure paired with a subset of vegetation sampling plots. Sediment sampling was conducted at eight locations at TFH and six at LT-R (Figure 8 and Figure 6). 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 frozen. 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 13).

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:

Bulk density (g/ml) = net dry weight (g) / 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).

Sediment type (using Coulter Laser Multisizer):

The grain size sample was dried at 65 ˚C to prevent fusing of clays and crushed using a mortar and pestle. A small subsample was placed in a 20 ml beaker and treated with 5 ml of 30% hydrogen peroxide within a fume hood to remove organic matter without damaging the particles. The beaker was then filled with an electrolight solution, sonified and processed through the Coulter Multisizer using standard protocols. The 100 micron tube was chosen since this would analyze grain sizes from 2.0 (clay) to 60 ìm (coarse silt) which was the anticipated grain size distribution. The average of two runs was used for analysis. The grain size distributions were analyzed using a customize script in Excel 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	Boulder
-9	512		
		Medium	Boulder
-8	256		
		Small	Boulder
-7	128		
		Very small	Boulder
-6	64		
		Very coarse	Gravel
-5	32		
		Coarse	Gravel
-4	16		
		Medium	Gravel
-3	8		
		Fine	Gravel
-2	4		
		Very fine	Gravel
-1	2		
		Very coarse	Sand
0	1		
	microns	Coarse	Sand
1	500		
		Medium	Sand
2	250		
		Fine	Sand
3	125		
		Very fine	Sand
4	63		
		Very coarse	Silt
5	31		
		Coarse	Silt
6	16		
		Medium	Silt
7	8		
		Fine	Silt
8	4		
		Very fine	Silt
9	2		
		Clay	

Figure 13 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 30 August 2011 and at LT-R on 23 August 2011, 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. Twenty-four plots were established at TFH and twenty-one plots at LT-R. 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 (LT-R) sites during 2011 (pre-restoration) 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 Nekton

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. Fish sampling activities prior to restoration were limited to a single sampling event (6 December 2011) using a set of four minnow traps in the pond within the restoration site (Figure 8). Traps were baited, set and allowed to fish for approximately 3 hours. Additional sampling events and methods (beach seine, fyke net) were not used due to the hydrology, sediment and tidal restricted conditions within the restoration site.

3.6 Aquatic Invertebrates

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/).

The aquatic invertebrate community within the TFH central pond was sampled using aquatic Invertebrate Activity Traps (IAT) (Figure 14). IAT were submerged and anchored within the water column of the pond and allowed to passively sample for approximately twenty-four hours. Two samples were taken on 12 August 2011. Traps were set on the date given and then retrieved the following day. Samples were run through a 0.5 mm sieve and all captured materials and organisms were field-preserved in 70% isopropyl alcohol for transport to the lab for processing.

Organisms were identified to an appropriate taxonomic level, typically species, using conventional literature for the groups involved (e.g. Barnes 1987; Gosner 1971). Organisms were identified by Patrick Stewart and Heather Levy of Envirosphere Consultants. Species abundance and number of species were estimated from the data.

Figure 14 Disassembled Invertebrate Activity Trap. Photograph by T. Bowron 2007.

3.7 Structured Winter Walk

On 7 March 2012, a structured winter site-walk was conducted at TFH and LT-R. Landscape photographs were taken along each transect from the forested upland edge at TFH and along the road at LT-R. Photographs were also taken of key features such as the culvert, pond, downstream side of highway, ice, areas of erosion or deposition and other features of interest.

4.0 Results and Discussion

4.1 Geospatial Attributes

DEM and Habitat Maps

A habitat map of TFH showing mean water level, central pond, vegetated wetland surface and the upland edge/site boundary is provided in Figure 15. The TFH DEM is presented in Figure 16. The wetland boundary, as delineated by elevation and the tree line, was determined to encompass a potential wetland area of approximately 2.26 ha. The potential restorable area was found to be in the range of 1.71 ha (projected extent of flooding by largest recorded tide - 15 June 2011) and the 2.26 ha site boundary. DEM statistics are provided in Table 2. Elevation profiles for the site show the center of the site to be lower in elevation than the edges and a gradual increase in elevation from the front (by the causeway) to the back (by the trail) of the wetland (Figure 18).

Table 2 Marsh surface elevation (DEM) statistic for TFH.

Minimum elevation	0.12 m
Maximum elevation	5.05 m
Mean elevation	1.08 m
Standard deviation	0.77 m

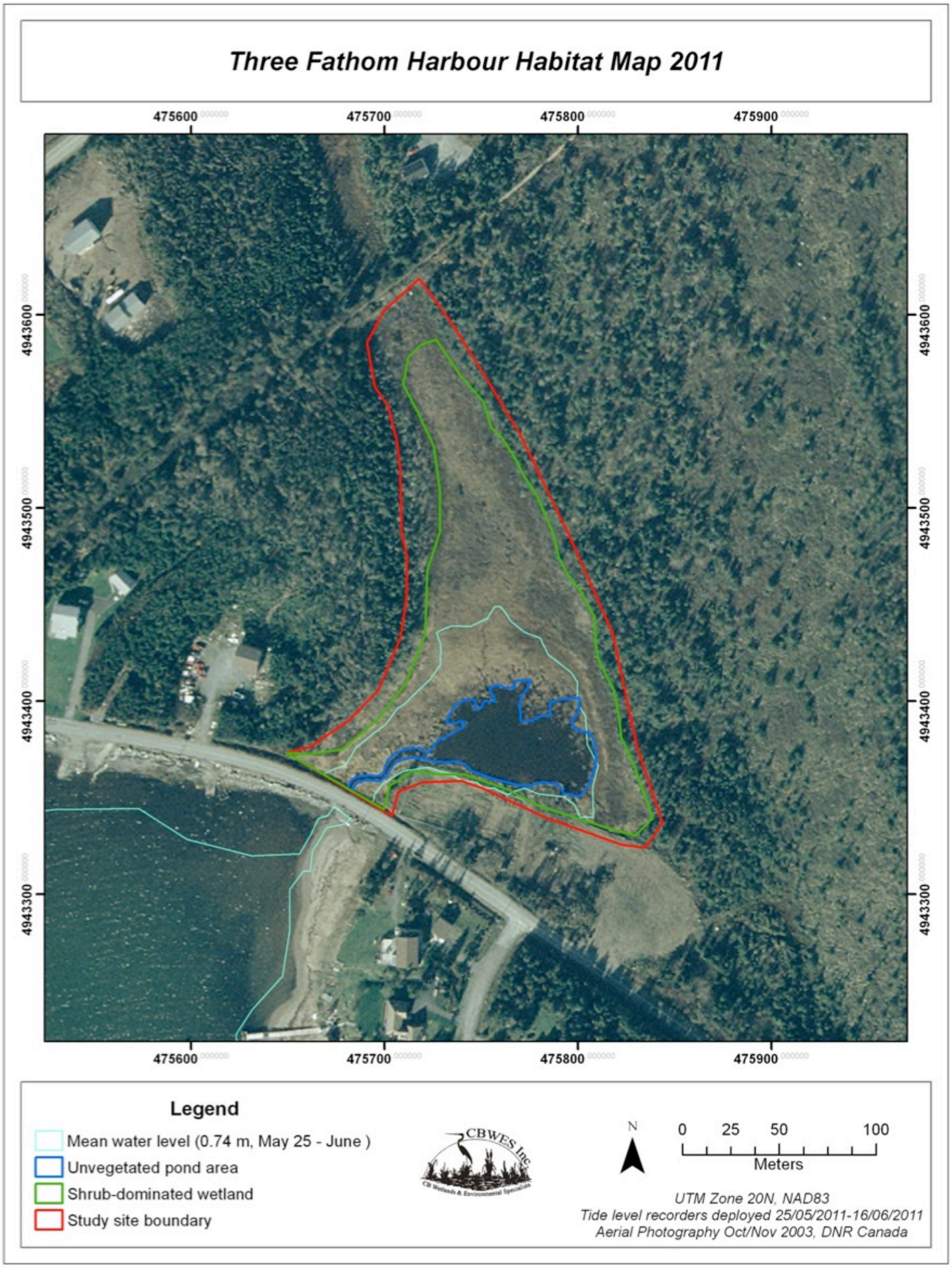


Figure 15 Basic habitat map of TFH.

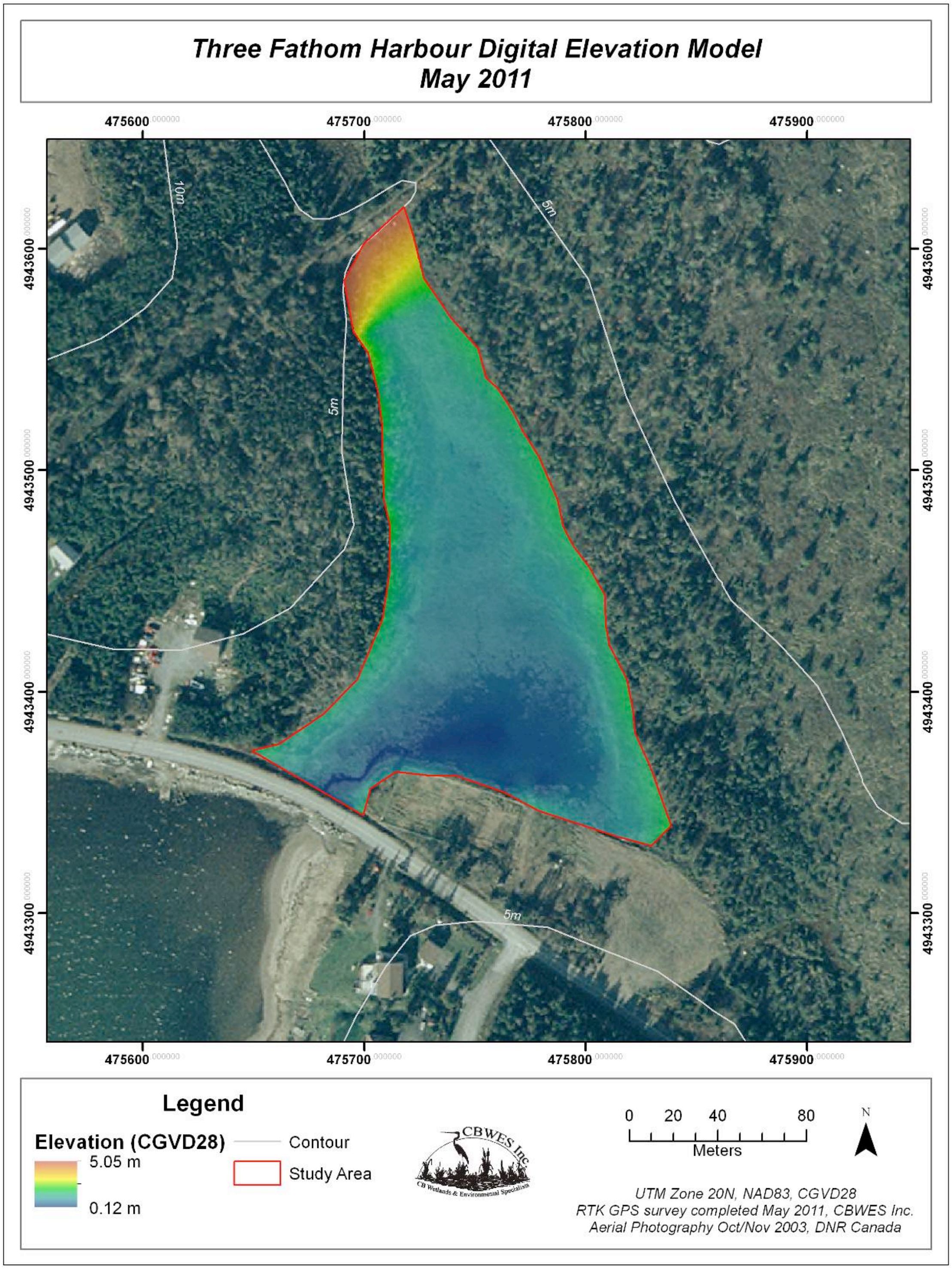


Figure 16 DEM of TFH.

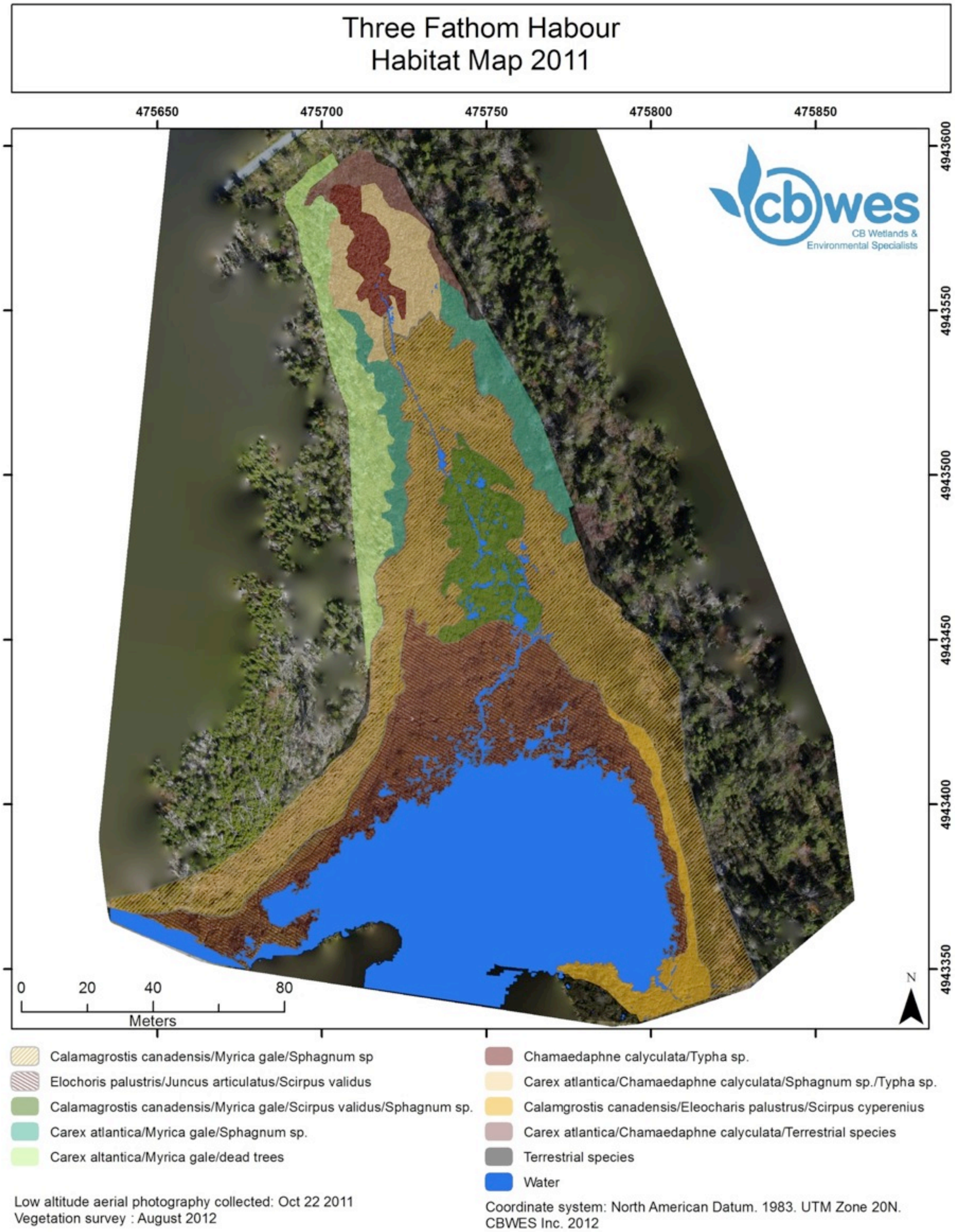


Figure 17 TFH habitat map (vegetation community structure) based on vegetation survey and low-altitude aerial photography.

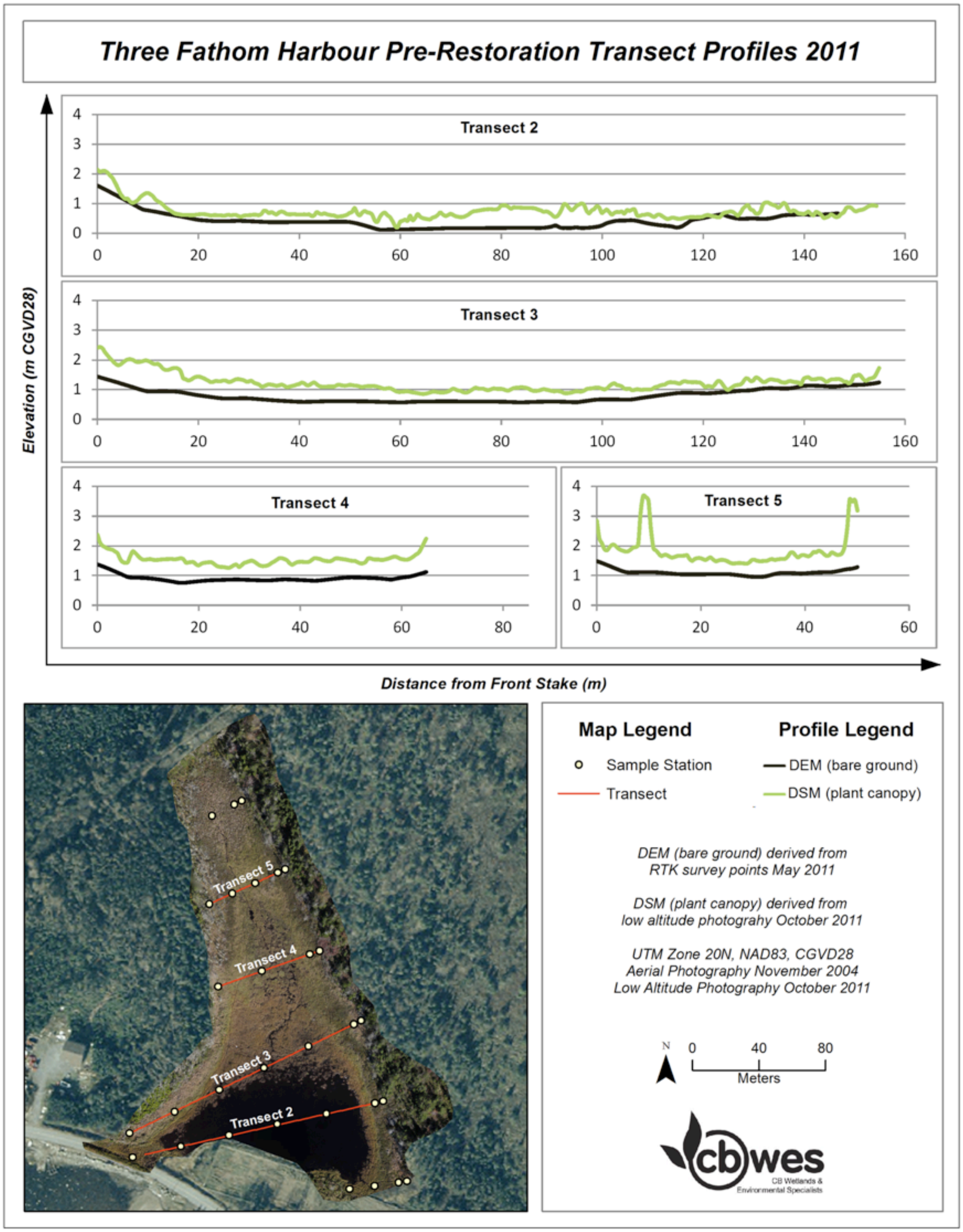


Figure 18 Elevation profiles for TFH. The black line derived from the DEM and represents the marsh surface. The green line is from the Digital Surface Model (DSM) (from the low-altitude aerial photograph) and represents the surface of the low-altitude aerial photograph image – top (height) of vegetation.

4.2 Hydrology

Hydroperiod and Tidal Signal

Water levels from all recorders were used to determine hydrological conditions under a variety of tidal scenarios, including existing conditions (recorded within site) and restored conditions with unrestricted tidal flows (downstream and in channel recorders). The results are shown in Table 3. Although water levels within the site increase and decrease minimally with tide height (~5 - 10 cm) water levels appeared to be predominantly driven by freshwater flows (Figure 20). Water levels within the site reached peak levels on 15 June 2011, flooding an area approaching both the potential tidal extent and the upland boundary/elevation break of the site. Although this event coincided with the high spring tide, the flooding was the result of a large precipitation event (Figure 20; precipitation data from Halifax Shearwater).

Current low water levels at the harbour and downstream channel recorders were found to be well below the minimum elevation in the site, indicating that the site could be allowed to drain entirely between tidal cycles depending on the elevation at which the culvert invert is placed. With the current invert height maintained (0.042 m; CGVD28), 0.13 ha would be flooded at low tide. The maximum recorded water level within the site under current conditions covered 1.59 ha, compared to 1.71 ha under unrestricted conditions. Although this does not represent a significant increase in area flooded, the resulting changes in water quality (salinity, temperature, dissolved oxygen), frequency of inundation, vegetation community structure, fish passage and overall wetland habitat condition would be significant. Table 4 and Table 5 show the tidal inundation period (hours) and area (ha) associated with each elevation class for unrestricted conditions during the recording period. While 50% of recorded water levels would not have flooded the site at all (below minimum elevation), only ~15% of the total potential area would never have been flooded. This area may be affected by storm events but would not frequently see tidal inundation. The hypsometric curve, shown in Figure 21, shows the area of marsh flooded at increasing tide heights up to the marsh upland edge. The actual and potential area (ha) flooded under current restricted and projected unrestricted conditions for a series of tidal conditions is presented in Figure 22; based on the June 2011 DEM and recorded tide levels.

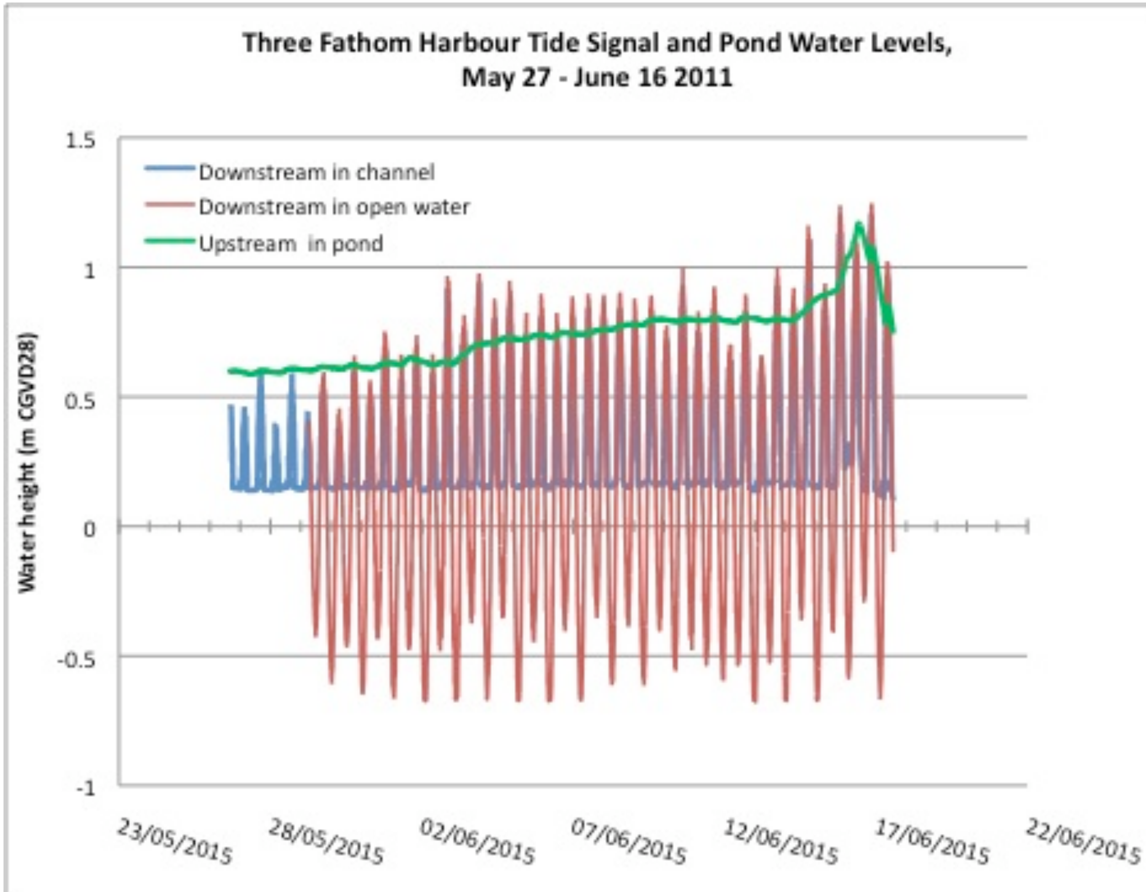


Figure 19 Tide signal for water level within the TFH central pond and for the two downstream locations in Three Fathom Harbour.

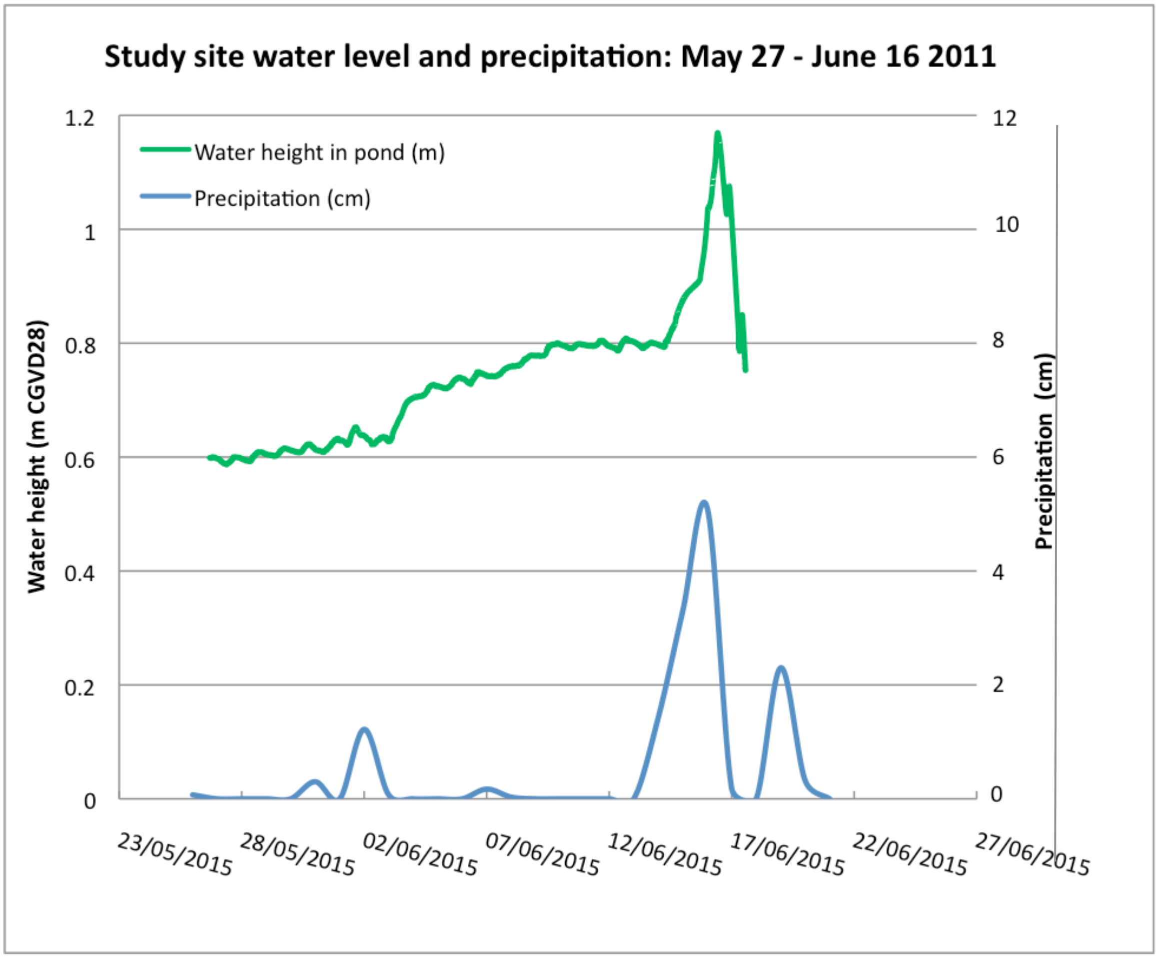


Figure 20 TFH change in pond water level compared to precipitation during the study period.

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

Measurement		Tide Level Recorder Location		
		Downstream in channel	***Downstream in open water***	***Study site in pond***
Minimum	*Water height*	--	-0.68	0.60
	Area flooded (ha)	--	0.00	0.54
Maximum	*Water height*	1.20	1.25	1.17
	Area flooded (ha)	--	1.71	1.59
Mean	*Water height*	--	--	0.74
	Area flooded (ha)	--	--	0.78
Culvert invert	*Water height*	0.36		
	Area flooded (ha)	0.13		

Table 4 Inundation period for each 10 cm elevation class during the recording period (27 May – 16 June 2011).

Elevation class (m; CGVD28)	Inundation period (hours)	Area (ha)
< 0.1	226.2	0
0.1 - 0.2	22.3	0.03
0.2 - 0.3	25.8	0.06
0.3 - 0.4	25.6	0.13
0.4 - 0.5	28.8	0.17
0.5 - 0.6	30.8	0.15
0.6 - 0.7	29.4	0.16
0.7- 0.8	29.9	0.17
0.8 - 0.9	25.4	0.21
0.9 - 1	8.8	0.21
1 - 1.1	4.8	0.14
1.1 - 1.2	3.9	0.15
1.2 - 1.3	1.1	0.13

Table 5 Total area flooded and total hours inundated shown as percent value.

Water level (m; CGVD28)	Percent area* flooded	Percent total hours inundated
0.1	0.00	50.0
0.2	1.24	45.3
0.3	3.86	39.9
0.4	9.81	34.5
0.5	17.17	28.3
0.6	23.94	21.8
0.7	31.19	15.6
0.8	38.64	9.3
0.9	48.12	3.9
1	57.45	2.1
1.1	63.72	1.1
1.2	70.54	0.2
1.25	76.33	0.02

*area = potential restoration area to tree line, 2.26 ha

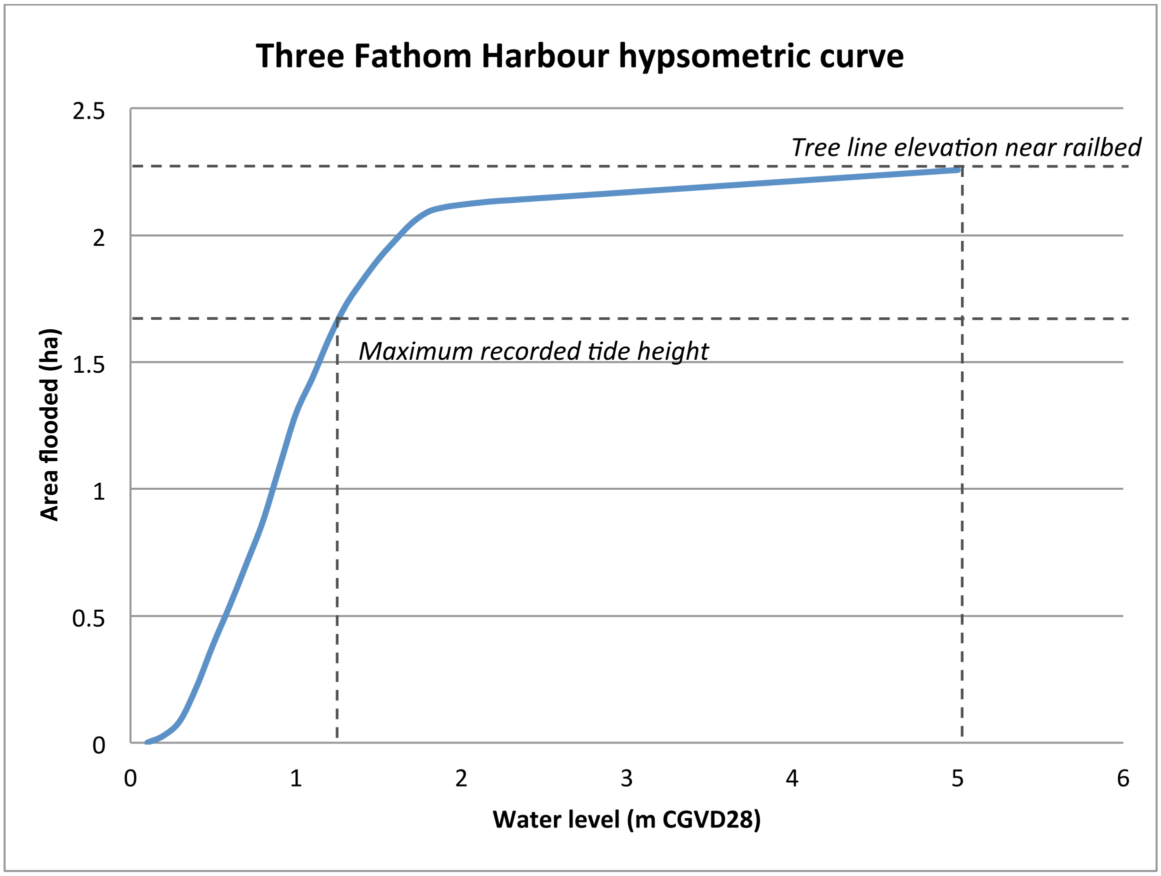


Figure 21 Hypsometric curve for TFH.

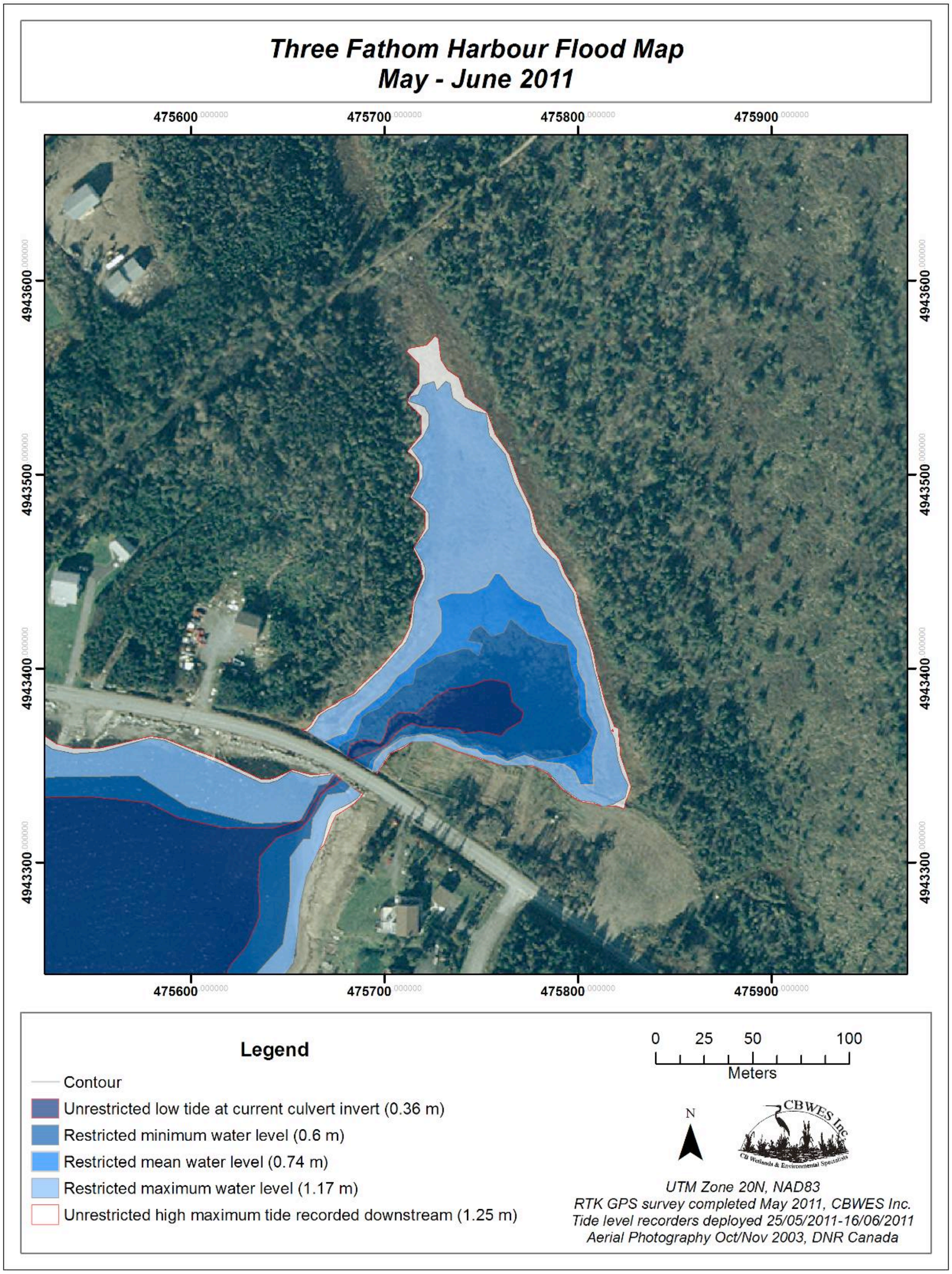


Figure 22 Flood map for TFH showing unrestricted flooding under low and high tide conditions and the restricted levels (min, mean, max) inside the site during the period 25 May to 16 June 2011.

4.3 Soils and Sediments

Pore Water Salinity

Salinity levels at TFH ranged from 0 to 7 ppt (all samples), with little difference between shallow and deep samples (Table 6). The highest salinities were recorded at the four stations (L2S5, L2S6, L3S3, L3S4) closest to the culvert and bordering the large central pond (Figure 8). All other stations were zero. Salinity readings indicated that aside from limited tidal (estuarine) intrusion through the culvert influencing the area immediately upstream of the causeway, the majority of the site could be characterized as freshwater habitat. The highest salinity levels recorded at the study site matched the lowest salinity levels recorded at the reference site (Table 6 and Figure 23).

Table 6 Pore water salinity levels for TFH and LTR.

	Shallow					Deep					All				
	N	Min	Max	Mean	SD	N	Min	Max	Mean	SD	N	Min	Max	Mean	SD
TFH	24	0	7.33	1.39	2.20	24	0	6.37	1.19	1.93	48	0	7.33	1.29	2.05
LTR	18	5.57	18.62	13.54	2.91	18	5.07	21.00	13.88	4.52	36	5.07	21.00	13.71	3.75

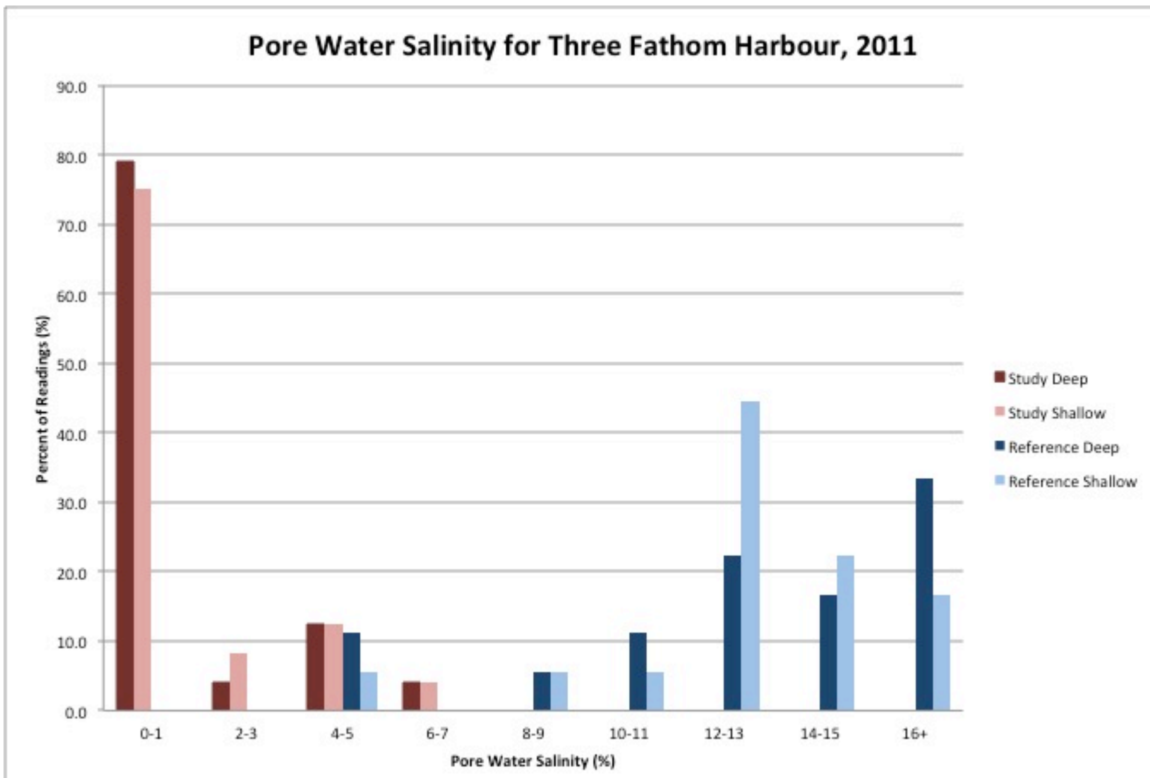


Figure 23 Percentage of interstitial pore water salinity readings within each salinity range class: TFH (study) and LTR (reference).

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 on 7 October 2011 for grain size analysis, organic matter, water content and bulk density determination. Cores were portioned into two halves with the exception of the for bulk density samples. The locations of the samples are illustrated in Figure 8.

All of cores were highly waterlogged, consisting mainly of peat and root fragments with low amounts of inorganic sediment. Water content was extremely high, ranging from 84.6% at L2S5 to almost complete saturation with 94.9% at L5S2. It is interesting that the highest water content within the cores was recorded for the sampling locations furthest away from the pond (Figure 8) and also at the highest elevation. 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 Lawrencetown 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 lower at the reference site compared with TFH study site.

Table 7 Sediment characteristics at TFH in 2011 for a) top 2 cm of core and middle of core mean and b) mean conditions at the LTR from 2006, 2008 and 2010. Elevations surveyed relative to CGVD28 vertical datum.

a) ID	Elevation (m)	2011					
		Bulk density (g•cm^{-3})		H_20 content (%)		Organic matter content (%)	
		top	mid	top	mid	top	mid
TFH-L1S2	0.37	0.05	-	90.9	92.3	79.9	76.3
TFH-L2S5	0.59	0.14	-	84.6	84.9	45.1	45.5
TFH-L3S2	0.64	0.16	-	88.1	83.4	71.5	50.1
TFH-L3S3	0.60	0.11	-	88.9	80.0	64.6	36.1
TFH-L3S4	0.58	0.13	-	89.8	72.3	61.2	24.2
TFH-L3S5	0.94	0.16	-	85.7	79.4	81.3	42.1
TFH-L5S2	1.04	0.05	-	94.9	93.7	85.3	90.1
TFH-L5S3	1.09	0.07	-	93.8	93.2	86.1	88.5

b) Location	Elev (m)	Water Content (%)				Organic Matter (%)				Dry Bulk Density (g·cm^{-3})			
		2006	2008	2010	mean	2006	2008	2010	mean	2006	2008	2010	mean
LTR-L1S1	0.71	85.17	86.48	76.10	82.58	65.17	58.50	36.20	53.29	0.10	0.11	0.11	0.11
LTR-L1S3	0.49	80.91	60.21	86.60	75.91	51.52	92.38	58.60	67.50	0.15	0.08	0.10	0.11
LTR-L1S4	0.64	65.91	74.93	74.50	71.78	19.75	64.87	40.50	41.71	0.39	0.08	0.11	0.19
LTR-L3S1	0.77	83.03	73.22	87.30	81.18	62.78	83.05	61.40	69.08	0.16	0.10	0.10	0.12
LTR-L3S3	0.67	86.69	77.54	85.80	83.34	59.05	78.33	56.90	64.76	0.13	0.08	0.10	0.10
LTR-L3S6	0.63	70.15	59.06	70.0	66.40	20.70	42.23	35.7	32.88	0.28	0.24	0.20	0.24

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 mineral (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 at TFH were low, ranging from 0.05 g•cm^{-3} at L5S2, L1S2 to 0.16 g•cm^{-3} at L3S2, L3S5 (Table 7a). Well decomposed organic soils typically range between 0.2 to 0.3 g•cm^{-3} and some peatland soils measure less than 0.05 g•cm^{-3} (Mitch 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.

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 (Table 8 to Table 14). In general, 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) (Figure 13) with the exception of L3S3 (Table 8). All cores were classified as very close to 100% mud (Table 9 to Table 14) and were poorly sorted (Table 8). 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 8). Otherwise the remaining cores exhibit a tail of fines suggesting a winnowing effect (Table 8). The bottom section of L1S2, however, was the exception and was coarsely skewed (Table 8).

Table 8 Grain size characteristics from coulter sediment analysis for a) top and bottom core sections at TFH for 2011 and b) LTR as the mean from 2008 to 2011. Classification based on modified Udden_Wentworth scale. Elevation expressed relative to CGVD28. Note: grain size analysis performed using a Coulter Laser instrument for LTR. A Coulter Multisizer instrument was used for TFH (2011) and will produce smaller size classes. 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.

ID	Elev (m)	Top				Bottom			
		Mean size (µm)	Folk class	Sorting	Skewness	Mean size (µm)	Folk class	Sorting	Skewness
L1S2	0.37	6.85	f.silt	poor	sym	5.58	f.silt	poor	coarse
L2S5	0.59	7.02	f.silt	poor	fine	7.05	f.silt	poor	Fine
L3S2	0.64	7.23	f.silt	poor	sym	7.97	m.silt	poor	sym
L3S3	0.60	7.26	m.silt	poor	Sym	6.89	f.silt	poor	sym
L3S4	0.58	7.62	f.silt	poor	Fine	8.11	m.silt	poor	Fine
L3S5	0.94	8.41	m.silt	poor	Sym	7.68	m.silt	poor	fine
L5S2	1.04	6.23	f.silt	poor	Sym	10.44	m. silt	poor	fine
L5S3	1.09	7.23	f.silt	poor	sym	9.08	m.silt	poor	sym

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 24). 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 samples show clear single 'round' settling (Krank and Milligan 1985) (e.g. L1S2 top, L2S5 bottom, L3S2 bottom, L2S5 bottom and L3S4 full core) which suggests one single event settling. Other samples 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 24).

Given the highly organic nature of the soils found within the potential restoration site, careful attention will need to be given to below ground decomposition and redox potential. Such waterlogged soils may not support the desired vegetative communities given below ground decomposition.

Table 9 Sediment Characteristics based on Coulter Laser Particle Size Analysis from the top 2 cm of core samples TFH-L1S2, L2S5 and L3S2 at TFH; Sediment characterization determined using Folk and Ward method in GRADISTAT (Blott and Pye 2001).

	L1S2 Top	L2S5 top	L3S2 top
ANALYST AND DATE:	In_CoaST Feb 25, 2012		
SIEVING ERROR:			
SAMPLE TYPE:	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted
TEXTURAL GROUP:	Mud	Mud	Mud
SEDIMENT NAME:	Very Fine Silt	Coarse Silt	Very Fine Silt
MEAN ($\bar{x}_a$):	6.847	7.015	7.230
SORTING (σ_G):	3.028	2.774	3.158
SKEWNESS (Sk_G):	0.008	-0.114	0.026
KURTOSIS (K_G):	0.765	0.773	0.781
MEAN:	Fine Silt	Fine Silt	Fine Silt
SORTING:	Poorly Sorted	Poorly Sorted	Poorly Sorted
SKEWNESS:	Symmetrical	Fine Skewed	Symmetrical
KURTOSIS:	Platykurtic	Platykurtic	Platykurtic
% GRAVEL:	0.000	0.000	0.000
% SAND:	0.000	0.000	0.820
% MUD:	100.000	100.000	99.180
% V COARSE GRAVEL:	0.000	0.000	0.000
% COARSE GRAVEL:	0.000	0.000	0.000
% MEDIUM GRAVEL:	0.000	0.000	0.000
% FINE GRAVEL:	0.000	0.000	0.000
% V FINE GRAVEL:	0.000	0.000	0.000
% V COARSE SAND:	0.000	0.000	0.000
% COARSE SAND:	0.000	0.000	0.000
% MEDIUM SAND:	0.000	0.000	0.000
% FINE SAND:	0.000	0.000	0.000
% V FINE SAND:	0.000	0.000	0.820
% V COARSE SILT:	7.533	4.426	9.535
% COARSE SILT:	19.495	20.904	18.025
% MEDIUM SILT:	19.407	24.094	19.866
% FINE SILT:	18.663	20.240	18.422
% V FINE SILT:	20.542	18.411	19.858
% CLAY:	14.360	11.925	13.474

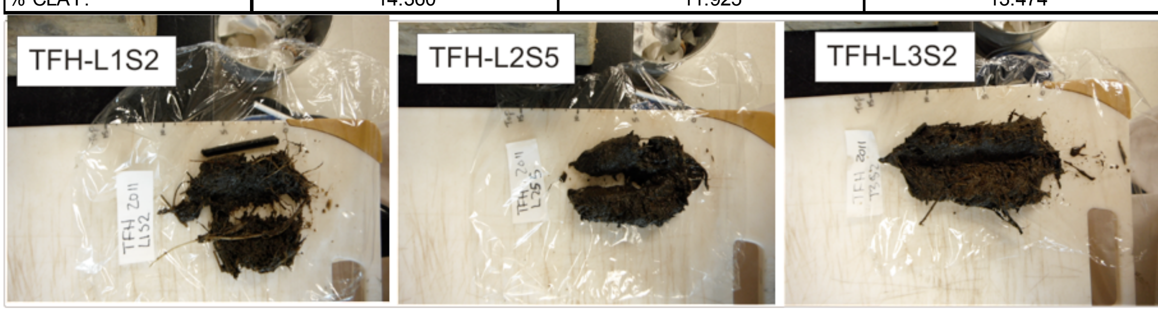


Table 10 Sediment Characteristics based on Coulter Laser Particle Size Analysis from the top 2 cm of core samples TFH-L3S3, L3S4 and L3S5 at TFH; Sediment characterization determined using Folk and Ward method in GRADISTAT (Blott and Pye 2001).

	L3S3 top	L3S4 top	L3S5 top
ANALYST AND DATE:			
SIEVING ERROR:			
SAMPLE TYPE:	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted
TEXTURAL GROUP:	Mud	Mud	Mud
SEDIMENT NAME:	Medium Silt	Very Fine Silt	Medium Silt
MEAN ($\bar{x}_a$):	7.258	7.620	8.406
SORTING (σ_G):	3.183	2.847	3.440
SKEWNESS (Sk_G):	0.011	-0.139	0.035
KURTOSIS (K_G):	0.784	0.861	0.718
MEAN:	Fine Silt	Fine Silt	Medium Silt
SORTING:	Poorly Sorted	Poorly Sorted	Poorly Sorted
SKEWNESS:	Symmetrical	Fine Skewed	Symmetrical
KURTOSIS:	Platykurtic	Platykurtic	Platykurtic
% GRAVEL:	0.000	0.000	0.000
% SAND:	0.580	0.031	2.733
% MUD:	99.420	99.969	97.267
% V COARSE GRAVEL:	0.000	0.000	0.000
% COARSE GRAVEL:	0.000	0.000	0.000
% MEDIUM GRAVEL:	0.000	0.000	0.000
% FINE GRAVEL:	0.000	0.000	0.000
% V FINE GRAVEL:	0.000	0.000	0.000
% V COARSE SAND:	0.000	0.000	0.000
% COARSE SAND:	0.000	0.000	0.000
% MEDIUM SAND:	0.000	0.000	0.000
% FINE SAND:	0.000	0.000	0.000
% V FINE SAND:	0.580	0.031	2.733
% V COARSE SILT:	9.744	6.999	14.593
% COARSE SILT:	18.872	21.788	17.645
% MEDIUM SILT:	19.449	23.800	16.396
% FINE SILT:	17.791	20.251	17.203
% V FINE SILT:	20.027	16.511	18.852
% CLAY:	13.536	10.620	12.578

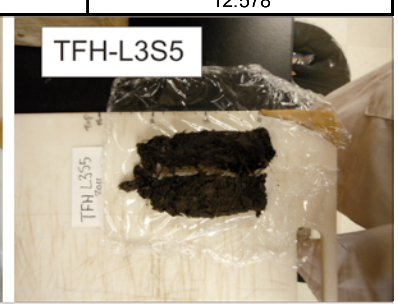
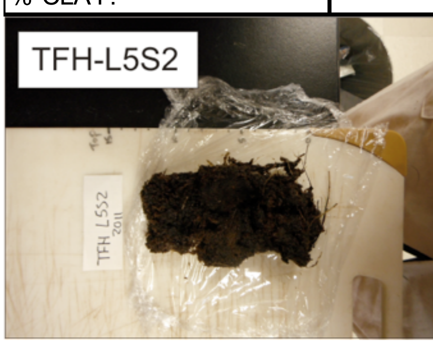


Table 11 Sediment Characteristics based on Coulter Laser Particle Size Analysis from the top 2 cm of core samples TFH-L5S2 and L5S3 at TFH; Sediment characterization determined using Folk and Ward method in GRADISTAT (Blott and Pye 2001).

	L5S2 top	**L5S3 top**
ANALYST AND DATE:		
SIEVING ERROR:		
SAMPLE TYPE:	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted
TEXTURAL GROUP:	Mud	Mud
SEDIMENT NAME:	Fine Silt	Coarse Silt
MEAN ($\bar{x}_a$):	6.234	7.729
SORTING (σ_G):	2.859	3.093
SKEWNESS (Sk_G):	0.124	-0.029
KURTOSIS (K_G):	0.885	0.698
MEAN:	Fine Silt	Fine Silt
SORTING:	Poorly Sorted	Poorly Sorted
SKEWNESS:	Symmetrical	Symmetrical
KURTOSIS:	Platykurtic	Platykurtic
% GRAVEL:	0.000	0.000
% SAND:	0.000	0.126
% MUD:	100.000	99.874
% V COARSE GRAVEL:	0.000	0.000
% COARSE GRAVEL:	0.000	0.000
% MEDIUM GRAVEL:	0.000	0.000
% FINE GRAVEL:	0.000	0.000
% V FINE GRAVEL:	0.000	0.000
% V COARSE SAND:	0.000	0.000
% COARSE SAND:	0.000	0.000
% MEDIUM SAND:	0.000	0.000
% FINE SAND:	0.000	0.000
% V FINE SAND:	0.000	0.126
% V COARSE SILT:	7.590	10.890
% COARSE SILT:	13.779	21.863
% MEDIUM SILT:	15.929	17.451
% FINE SILT:	23.808	17.132
% V FINE SILT:	24.722	20.542
% CLAY:	14.171	11.997



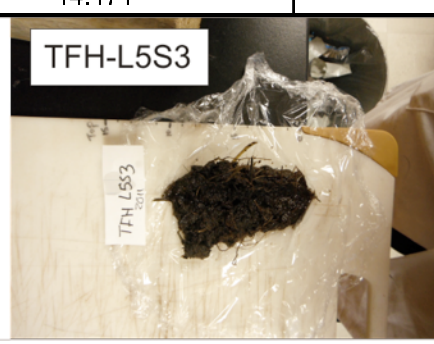


Table 12 Sediment Characteristics based on Coulter Laser Particle Size Analysis from the middle 2 cm of core samples TFH-L1S2, L2S5 and L3S2 at TFH; Sediment characterization determined using Folk and Ward method in GRADISTAT (Blott and Pye 2001).

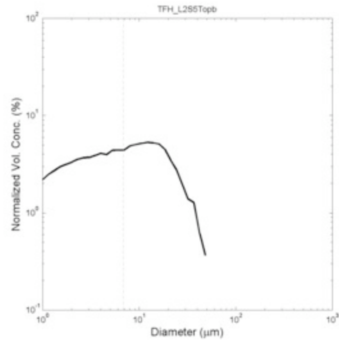
	L1S2 mid	L2S5 mid	L3S2 mid
ANALYST AND DATE:	In_CoaST Feb 25, 2012	In_CoaST Feb 25, 2012	In_CoaST Feb 25, 2012
SIEVING ERROR:			
SAMPLE TYPE:	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted
TEXTURAL GROUP:	Mud	Mud	Mud
SEDIMENT NAME:	Very Fine Silt	Coarse Silt	Medium Silt
MEAN ($\bar{x}_a$):	5.583	7.053	7.972
SORTING (σ_G):	3.048	2.788	3.089
SKEWNESS (Sk_G):	0.133	-0.135	-0.047
KURTOSIS (K_G):	0.781	0.752	0.857
MEAN:	Fine Silt	Fine Silt	Medium Silt
SORTING:	Poorly Sorted	Poorly Sorted	Poorly Sorted
SKEWNESS:	Coarse Skewed	Fine Skewed	Symmetrical
KURTOSIS:	Platykurtic	Platykurtic	Platykurtic
% GRAVEL:	0.000	0.000	0.000
% SAND:	0.000	0.000	1.449
% MUD:	100.000	100.000	98.551
% V COARSE GRAVEL:	0.000	0.000	0.000
% COARSE GRAVEL:	0.000	0.000	0.000
% MEDIUM GRAVEL:	0.000	0.000	0.000
% FINE GRAVEL:	0.000	0.000	0.000
% V FINE GRAVEL:	0.000	0.000	0.000
% V COARSE SAND:	0.000	0.000	0.000
% COARSE SAND:	0.000	0.000	0.000
% MEDIUM SAND:	0.000	0.000	0.000
% FINE SAND:	0.000	0.000	0.000
% V FINE SAND:	0.000	0.000	1.449
% V COARSE SILT:	5.787	4.103	9.334
% COARSE SILT:	15.017	22.504	18.781
% MEDIUM SILT:	17.552	23.622	22.165
% FINE SILT:	18.592	19.590	20.459
% V FINE SILT:	23.807	17.652	17.170
% CLAY:	19.244	12.530	10.642

Table 13 Sediment Characteristics based on Coulter Laser Particle Size Analysis from the middle 2 cm of core samples TFH-L3S3, L3S4 and L3S5 at TFH; Sediment characterization determined using Folk and Ward method in GRADISTAT (Blott and Pye 2001).

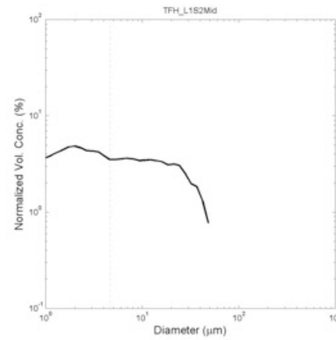
	L3S3 mid	L3S4 mid	L3S5 mid
ANALYST AND DATE:	In_CoaST Feb 25, 2012	In_CoaST Feb 25, 2012	In_CoaST Feb 25, 2012
SIEVING ERROR:			
SAMPLE TYPE:	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted
TEXTURAL GROUP:	Mud	Mud	Mud
SEDIMENT NAME:	Medium Silt	Medium Silt	Medium Silt
MEAN ($\bar{x}_a$):	6.891	8.109	7.676
SORTING (σ_G):	2.667	2.676	2.702
SKEWNESS (Sk_G):	-0.073	-0.132	-0.056
KURTOSIS (K_G):	0.862	0.961	0.960
MEAN:	Fine Silt	Medium Silt	Medium Silt
SORTING:	Poorly Sorted	Poorly Sorted	Poorly Sorted
SKEWNESS:	Symmetrical	Fine Skewed	Fine Skewed
KURTOSIS:	Platykurtic	Mesokurtic	Mesokurtic
% GRAVEL:	0.000	0.000	0.000
% SAND:	0.000	0.072	0.121
% MUD:	100.000	99.928	99.879
% V COARSE GRAVEL:	0.000	0.000	0.000
% COARSE GRAVEL:	0.000	0.000	0.000
% MEDIUM GRAVEL:	0.000	0.000	0.000
% FINE GRAVEL:	0.000	0.000	0.000
% V FINE GRAVEL:	0.000	0.000	0.000
% V COARSE SAND:	0.000	0.000	0.000
% COARSE SAND:	0.000	0.000	0.000
% MEDIUM SAND:	0.000	0.000	0.000
% FINE SAND:	0.000	0.000	0.000
% V FINE SAND:	0.000	0.072	0.121
% V COARSE SILT:	4.050	5.972	7.190
% COARSE SILT:	18.028	22.471	18.149
% MEDIUM SILT:	26.714	25.784	26.413
% FINE SILT:	22.902	21.844	23.353
% V FINE SILT:	17.922	15.106	16.426
% CLAY:	10.384	8.751	8.349

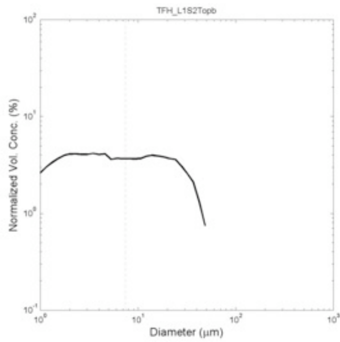
Table 14 Sediment Characteristics based on Coulter Laser Particle Size Analysis from the middle 2 cm of core samples TFH-L5S2 and L5S3 at TFH; Sediment characterization determined using Folk and Ward method in GRADISTAT (Blott and Pye 2001).

	L5S2 mid	**L5S3 mid**
ANALYST AND DATE:	In_CoaST Feb 25, 2012	In_CoaST Feb 25, 2012
SIEVING ERROR:		
SAMPLE TYPE:	Polymodal, Poorly Sorted	Polymodal, Poorly Sorted
TEXTURAL GROUP:	Mud	Mud
SEDIMENT NAME:	Coarse Silt	Coarse Silt
MEAN ($\bar{x}_a$):	10.444	9.083
SORTING (σ_G):	3.488	3.030
SKEWNESS (Sk_G):	-0.111	-0.065
KURTOSIS (K_G):	0.822	0.850
MEAN:	Medium Silt	Medium Silt
SORTING:	Poorly Sorted	Poorly Sorted
SKEWNESS:	Fine Skewed	Symmetrical
KURTOSIS:	Platykurtic	Platykurtic
% GRAVEL:	0.000	0.000
% SAND:	4.682	0.000
% MUD:	95.318	100.000
% V COARSE GRAVEL:	0.000	0.000
% COARSE GRAVEL:	0.000	0.000
% MEDIUM GRAVEL:	0.000	0.000
% FINE GRAVEL:	0.000	0.000
% V FINE GRAVEL:	0.000	0.000
% V COARSE SAND:	0.000	0.000
% COARSE SAND:	0.000	0.000
% MEDIUM SAND:	0.000	0.000
% FINE SAND:	0.000	0.000
% V FINE SAND:	4.682	0.000
% V COARSE SILT:	17.843	14.676
% COARSE SILT:	19.421	21.801
% MEDIUM SILT:	17.718	20.122
% FINE SILT:	16.095	18.674
% V FINE SILT:	14.101	15.643
% CLAY:	10.141	9.083

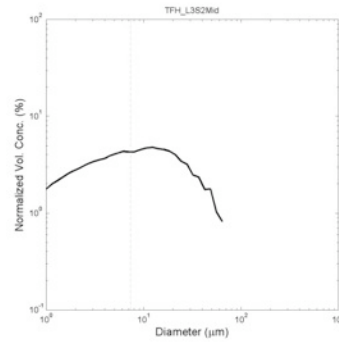


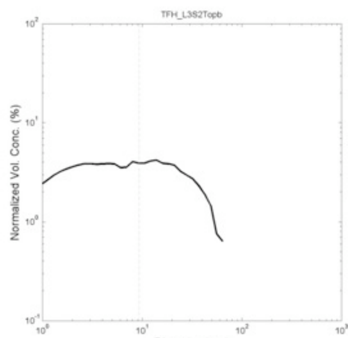
TFH L1S2



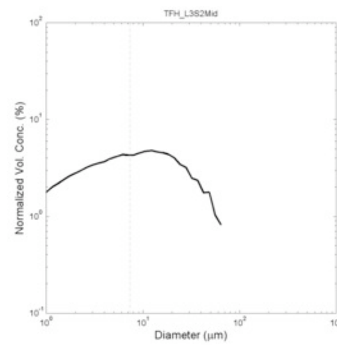


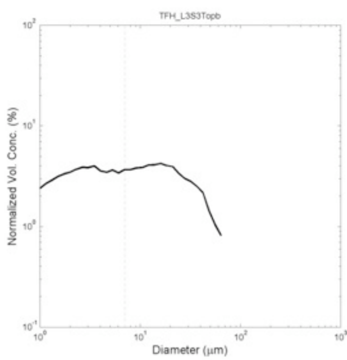
TFH L2S5



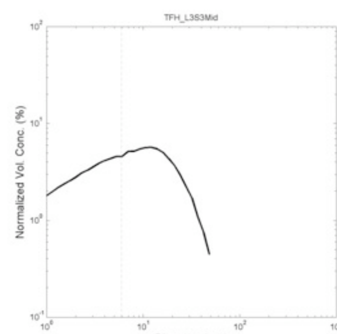


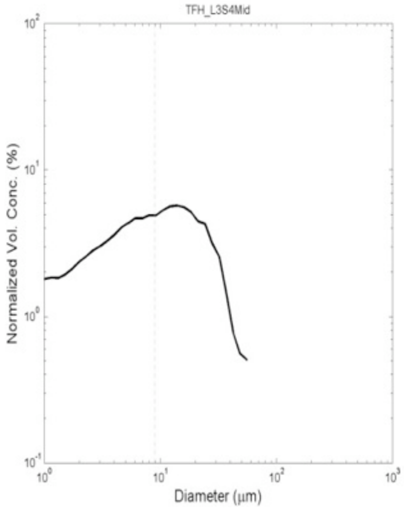
TFH L3S2



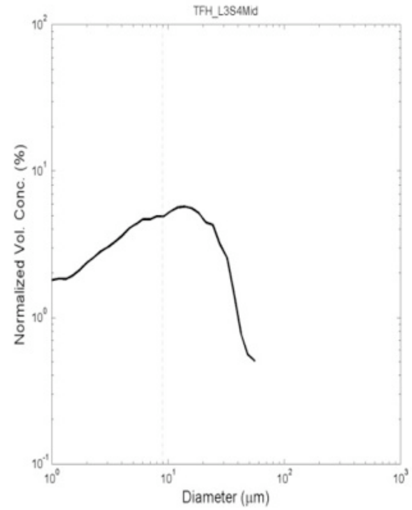


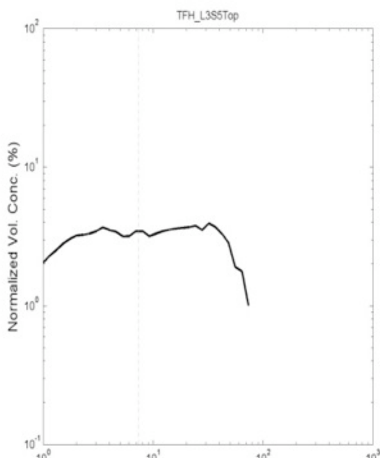
TFH L2S5



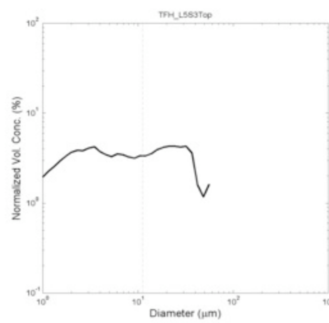


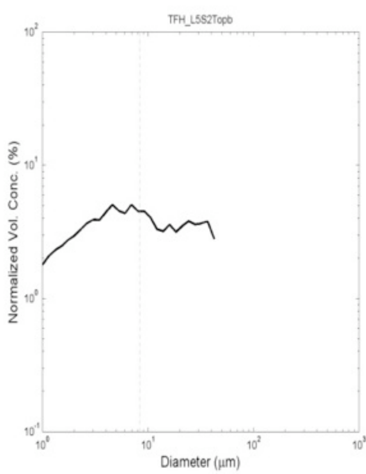
TFH L3S4



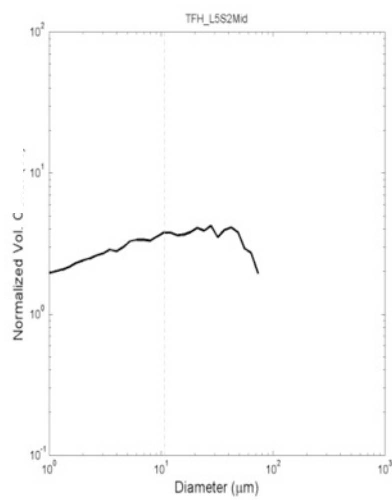


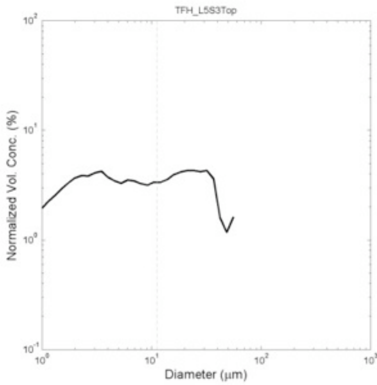
TFH L3S





TFH L5S2





TFH L5S3

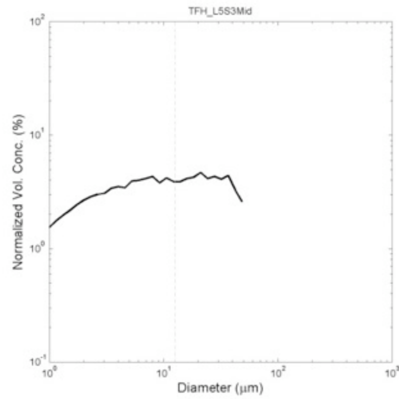


Figure 24 Merged (30 and 200 µm) grain size spectra from Coulter Multiziser 3 for top (left) and bottom (right) sections of core at TFH.

4.4 Vegetation

TFH currently contains no salt marsh vegetation of any kind (Table 15). There is a complete separation between reference site plots (LT-R or TFH-R) which range from low marsh to high marsh, to brackish (Figure 26). For comparison in future years, the non-parametric multivariate ANOVA indicates significant differences in vegetation composition between the two sites (F=10.85; R^2=0.20; P=0.001). The study site is currently dominated by productive fen/freshwater wetland species including *Myrica gale*, *Typha latifolia, Scirpus validus, Calamagrostis canadensis* (Figure 25). The study site has greater average species richness (Figure 27a), as it contains a community that typically has more species than salt or brackish marsh (F=6.76; P=0.01). The reference site had more halophytic species (Figure 27b; F=82.8; P<0.0001) and much greater halophytic abundance than the study site (Figure 27c; F=100.7; P<0.0001). There was no difference in unvegetated area between the sites (Figure 27d; F=0.28; P=0.59).

Table 15 Mean plot abundances (coverage: average # contacts/m^2) and frequency (total # of plots at site containing the species) for TFH and reference site (LT-R) for 2011.

	TFH coverage	**TFH # plots**	**LT-R coverage**	**LT-R # plots**
Agrostis stolonifera	0.17	2	1.89	7
Algae	0.00	0	1.67	2
Andromeda polifolia	0.08	1	0.00	0
Aster sp.	0.05	2	0.00	0
Astriplex glabrisculata	0.00	0	0.06	3
Bidens cernua	0.04	1	0.00	0
Bidens frondosa	0.13	3	0.00	0
Calamagrostis canadensis	8.93	13	0.00	0
Calystegia sepia	0.00	0	0.17	2
Carex atlantica	3.14	10	0.00	0
Carex brunnescens	2.67	9	0.00	0

	TFH	TFH	LT-R	LT-R
	coverage	# plots	coverage	# plots
Carex hormathodes	0.00	0	0.01	1
Carex nigra	0.01	1	0.00	0
Carex paleacea	0.00	0	5.34	9
Carex scoparia	1.25	9	0.00	0
Carex sp.	0.08	1	0.00	0
Carex trisperma	0.04	1	0.00	0
Chamaedaphne calyculata	2.25	8	0.00	0
Taraxacum officinale	0.00	0	0.01	1
Eleocharis palustris	3.50	6	0.00	0
Festuca rubra	0.00	0	6.54	7
Galium mollugo	0.04	1	0.00	0
Galium palustre	0.18	7	0.38	3
Glyceria laxa	0.11	5	0.00	0
Glyceria striata	0.08	1	0.00	0
Hierochloe odorata	0.00	0	2.97	6
Juncus balticus	0.00	0	4.63	5
Juncus brevicaudata	0.08	1	0.00	0
Juncus canadensis	0.08	2	0.00	0
Juncus effusus	1.89	7	0.00	0
Juncus gerardii	0.00	0	0.33	1
Juncus sp.	0.01	1	0.00	0
Limonium nashii	0.00	0	0.01	1
Lycopus americanus	0.13	1	0.00	0
Lycopus uniflora	0.34	4	0.00	0
Lysimachia terrestris	1.01	7	0.00	0
Myrica gale	5.29	10	0.00	0
Myrica pennsylvanica	0.02	2	0.00	0
Poa palustris	0.00	0	1.17	2
Polygonum hydropiper	0.01	1	0.00	0
Polygonum sagittatum	0.30	4	0.00	0
Potentilla anserina	0.00	0	0.01	1
Potentilla palustre	0.04	1	1.18	4
Ranunculus repens	0.01	1	0.00	0
Rubus strigosus	0.01	1	0.00	0
Ruppia maritima	0.00	0	0.33	1
Salicornea europea	0.00	0	0.01	1
Scirpus americanus	1.19	6	0.00	0
Scirpus cyperinus	2.38	6	0.00	0
Scirpus maritimum	0.04	1	0.00	0

	TFH coverage	TFH # plots	LT-R coverage	LT-R # plots
Scirpus validus	2.39	5	0.00	0
Scutellaria galericulata	0.01	1	0.08	1
Solidago sempervirens	0.00	0	0.05	2
Spartina alterniflora	0.00	0	6.21	13
Spartina patens	0.00	0	8.19	12
Spartina pectinata	1.08	6	1.63	2
Sphagnum sp.	2.67	4	0.00	0
Spirea latifolia	2.43	12	0.00	0
Symphotrichum lanceolata	0.01	1	0.00	0
Symphotrichum novi-belgii	0.08	1	0.58	3
Symphotrichum puniceum	0.00	0	0.33	1
Thalictrum pubescens	0.00	0	0.01	1
Triadenum fraseri	0.80	11	0.00	0
Triglochin maritimum	0.00	0	0.01	1
Typha latifolium	0.50	3	0.04	1
Vaccinium macrocarpon	0.42	1	0.13	1
Vicia sp.	0.00	0	0.63	3

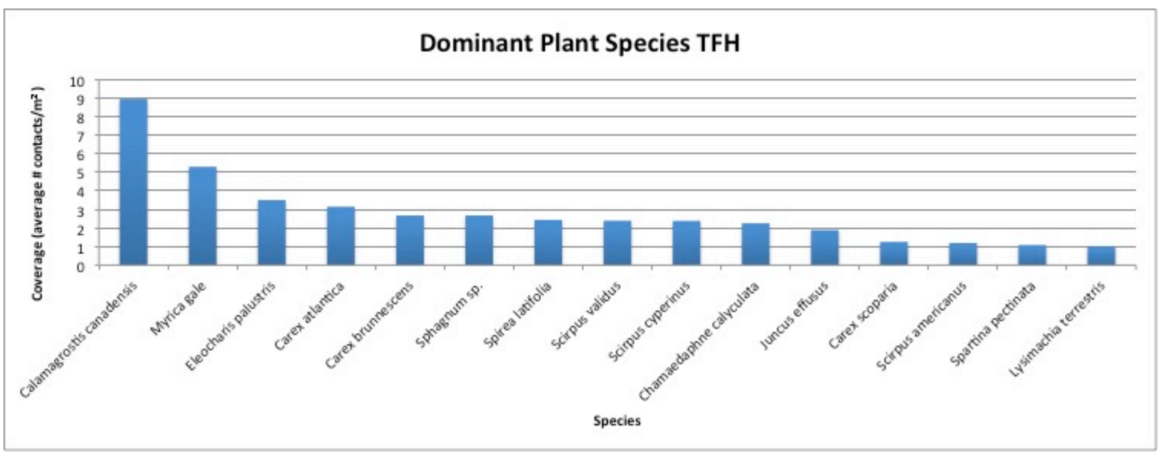


Figure 25 Dominant plant species at TFH.

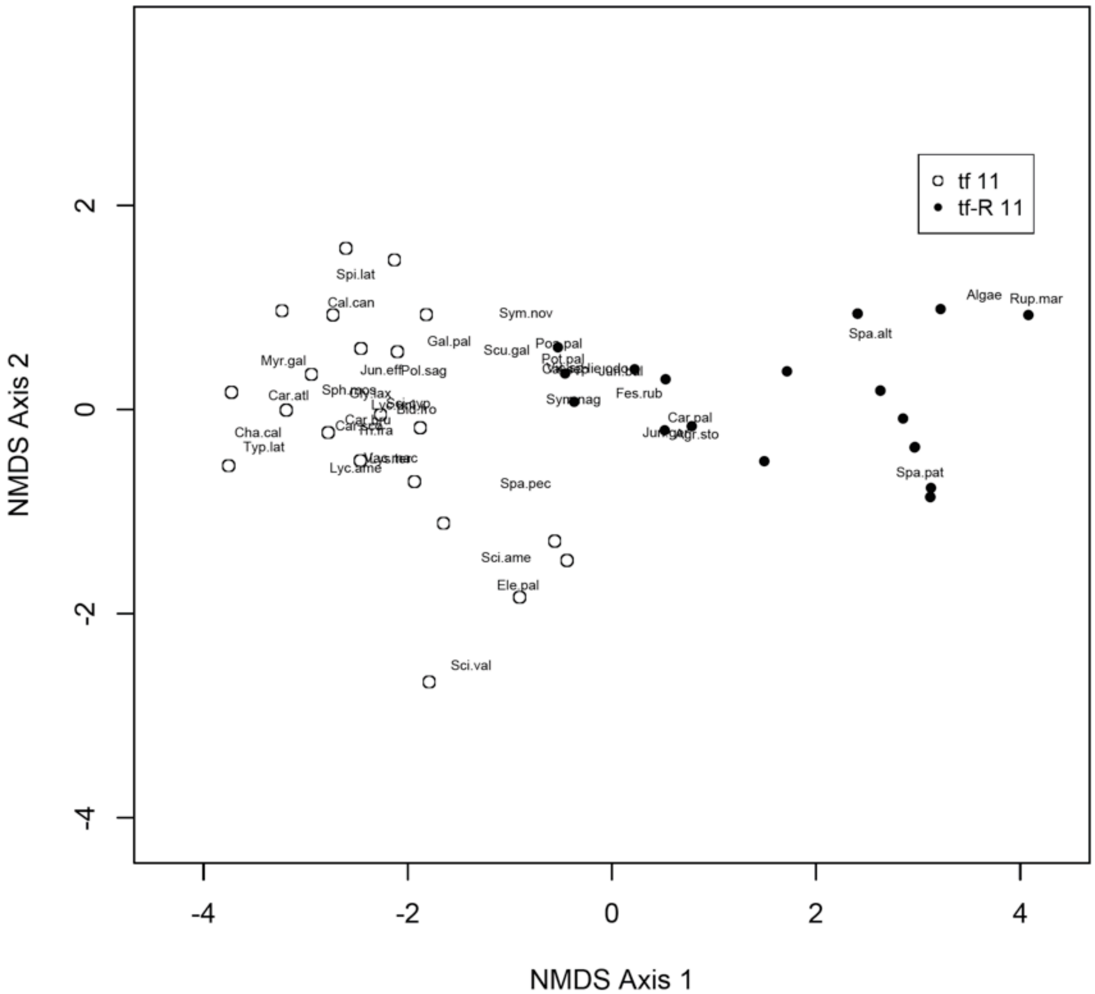
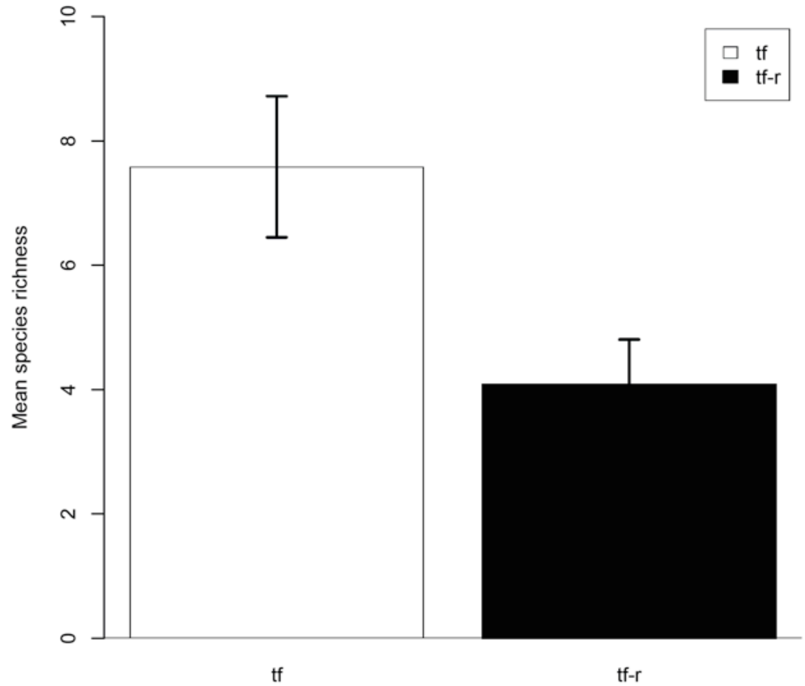
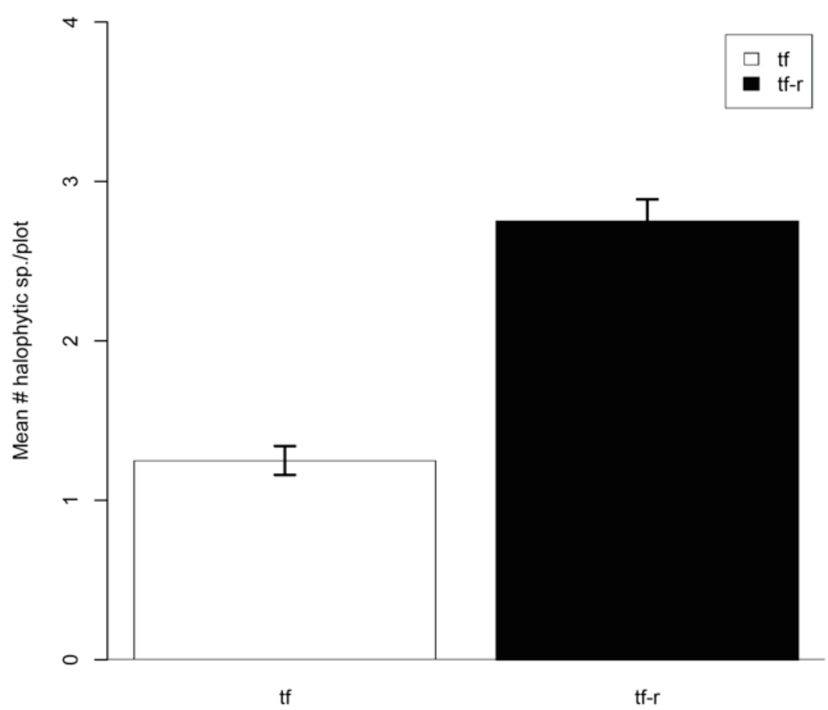


Figure 26 Non-metric multidimensional scaling ordination of vegetation plots comparing reference and study sites at TFH in 2011.

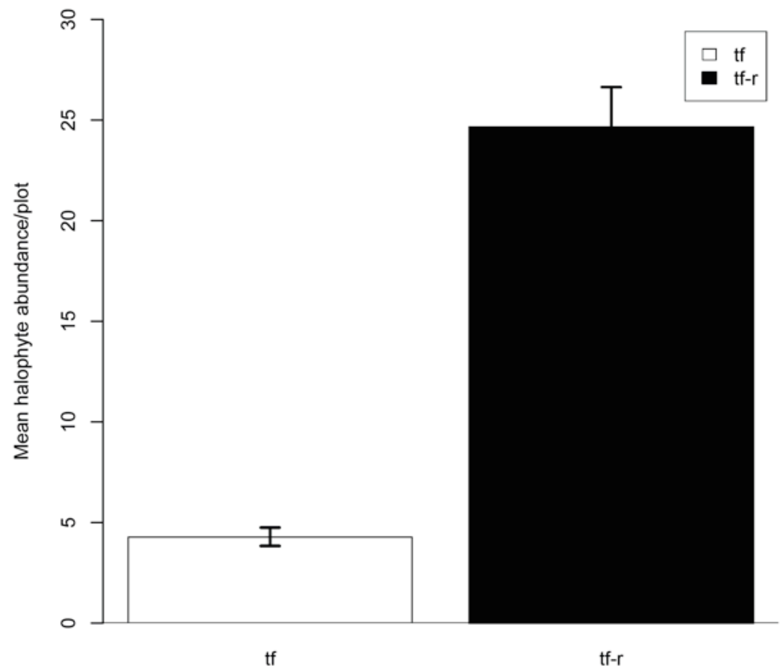
a)


10
8
6
4
2
0
Mean species richness
tf
tf-r
tf
tf-r

b)


4
3
2
1
0
Mean # halophytic sp./plot
tf
tf-r
tf
tf-r

c)



d)

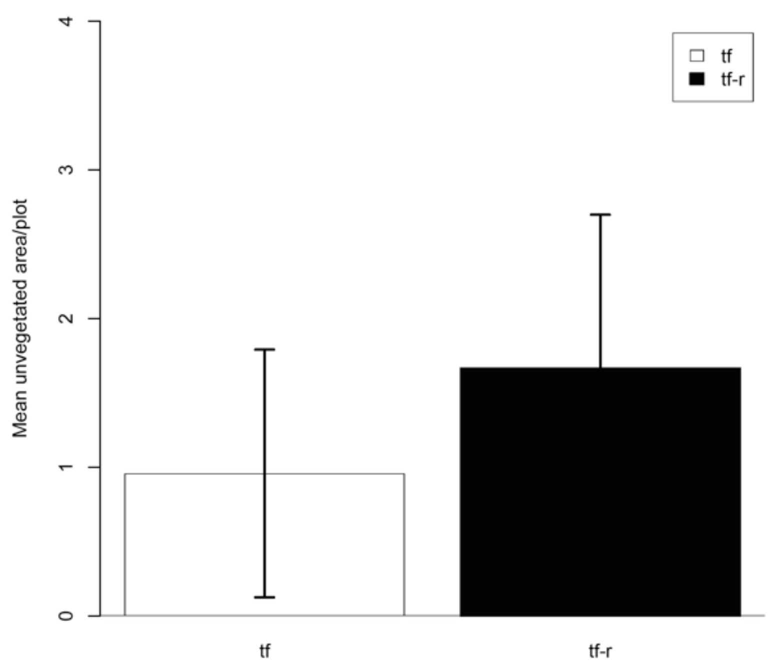


Figure 27 Comparisons of mean plot species richness (a), halophytic richness (b), halophytic abundance (c), and unvegetated area (d) between TFH reference and study sites in 2011.

4.5 Nekton

Of the four traps set throughout the main pond at TFH, only the trap set in the channel approaching the culvert caught fish. A total of seven mummichogs (*Fundulus heteroclitus*) were captured. Three individuals were at the high end of the size range class 10 – 40 mm, while the other four were in the 41 – 70 mm range. Size equates to maturity and for this species 40 mm and greater is indicative of sexual maturity. Smaller (1-9 mm) individuals were captured earlier in the season in the IATs, indicating that a broader range of age classes was likely present within the site.

Given the hydrological conditions of the site, it was not unexpected for a fresh to brackish water environment such as this one to contain a resident population of mummichogs. The periodic (likely storm driven) opening of the culvert and downstream channel would have allowed access to the site for mummichogs while limiting or completely restricting access to larger predatory species. Given the mummichogs ability to survive and thrive in extreme habitat conditions (poor water quality), it was not surprising to find a robust population within the site prior to restoration. Additional fish sampling activities are planned for spring/summer 2013 in advance and immediately following restoration, as time of year would have affected results.

4.6 Aquatic Invertebrates

Species identifications and abundance are presented in Table 16. Activity traps sample a cross-section of organisms from the aquatic biological community including freshwater, estuarine, and marine macroinvertebrates; meiofauna (small organisms such as nematodes, ostracods, harpacticoid copepods); plankton (e.g. copepods and planktonic stages of invertebrates); and fish (of which various stages including eggs, larvae and adult may be present). Abundance in activity trap samples was expressed as the total of all organisms present on a "per sample" basis.

Activity trap samples contained a mix of estuarine and freshwater animals, and showed moderate diversity and abundance. Samples were typically dominated numerically by water boatmen (Corixidae) and small copepod crustaceans. Samples also included ostracods and a Hydrachnid (water mite), as well as occasional freshwater insects including Coleoptera (beetles), Odonata (dragonfly nymphs) and Hemiptera (water bugs), and one fish species (Banded Killifish—*Fundulus diaphanus*).

Table 16 Species composition and abundance (number per sample) of aquatic invertebrates and fish in IAT samples, TFH.

Type of Organism	Trap 1: L1 Pond	Trap 2: L2 Pond
	Abundance per Sample	
INSECTS		
Coleoptera		
Dytiscidae adult sp. A		2
Haliplidae-adult (*Haliplus*)		1
Haliplidae-adult (*Peltodytes*)		2

Type of Organism	**Trap 1: L1 Pond**	**Trap 2: L2 Pond**
	Abundance per Sample	
Haliplidae-larvae (*Haliplus*)		1
Noteridae-adult		1
Hemiptera		
Corixidae-adult	14	113
Corixidae-juvenile	161	436
Unidentified adult		2
Odonata		
Libellulidae?		2
CRUSTACEANS		
Copepoda	2	
Ostracoda	75	
HYDRACHNIDIA sp. A	1	
FISH		
Banded Killifish (*Fundulus diaphanus*)	2	
SUMMARY		
ABUNDANCE (#/SAMPLE)	255	560
SPECIES/SAMPLE	6	9

4.7 Structured Winter Walk

Nova Scotia, as with much of southern Canada, experienced a warmer-than-normal winter in 2012. Cold temperatures and heavy snowfall were limited to only a few events in early January. Snow and ice conditions on the marshes were low to non-existent for much of the winter.

Temperatures were sufficiently low to result in the freezing of the central pond within the TFH site for much of the winter. During the 6 March 2012 structured winter walk, there did appear to be limited water flow through the culvert as evidenced by the ice-free conditions immediately upstream of the structure (Figure 28).

A selection of landscape photographs from the SG and SG-R winter walk are provided in Appendix B.

Figure 28 Ice-free channel immediately upstream of the culvert. Photograph by T. Bowron, 6 March 2012.

5.0 Summary and Restorable Area

The results of the 2011/12 pre-restoration baseline monitoring of the Three Fathom Harbour tidal wetland restoration project were presented in this report. This was the first of a six year monitoring program designed to span twelve years (one year pre- and immediate, one, three, five and ten years post-restoration) that was developed for this project. The goals of the monitoring program are to provide a scientific record of habitat conditions at both the restoration and reference sites, to document the change in conditions in response to manipulation and to facilitate adaptive management if warranted.

The vegetation community was dominated by a mix of fresh water 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.

It was determined that the current TFH causeway-culvert structure significantly restricted tidal flow and fish passage to TFH and has resulted in the alteration of the natural hydrological regime, wetland habitat condition and a general decline in the ecological integrity and function of the site. Based on the elevation and tide signal data collected during the period of 25 May to 16 June 2011, it was determined that replacement of the existing culvert with a larger structure (3.5 to 4.0 m) would result in a significant reduction of the tidal restriction.

With the elimination of the hydrological restriction, the potential area of restored tidal wetland habitat within the TFH site would be between 1.71 ha (flood extent on largest recorded tide 15 June 2011) and 2.26 ha (site boundary delineated at tree line). The restoration of a more natural (unrestricted) hydrological regime to this site would result in the restoration of tidal flow and fish passage; increased frequency, extent and duration of tidal flooding; reduced flood risk (by freshwater); improved water quality; re-establishment of a tidal wetland vegetation community; and the general long-term improvement in the ecological integrity and resilience of the site. These improvements in hydrology and habitat conditions would benefit the entire 2.26 ha wetland area, as well as surrounding upland habitats and downstream marine environment.

6.0 Recommendations for Post-Restoration Monitoring

Pre- and post-restoration monitoring is an essential component of any habitat restoration project. Monitoring measures the effectiveness of the restoration effort; provides valuable information on the ecological condition of the restoration and reference sites; and the response of physical and biological elements as well as the overall system to the restoration treatment. 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 recommended long-term monitoring program, methods and sampling frequencies are outlined in Table 1 (Section 2.3). This program will enable the continued documentation of the ecological conditions, changes and habitat/species responses to restoration and the determination of project success.

It is recommended that in advance of culvert replacement (construction) that additional water quality, interstitial pore water salinity, and fish sampling be conducted at TFH. The marker horizons that were installed in 2011 should be cored in order to determine the pre-restoration sediment accretion rate.

The formal post-restoration monitoring program starts immediately following culvert installation. The structure itself as well as the area immediately upstream and downstream should be surveyed to establish the "as constructed" baseline elevation condition. Tide signal, water quality, salinity and fish should also be sampled at this time. The post-restoration monitoring program, as outlined in Table 1, will involve monitoring activities conducted one, three, five and ten years following culvert replacement. By taking an active adaptive management approach to the restoration project, it is not necessary for each ecological parameter to be sampled during each of the scheduled sampling years, unless indicated by the results of the previous monitoring year.

This longer-term post-restoration monitoring schedule is recommended due to the more gradual rate of change/response anticipated by some of the habitat conditions (e.g. vegetation, soil characteristics).

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Appendix A - Summary of CBWES Supported Student/Research Projects

In addition to the undergraduate and graduate research projects described below, CBWES routinely collaborates with universities, community colleges, and local elementary schools 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:

Masters of Applied Science

Department of Geography
Saint Mary's University
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.

Almost all life on earth depends on plants for their existence. Plants form the base of most food webs, but they also serve as habitat for many invertebrate, fish, birds and other species. Therefore, any attempt to restore a habitat should primarily aim at restoring vegetation structure. However, in Atlantic Canada there are few salt marsh restoration models or projects for managers to draw upon. This project aims to study the dynamics controlling vegetation community structure, so that a greater understanding of plant propagation patterns can be understood and modeled. The goal is to examine how surface morphology contributes to vegetative re-colonization. Low altitude photometric approaches, such as the use of a helium filled blimp, to document vegetation re-colonization patterns will be used. The contribution that surface features, such as the ponds created at the St. Croix River High Salt Marsh and Floodplain restoration site as well as internal creek structures of the Cogmagun River Salt Marsh restoration site, have on salt marsh propagation will be examined so that a vegetative propagation model can be created. Understanding how marsh morphology changes in time and the response of vegetation to those changes will serve to improve our understanding how habitat restoration is progressing and will further contribute to the continued progression of salt marsh restoration science.

Masters of Applied Science

Department of Geography
Saint Mary's University
Jennie M. Graham
NSERC Industrial Postgraduate Scholarship
2010-2012

Tidal Creek Hydraulic Geometry for Salt Marsh Restoration in the Upper Bay of Fundy

CBWES Inc. has been engaged in tidal wetland restoration and monitoring projects in Nova Scotia since 2005. In 2009, CBWES Inc. developed the project design and undertook restoration at two former tidal wetland systems in the Bay of Fundy; a 8 ha site on the Cogmagun River (COG) and a 19 ha site on the St. Croix River (SC). Both projects involved the breaching of an existing dyke in one or more locations and the excavation and recreation of historical tidal channel networks. The restoration designs put forward the problem of identifying appropriate locations for dyke breaches and excavated tidal channels in order to restore a more natural hydrological regime to the systems including the re-activation of relict creek systems while avoiding excessive erosion. During the restoration design phase of the SC project (Graham et al. 2008) a set of preliminary hydraulic equations were established for the Bay of Fundy region using the methods laid out by Williams et al. (2002). These equations were used to determine width and depth of excavated creeks and were further tested and refined through observations and application to a previously restored salt marsh (Walton River; Bowron et al. 2009).
The results of this preliminary work brought up several questions which would be addressed in this research project by:

- Ground-truthing reference marsh systems (i.e. creek widths and depths) to improve the quality of the data set.
- Improving the correlation of hydraulic geometry relationships through the refinement of the existing dataset and the addition of other marsh systems in the region, particularly large pristine marshes.
- Further analyzing the function of channelized versus free flow conditions on creek network development and maintenance and incorporating an analysis of flow velocity within channels using.
- Addressing the importance of additional variables such as location in the tidal frame and depth/width characteristics of the water body that the constructed creek network is entering.
- If possible, examining the impact of large (or multiple) storm events, freshwater runoff, and ice movement on newly constructed creeks which are particularly vulnerable to erosion.

The overall goal for this thesis project will be to produce a GIS-based model and protocol for future use in the design of marsh restoration projects in macrotidal environments.

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Graham, J.M., D. van Proosdij, N.C. Neatt & T.M. Bowron. 2008. Restoration Design Proposal 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. Report No.4.

Williams, P.B; Orr, M.K. and N.J. Garrity. 2002. Hydraulic geometry: a geomorphic design tool for tidal marsh channel evolution in wetland restoration projects. Restoration Ecology 10(3): 577-590.

Undergraduate Honours

Environmental Science
Saint Mary's University
Christa Skinner
2012-2013

Changes in grain size spectra and floc content over time in a macrotidal salt marsh restoration site

One of the indicators of success of a salt marsh restoration project is if the site is trending towards conditions present at a reference site. Several factors influence the soil characteristics at each sample location. These factors include source material, the elevation of the site within the tidal frame, distance from the estuary's mouth, distance from the creek bank and flow velocity. The grain size spectrum of a sample location is influenced by source material and velocity of current. The purpose of this project is to explore changes in source material and hydrodynamic processes in a restoration site over time with the use of disaggregated grain size (DIGS) analysis. It is hypothesized that over time the differences in source material and hydrodynamic processes at the restoration site will become minimal. The research was conducted within a newly restored salt marsh (and associated reference site) in the upper Bay of Fundy currently being monitored as a compensation project. Cores were taken from the restoration site and the reference site in 2008 and 2010. Samples taken from the cores were processed with hydrogen peroxide to remove organic material. The samples were processed through a Coulter Counter Multisizer 3 and using DIGS analysis a grain size spectrum and floc composition was produced for each sample. The shape of the resulting grain size spectrum gives an indication of source material and hydrodynamic processes. Minimal differences were observed in the data collected from the reference marsh and most of the samples processed from the restoration marsh. This indicates a similar source of material and similar hydrodynamic processes were experienced at both reference and part of the restoration site. However approximately half of the samples at the restoration site suggested different processes and source material. DIGS analysis was found to be a useful to identify changes in hydrodynamic processes and source material over time.

Completed Projects:

Undergraduate Honours

Environmental Science
Saint Mary's University
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

Six years of research and experience with restoring Bay of Fundy (Nova Scotia) salt marshes has shown that salt marsh plant species can colonize readily without planting, if the barriers to tidal flow are removed and suitable abiotic conditions (i.e. elevation) are present. Reactivated hybrid creek networks are potentially highly important to the restoration process, as they may represent the primary transport mechanism for seeds and vegetative material for re-colonization. It is unknown how important creeks are for the actual colonization of target species (*Spartina alterniflora; S. patens; Salicornia europaea; Suaeda maritima; Atriplex spp.*). Utilizing the Cogmagun River salt marsh restoration site (Hants County), which was restored in 2009, this research aims to examine if there is a relationship between proximity to creek and colonization rates of common salt marsh species, as well as if seedling coverage of *Suaeda maritima* in the previous year had a relationship with colonization rates of the following year. Colonization rates were positively related to proximity to the main tidal creek for four out of five target species (*S. alterniflora, S. europaea, S. maritima, and Atriplex spp),* and the presence of *S. maritima* in the previous year did increase the colonization rates of newly established communities. These results provide a fine-scale complement to existing and ongoing macro-scale studies and further clarify the relationships between abiotic properties of a recently restored tidal wetland and colonization.

Undergraduate Honours

Department of Environmental Science
Dalhousie University
Rachel Deloughery
2010

Contribution of seed hydrochory to re-colonization of vegetation in macro-tidal Bay of Fundy salt marsh restoration projects

This project examines the role of seed dispersal *via* water, or hydrochory, in the re-colonization of restored salt marsh vegetation communities. The chosen study sites were macro-tidal coastal wetlands on the Bay of Fundy in Nova Scotia, Canada where CB Wetland and Environmental Specialists have undertaken restoration projects. Actively returning salt water marshes to more natural hydrological regimes through designed and monitored projects is a relatively new practice in Atlantic Canada, but one that is increasingly seen. Research exploring the patterns and mechanisms of initial stages of re-vegetation is limited. This study examined the degree to which hydrochory was occurring, and its contribution to re-colonization by target salt marsh species, on the study sites where tidal flooding was enhanced through construction of breaches in 2009. Using artificial turf traps and seed extraction of collected material, rates and richness of seed dispersal in flooding were assessed. Vegetation surveys measured richness and abundance of emergent vegetation on the sites in August 2010, approximately one-year following restorations. The turf trap and survey data were analysed for overlap of species, relative contributions to target species pool, and similarities in relative abundance at corresponding sample points. Results indicate that hydrochory was contributing to availability of propagules at both sites. Proportions of target species seeds in the turf traps were small or undetected, but this does not necessarily signify a minor effect on above-ground community. Rates and patterns of seed hydrochory, and its relationship to emergent vegetation, are site-specific. Differences in environmental histories, relative locations within the estuary, natural flooding regime dynamics, existing vegetation communities and salinity levels are all possible contributors to the discrepancies seen here.

Undergraduate Honours

Department of Biology
Saint Mary's University
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

The aim of this project was to determine if hydrochory (seed transport by water) was a more likely source of early colonists than the soil seed banks of newly restored salt marshes. The project had two sample sites, St. Croix River and Cogmagun River salt marsh restoration sites. Soil seed banks in this study were defined as viable seeds based in the first 10 cm of soil on the surface of the restoration site. The project aimed to determine the relative contribution of the soil seed bank prior to breaching of the dyke and hydrochory post dyke breach to salt marsh vegetation re-colonization. The soil seed banks of the Cogmagun site and the St. Croix site were both sampled prior to the breaching of the dyke. The soil seed bank was sampled by placing quadrats at pre-determined sample points and sampling the soil using soil cores. This soil was then taken to a greenhouse, allowing any seeds present to grow, and then species and relative seed abundance was determined. The hydrochory traps for the St. Croix site were sampled by placing artificial turf traps at the same locations as the soil seed bank samples post breaching of the dyke. For the Cogmagun traps, due to time constraints with the thesis requirements, artificial turf traps were deployed prior to the dyke breach on an adjacent marsh. This would give a good indication of the potential for seed transport via tidal waters. The traps were deployed for the first spring tide period following the breaching of the dykes, during which time Hurricane Bill passed over Nova Scotia. The storm surge most likely washed away many of the seeds and sediment from the artificial turf traps. The traps were then collected, cold stabilized, and washed on a sieve to collect seeds and sediment which was then sent to the greenhouse for germination.

Preliminary results showed that the dominant plants found in the both the St. Croix artificial turf traps and hydrochory traps were mostly of the *Poacaea* genus. The samples from the Cogmagun soil seed bank were dominated by cattails (*Typha sp.)*. These findings point to the soil seed banks being reflective of the above ground vegetation. The hydrochory traps point to the localized seed transport as species from the St. Croix soil seed bank were dominated by grasses (*Poacaea*). Species for the Cogmagun site are still growing in the greenhouse as they need to flower so that their identification can be complete.

Undergraduate Honours

Department of Biology
Saint Mary's University
Emile Colpron
2008

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

This study focused on the avian fauna of four salt marshes found in the upper Bay of Fundy, on the Minas Basin. The Bay of Fundy salt marshes are important coastal ecosystems for many avian species. They provide breeding and foraging habitat for numerous species of shorebirds, passerines and waterfowl. Many species which breed in the Arctic make use of tidal marshes as well, either for over-wintering, or as stop-over areas to rest and feed during annual migrations (Brawley et al. 1998).

Despite the importance of salt-water marshes for biodiversity conservation, the avian responses to alterations are poorly understood (Benoit & Askins 2002, Shriver et al. 2004, Hanson & Shriver 2006). The loss of salt marshes is especially a threat to salt-marsh specialist species such as the Nelson's sharp-tailed sparrow (*Ammodramus nelsoni*) and the willet (*Tringa semipalmata*). Both Nelson's sharp-tailed sparrow and the willet have been listed as a species at risk by COSEWIC (Committee On the Status of Endangered Wildlife In Canada) in the past due to population declines.

The objectives of this study were to (1) compare the species richness and abundance of avian fauna in restored and natural salt marshes, and (2) to determine the use of restored and natural salt marshes by avian salt marsh specialists.

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Benoit, L.K. and R.A. Askins. 2002. Relationship between habitat area and the distribution of tidal marsh birds. *The Wilson Bulletin*. 114(3):314-323.

Brawley, A.H., R.S. Warren and R.A. Askins. 1998. Bird use of restoration and reference marshes within Barn Island Wildlife Management Area, Stonington, Connecticut, USA. *Environmental Management*. 22(4):625-633

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Shriver, W.G., T.P. Hodgman, J.P. Gibbs and P.D. Vickery. 2004. Landscape context influences salt marsh bird diversity and area requirements in New England. *Biological Conservation*. 119:545-553.

Appendix B - Structured Winter Walk

STRUCTURED WALK PHOTOGRAPHS TFH (select images):

Figure 1 Transect two.

Figure 2 Transect four.

Figure 3 Transect five.

Figure 4 Upstream side of culvert and road.

Figure 5 Downstream side of culvert and Three Fathom Harbour.