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

Pre-Restoration Monitoring (Baseline) of the Morris Island Salt Marsh Restoration Project

Prepared by:
Tony M. Bowron, Nancy C. Neatt, Jennifer M. Graham, Dr. Danika van Proosdij, and Dr. Jeremy Lundholm

CBWES Inc.

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Executive Summary

CBWES Inc. was commissioned by the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR) in September 2012 to complete a restoration feasibility and design study for a tidally restricted wetland at Morris Island, Yarmouth County, Nova Scotia (NS). It was determined that replacement of the existing tidally restrictive and failing culvert with a more appropriately sized structure would result in a significant reduction in the hydrological barrier.

The primary goals of the restoration efforts at the Morris Island Tidal Wetland Restoration Project site were to:

- Significantly reduce the tidal restriction caused by the 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 collapsed, buried, and undersized culvert with a more appropriately sized structure (capacity to (at least) accommodate a 3.6 m^3/s of discharge; predicted cross-sectional area of 0.82 m based on highest recorded tide; diameter of a round pipe fitting that cross-sectional area would be 1.02 m) in order to restore a more natural tidal regime to the system and to improve fish passage; and
- Develop and implement a pre- and post-restoration ecological monitoring program to ensure project success.

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

- 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;
- Document the efficacy of the compensation being undertaken to restore the Morris Island tidal wetland system; 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 tidal wetland 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 vegetation, was determined to encompass a total area of approximately 8 ha. When combined with the hydrology data, the area of potential direct tidal influence (restorable area) was on the order of 1 ha.

Hydrology

Hydroperiod and Tidal Signal

Comparison of the upstream and downstream tide signals confirmed that the causeway-culvert (collapsed) represented a significant restriction to tidal flow. The mean difference (restriction) was 14 cm, with a maximum restriction of 50 cm (2.53 m downstream, 2.02 m upstream). The maximum recorded tide (2.5 m) would flood approximately 1.12 ha (potential restorable area). High water events (i.e. storm surge) greater than this water level would flood a larger area of the wetland.

Water Quality

There was little difference in DO, pH or temperature readings between sampling locations, with all measurements being within the expected range for the location and time of year. Salinity levels were significantly higher at the reference site (28/29 ppt) and showed no variation. Salinity levels within the restoration site ranged from 24 ppt immediately upstream of the culvert to 0.12 ppt approximately 60 m upstream. The difference in salinity levels and the rapid decline with distance from the causeway is reflective of the reduced tidal influence.

Ground Water

Freshwater (precipitation) was found to be the primary driver of hydrological conditions within the restoration site, with tidal influence limited to the area immediately upstream of the causeway-culvert. Water levels across all sampling stations increased following a rain event, and then gradually decreased until the next rain event.

Soils and Sediments

Pore Water Salinity

Interstitial pore-water salinity was found to be both lower and less variable at MI than MIR, reflecting the dominance of freshwater at the restoration site. Significant differences in salinity levels between the two sites, as well as between shallow and deep salinity levels within each site were found. Salinity decreased with distance upstream of the causeway, and increased with distance downstream. Seasonal variations within the restoration site were a reflection of the influence of freshwater as the main hydrological driver compared to the tidally driven conditions at the reference site.

Soil Characteristics

Sediment samples from both sites were predominantly comprised of peaty material and had a soil matrix that was mainly organogenic in nature. The presence of sphagnum moss within cores from the restoration site suggests acidic conditions, which is also a characteristic of bog-like conditions. Water content levels for MI were further evidence of the site being freshwater driven. Organic matter content for MI was twice that of the reference, while bulk density was much lower. Differences in grain size between the two sites further supported the freshwater source and upstream influence for the restoration site compared to the tidal/marine dominated reference site.

Soil Chemistry (Redox Potential)

The redox potential measurements at the restoration site indicated moderate anaerobic stress on vegetation and potential for moderate decomposition rates within the soil under anaerobic conditions. The reference site was found to be more oxidized (low stress on vegetation) than the restoration site (stressed conditions). Overall, both sites were experiencing similar dominant reduction reactions which create stress on the vegetation. The vegetation types at both sites were [different] wetland species that are adapted to this kind of soil condition and stress.

Vegetation

The vegetation community structure at the restoration site was a combination of brackish species at the front part of the site (adjacent to the causeway) and freshwater/bog species towards the back of the site. Vegetation type showed a distinct correlation to hydrological conditions. The reference site contained both brackish and halophytic species, and could be classified as a salt marsh, but with strong freshwater influence likely due to the presence of the causeway and the narrow marsh profile. The restoration site had greater species richness because of the mix of habitat types (bog, fen, freshwater, brackish) compared to the single habitat type of the reference (salt marsh). Halophytic richness and abundance were both greater at the restoration site. Halophytic species were present at the restoration site indicating some salt water influence.

Nekton

The minnow trap set immediately upstream of the culvert was the only trap within the restoration to contain fish (10 *Fundulus heteroclitus;* 1 *Gasterosteus aculeatus*). *F.* heteroclitus was also the dominant species in both fyke net and minnow traps at MIR. The fyke net samples contained five different species of fish. The presence of species such as *Alosa pseudolarengus*, *Anguilla rostrata*, *Microgadus tomcod,* are indicative of higher order species within the reference site that would likely be accessing the restoration site if not for the tidal restriction.

Aquatic Invertebrates

Species richness was similar between the two sites, however, the species composition was quite different. Invertebrate samples from the reference site were mainly comprised of estuarine and marine species (i.e. small copepod crustaceans and nematodes), while the reference site contained mainly freshwater species (i.e. chironomidae larvae). The reference site, however, was significantly more productive. With the restoration site, species richness and diversity increased with distance from the causeway, away from tidal influence and predatory pressure.

Summary

The current causeway-culvert structure at MI represents a significant barrier to tidal flow, has resulted in an alteration of the natural hydrological regime and a loss of halophytic species and tidally influenced wetland habitat conditions. Pre-restoration monitoring confirmed MI to be a freshwater wetland environment with a mix of bog, fen and brackish wetland 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 the site and downstream of the causeway, and marsh surface elevations within the site, indicate that the site would experience increased 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.

With the elimination of the hydrological restriction, the potential area of the restored tidal wetland habitat at MI would be approximately 1.12 ha (based on recorded tide elevations and current wetland surface elevations). While it is difficult to predict the exact size and 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 will enable the documentation of early stages of the wetland recovery process and verification of an acceptable restoration trajectory.

Acknowledgements

Financial and in-kind supporters of this project include: Nova Scotia Department of Transportation and Infrastructure Renewal, Natural Sciences and Engineering Research Council of Canada (NSERC), Employment and Social Development Canada (ESDC), Community-Based Environmental Monitoring Program (Saint Mary's University (SMU)), Maritime Provinces Spatial Analysis Research Centre (MP_SpARC) (SMU), the Intertidal Coastal Sediment Transport Research Unit (In_CoaST) (SMU) and the Ecology of Plants In Communities Research Lab (EPIC) (SMU).

1.0 The Morris Island Tidal Wetland Restoration Project

1.1 Background

CBWES was commissioned in September 2012 by the Nova Scotia (NS) Department of Transportation and Infrastructure Renewal (NSTIR) to conduct a tidal wetland restoration feasibility and design study for the restoration of a more natural hydrological regime, fish passage and tidal wetland habitat conditions to the former tidal system at Morris Island, Yarmouth County, NS (CBWES 2013) (Figure 1). It was determined that the replacement of the tidally restrictive culvert with a more appropriately sized and placed culvert would result in a significantly reduced hydrological barrier. More specifically the project would:

- re-establish a more natural connection between habitats upstream and downstream of the causeway,
- increase halophyte species within the restoration site,
- improve transport/access of materials and species (i.e. fin and shellfish),
- allow tidal flooding of the (>/=) 1 ha portion of the site immediately upstream of the causeway by high water events, and
- create a more defined channel upstream to allow for improved hydrological flow and access of tidal waters and aquatic organisms to the site and marsh surface.

The Morris Island Tidal Wetland Restoration Project is the proposed –fish habitat and wetland compensation for the Tusket River and Indian Sluice Bridges. The determination of restoration potential was the first step in the process to fulfill NSTIR's compensation requirements (CBWES 2013). This was followed by the development of a long term monitoring program to meet the regulatory environmental permitting requirements of NS Department of Environment (NSE) and Fisheries and Oceans Canada (DFO), and then the implementation of baseline (pre-restoration) and post-restoration monitoring.

The proposed restoration site is approximately 8 ha of tidally restricted coastal wetland complex that is part of the Tusket River Estuary. The natural hydrological regime of the site was significantly altered by the original construction of a causeway-culvert structure across the mouth of the system as part of Route 308. The existing culvert is too small to allow for adequate tidal exchange to sustain the natural tidal wetland conditions of the site. Subsequent decline in culvert condition (collapse, slumping, blocked by armour stone) has further restricted the movement of water, species, and materials into and out of the wetland site. The amount of potential restorable area is 1.12 ha based on the feasibility study completed.

The results of the baseline monitoring are presented in this report.

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, Christa Skinner and Carly Wrathall 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.).

1.2 CBWES Inc.

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

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

To date, two peer-reviewed papers have been published focusing on separate restoration projects. One was published in *Restoration Ecology* on the Cheverie Creek Restoration Project titled "*Macro-Tidal Salt Marsh Ecosystem Response to Culvert Expansion*" (Bowron et al. 2011) and the second appeared in the journal *Ecological Engineering* on the Walton River Restoration Project titled *Ecological Re-engineering of a Freshwater Impoundment for Salt Marsh Restoration in a Hypertidal System* (van Proosdij et al. 2010). A third paper, "*Classification and environmental correlates of tidal wetland vegetation: implications for ecological restoration and monitoring"* is being peer-reviewed for publication in the journal *Estuaries and Coasts* (Porter et al. submitted). A book chapter has also recently been published titled "Chapter 13 – Salt Marsh Tidal Restoration in Canada's Maritime Provinces" in *Tidal Marsh Restoration: A Synthesis of Science and Management* (Roman et al. 2012). Abstracts for each of these publications appear in Appendix A.

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[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. 2011; Bowron et al. 2012a,b; Bowron et al. 2013a,b,c; Bowron et al. 2014a,b; CBCL 2011; Neatt et al. 2013; van Proosdij et al. 2010; CBWES reports available for download at www.gov.ns.ca/tran/enviroservices/enviroSaltMarsh.asp).

[2]6th Annual Atlantic Reclamation Conference (ARC 2013); Coastal and Estuarine Research Federation 22nd International Conference (CERF 2013); 2013 Mid-Atlantic Living Shorelines Summit (RAE 2013); Canadian Land Reclamation 37th National Conference (CLRA 2012); Atlantic Canada Coastal and Estuarine Science Society 2012 (ACCESS 2012); BoFEP's 9th Bay of Fundy Science Workshop (BoFEP 2011); Coastal and Estuarine Research Federation's 21st International Conference (CERF 2011); Restore America's Estuaries 5th National Conference on Coastal and Estuarine Habitat Restoration (RAE 2010); Atlantic Reclamation Conference (ARC 2008; 2009, 2010); Coastal and Estuarine Research Federation's 2009 International Conference (CERF 2009); BoFEP's 8th Bay of Fundy Science Workshop (BoFEP 2009); Canadian Water Resources Association - Maritime Water Resources Symposium (CWRA 2008); Atlantic Canada Coastal and Estuarine Science Societies' 2008 conference (ACCESS 2008); Estuarine Research Federations' 2007 International Conference (ERF 2007); Canadian Land Reclamation Associations National Conference (CLRA 2007); Ecology Action Centre's "Six Years in the Mud – Restoring Maritime Salt Marshes: Lessons Learned and Moving Forward" workshop (EAC 2007).

2.0 Description of Restoration and Reference Sites

2.1 Restoration Site

The Morris Island Restoration Site (hereafter referred to as "MI") is a coastal wetland complex (tidal, brackish, treed swamp, bog) approximately 8 ha (19.8 acre; 8,000 m^2) in size on Morris Island, Yarmouth County, Nova Scotia (NS) (Figure 1 to Figure 3). The site was historically part of the broader Tusket River Estuary, but its' hydrological connection was significantly reduced by the construction of a causeway-culvert structure across the lower portion of the site. This structure altered the natural hydrological regime of the site causing a reduction in area of tidally influenced wetland within the site. The subsequent failure (collapse) of the culvert further reduced tidal influence and led to an almost complete loss of tidal wetland conditions.

Route 308 crosses the tidal wetland habitat as a two-lane, rock-filled causeway-culvert structure (Figure 9). The existing culvert is an aluminum structure that is approximately 16.15 m long, with inverts sitting at 1.521 m CGVD28 upstream and 1.836 m downstream (Figure 6 to Figure 8). This culvert has been in decline (collapse, slumping), although some tidal influence still occurs on the higher high tide events enabling the persistence of several halophytes and brackish species immediately upstream of the culvert (e.g. *Spartina patens* (Salt meadow cord grass), *Limonium nashii* (Sea lavender), *Juncus gerardii* (Black grass), *Scirpus americanus* (Three-square bulrush), spike rushes, *Juncus balticus* (Baltic Rush), *Elymus* sp. and *Typha* sp.) (Figure 4). Much of the restoration site is dominated by bog vegetation (*Vaccinium* (Cranberry), *Chamaedaphne calyculata* (Leatherleaf), *Sarracenia purpurea* (Pitcher-plant) and sedges), which transitions to mixed scrub-shrub and bog habitat. During heavy rainfall events the site is unable to drain water efficiently, causing considerable ponding upstream. Subsequently the soils upstream are waterlogged and could be classified as organogenic, or derived from organic substances. The channel directly upstream of the culvert is undefined (Figure 8).

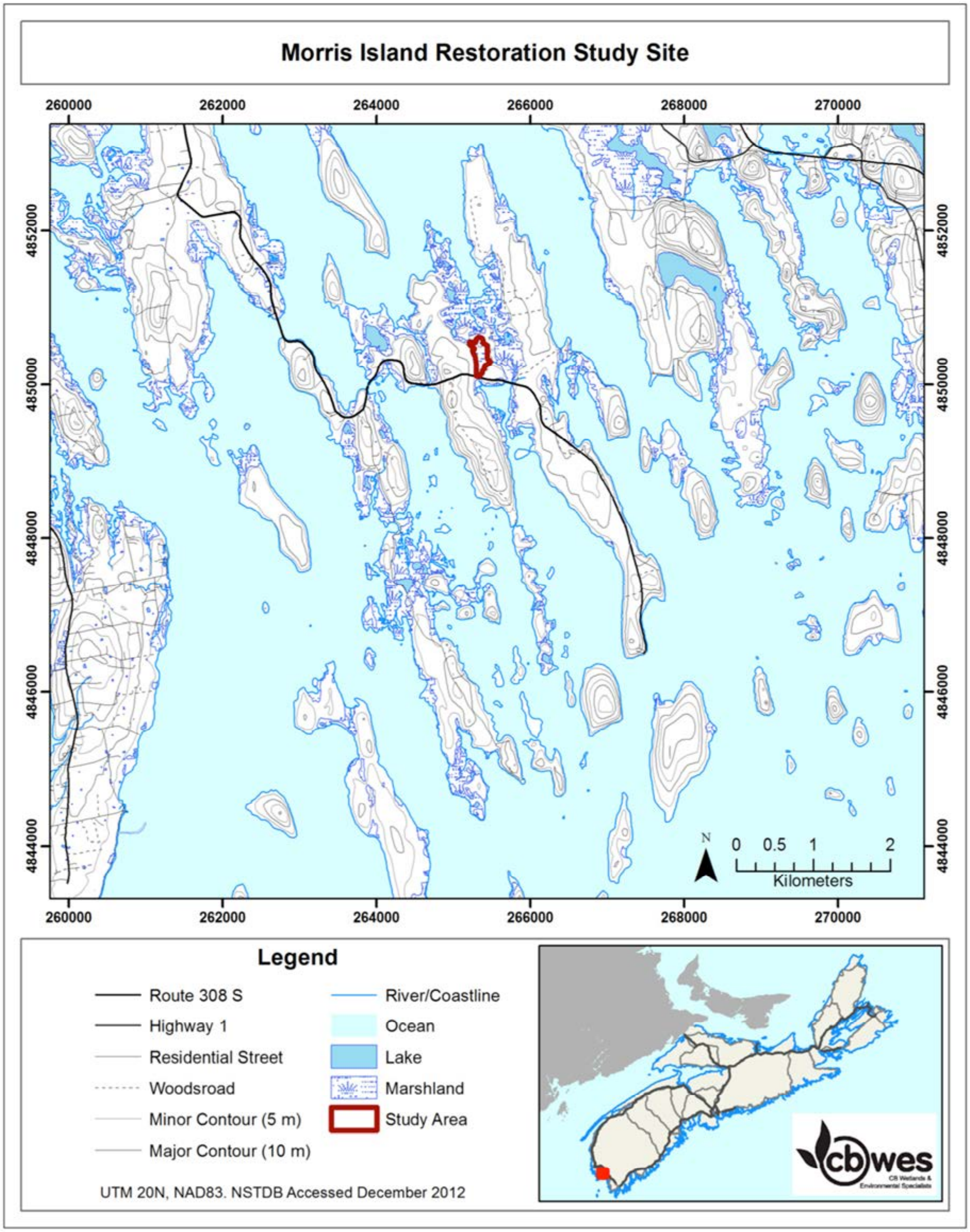


Figure 1 Location of Morris Island Restoration Site (red)

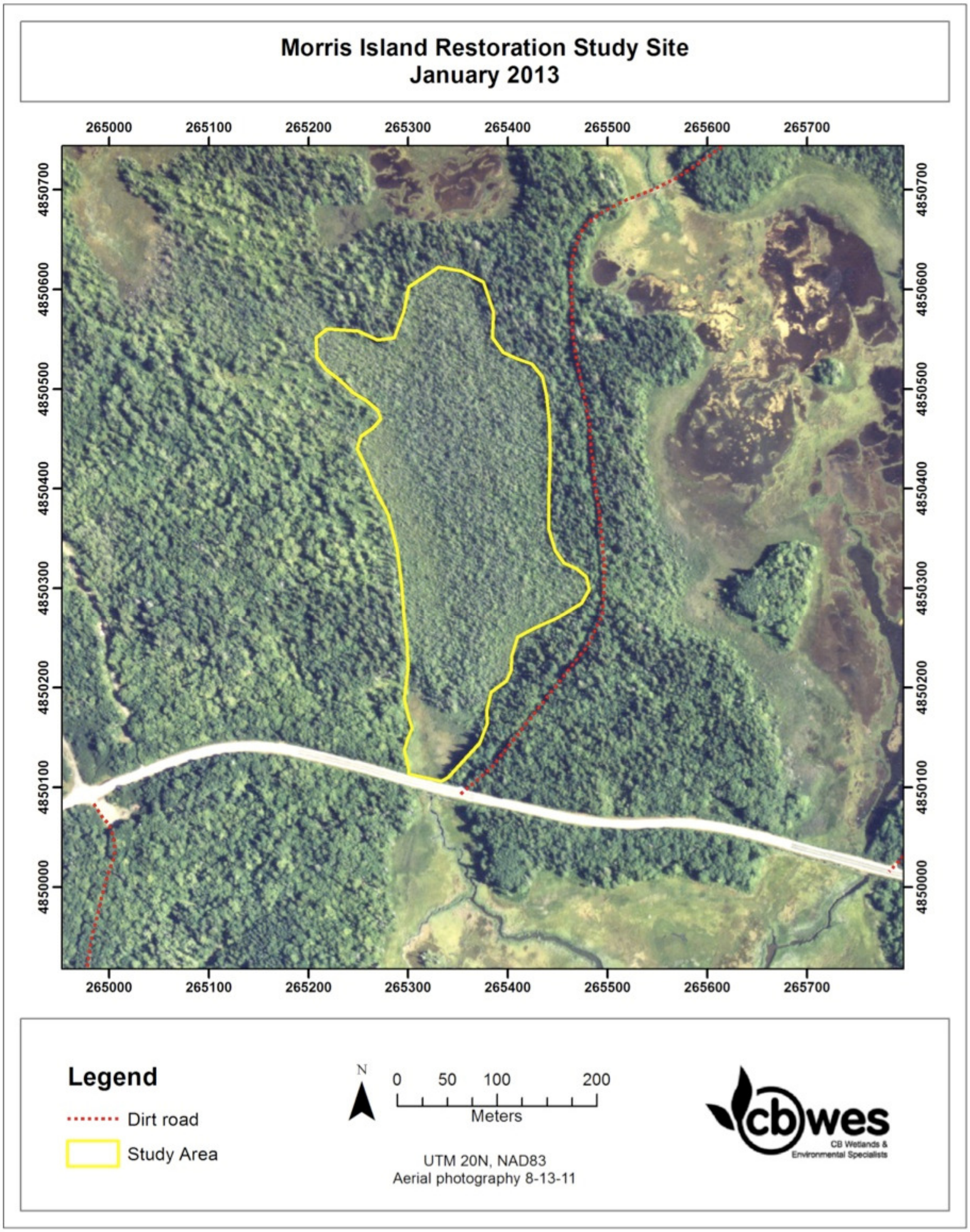


Figure 2 Morris Island wetland study area. Monitoring efforts focus on the front portion of the site, the area to be most directly affected by restoration activities.

Figure 3 Google Earth image showing adjacent habitat to the Morris Island Restoration Site (white box) including downstream salt marsh and channels.

Figure 4 Morris Island Restoration Site from the road (16 September 2012).

Figure 5 Site's interior scrub-shrub and treed wetland habitat (16 September 2012).

Figure 6 Downstream end of culvert (16 September 2012).

Figure 7 Culvert upstream: partial blockage by armour stone (24 February 2014).

Figure 8 Culvert upstream and the undefined channel (16 September 2012).

Figure 9 Downstream location of Levelogger showing causeway (Route 308) crossing (12 October 2012).

2.2 Reference Site

The reference site (MIR) for the monitoring program is located immediately downstream of MI, on the opposite side of the Route 308 causeway (Figure 10 and Figure 11). The area of downstream marsh used as the reference site is similar in spatial extent (1.9 ha) as the restoration site. The causeway, and therefore upper boundary of MIR, is approximately one kilometer from the head of the marsh channel where it meets “The Basin” (Figure 10). MIR exhibits the typical salt marsh habitat zonation pattern, well developed tidal creek, a minimal panne system, and host of plant species common to tidal wetlands along the Atlantic coast.

Figure 10 Google Earth image showing downstream habitat to the Morris Island Reference Site (white box).

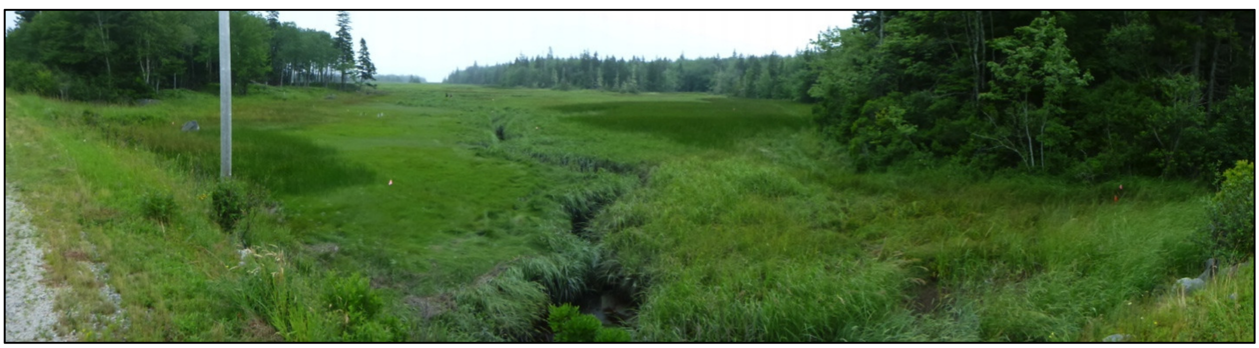


Figure 11 Morris Island Reference Site downstream of MI (30 July 2013).

3.0 Monitoring Program and Methods

Monitoring Program

The MI Tidal Wetland Restoration Project monitoring program was developed based on experience with similar restoration projects in the region (Bowron et al. 2011; Neckles et al. 2002; van Proosdij et al. 2010). The monitoring program was used in 2013 to establish a baseline habitat condition against which future conditions could be compared, and to enable a comparison between reference site and restoration site conditions. In future monitoring years, the 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).

Annual monitoring during the first three years following restoration is critical because it is during these initial years following restoration that the greatest and most rapid changes are likely to occur. Monitoring of other tidal wetland restoration projects in the region have shown that although physical change can occur quite quickly and that the biological communities can be highly responsive, it can take many years, and be highly varied between sites, for conditions at restoration sites to approach those of reference sites (Bowron et al. 2014a; Neatt et al. 2013). Monitoring beyond the first three years following restoration allows for documentation of the longer term, often more gradual, changes in response to restoration and for conditions (e.g. soil salinity, vegetation species composition) to begin to show indications of parity with the reference habitat (Able et al. 2008; Burden et al. 2013; Garbutt and Wolters 2008; Mitsch et al. 2012; Perry et al. 2001). Therefore, the MI monitoring program also includes a comprehensive fifth year of post-restoration monitoring, allowing a greater period of time for change to occur.

The monitoring program makes use of a suite of salt marsh indicators and data collection methods that have been tailored to this project, and which seek to characterize a broader range of tidal 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 sampling schedule recommended for this project are identified in Table 1.

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

Table 1 The Morris Island Restoration monitoring program, including core and additional ecological indicators, methodologies, and sampling frequency (annual application indicated by X – all sites; S – study site only; R – reference site only; Y – scheduled future sampling).

Category	Parameters	Sampling Method	Annual Sampling Frequency	Monitoring Year					
				Pre	Post-Restoration (2014-2019)				
				2013	Immediate post	1	2	3	5
Hydrology	Tidal signal	Automated water level recorders (5 minute intervals) (Solinst Levelogger (Model 3001)	Once per required sampling year. Oct 17 – Dec 7 2012	X	Y	Y		Y	Y
	Surface water quality (flood waters)	YSI 650 MDS; YSI 556 MPS; pH Handheld DO Instruments	09/10/13	X	Y	Y	Y	Y	Y
	Ground water	5 automated water level recorders (30 minute intervals) (Solinst Levelogger (Model 3001) set in wells.	01/08/13 – 23/09/13	S	Y	Y		Y	Y
Soils & Sediments	Marsh surface elevation	Digital Elevation Model (DEM); Differential GPS	Once per required sampling year.	X	Y	Y		Y	Y
	Interstitial pore water salinity	FieldScout EC 110 Meter	30/07/13, 20/08/13, 23/09/13	X		Y	Y	Y	Y
	Sediment accretion	Marker horizons (NH) sampled using a cryogenic corer (Cahoon et al. 1996) Rod Surface Elevation Tables (RSET). 1 per site	MH Installed: 29/07/13 RSET to be installed in advance of restoration	Install X		Y	Y	Y	Y
	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). MI: 8 MIR: 8	29-30/07/13	X		Y		Y	Y
	Redox Potential	Thermo Scientific Orion Star A221 milivolt meter with platinum electrodes &	29/8/13	X		Y		Y	Y

Category	Parameters	Sampling Method	Annual Sampling Frequency	Monitoring Year					
				Pre	Post-Restoration (2014-2019)				
				2013	Immediate post	1	2	3	5
		accument calomel reference electrode							
Vegetation	Composition Abundance Height	Point Intercept Method (1 m^2 plots) MI: 26 plots; MIR: 26 plots	30/07/13, 29-30/08/13	X		Y	Y	Y	Y
	Habitat map	Aerial photograph (8-13-11), DGPS/GIS, Low-altitude aerial photography	Low-altitude Aerials: 29/10/13	X		Y		Y	Y
Nekton	Composition Species richness Density Length	Minnow traps in pannes/ponds, tidal channels (small fish); fyke net (30 m x 1 m; 6 mm mesh) on marsh surface (all sizes)	23/09/13, 09/10/13	X		Y	Y	Y	Y
Aquatic Invertebrates	Abundance/species richness of aquatic invertebrates	Invertebrate Activity Traps	30-31/07/13, 29-30/08/13	X		Y		Y	Y
Winter Conditions	Ice/snow conditions	Structured winter walk; photographs along each transect	24/2/14	X	Y	Y	Y	Y	Y

Sampling Layout

Sampling was conducted at both the restoration and reference site using a series of transects established in a non-biased, systematic sampling design. Six transects were established at MI, running perpendicular to the culvert and future tidal flow, and marked along the upland edge with permanent wooden stakes (Figure 12). The first four transects were established 20 m apart, with sampling stations every 20 m along each transect. Transect five and six were established 25 m apart with sampling stations every 25 m on transect five and every 30 m on transect six. Five transects were established at MIR in the same manner (transects 20 m apart; sampling stations every 20 m) (Figure 12). A combination of 100 m field tape, compass, and Trimble R8 GNSS RTK surveying system[3] were employed to produce and digitally map straight, reproducible transects.

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

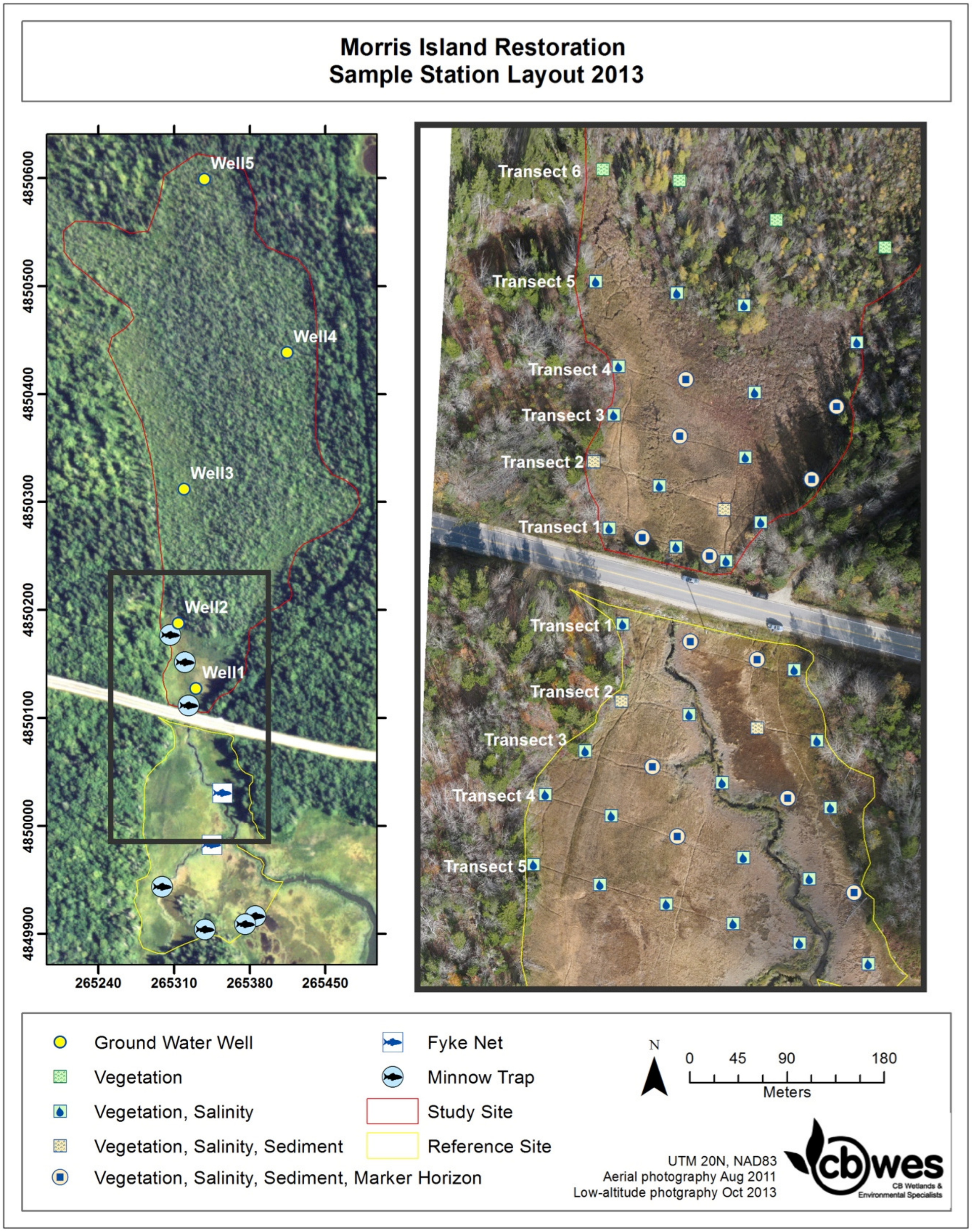


Figure 12 Sampling layout map of MI and MIR.

3.1 Habitat Map and Digital Elevation Model (DEM)

The habitat map and DEM for MI and MIR were updated from those developed as part of the feasibility study (Bowron et al. 2013c). The DEM for MI and MIR were originally produced using topographic data collected during an elevation survey on 7 December 2012 using a Trimble R8 GNSS RTK surveying system. The DEM was updated with additional elevation data and low-altitude aerial imagery collected during baseline monitoring (2013). The original estimate of restorable area was determined using the feasibility study DEM.

The habitat map (surface cover) provided a foundation for monitoring activities and a visual record of changes in habitat conditions following restoration. The habitat map, originally produced using the elevation survey data, provincial aerial photography and on-site observations, was updated during the baseline monitoring year (2013) with vegetation survey data collected and low-altitude aerial photography. An orthorectified image mosaic was produced from the aerial imagery to be used as the base layer for the maps.

The DEM and habitat maps will be updated immediately post-restoration when new data is collected.

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.

When attempting to understand changes in vegetation, water table level can be a valuable parameter to monitor as it provides information on the degree of waterlogging or drainage that is occurring on a marsh (Roman et al. 2001). Surface water quality (salinity, dissolved oxygen, pH and temperature) of flood waters can also influence the diversity, distribution and abundance of plants and animals in a salt marsh.

Hydroperiod and Tidal Signal

The hydroperiod (frequency and duration of tidal flooding) of the restoration site pre-restoration (feasibility and design phase) was modeled using the tidal signal (pattern of water level change with respect to a reference point) and marsh surface elevation (DEM). The tidal signal was measured between 17 October and 7 December 2012 using a pair of Solinst Levelogger Gold (Model 3001[4]). The tidal signal will be measured again immediately post-restoration.

Water Quality

A YSI 650 MDS sonde was used to measure four physical components of water: temperature (± 0.1 C°), dissolved oxygen (DO) (± 0.1 mg/L), salinity (± 0.1 ppt) and pH. A series of water quality measurements were taken within an eighteen minute window of peak tide (spring) on 9 October 2013. Measurements of tidal waters were taken at four locations above and below the causeway.

[4] www.solinst.com/Prod/3001/3001d2.html

Ground Water

Water level within the MI site was monitored during the period of 1 August to 23 September 2013 was using five Solinst Levelogger Gold (Model 3001[5]). Leveloggers were deployed at depth of 1 m (below soil surface) using still wells. Wells were located along a transect running from just upstream of the culvert (T1), north to the back portion of the wetland system (Figure 12). Leveloggers were programed to measure water level at thirty minute intervals.

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, productivity and the vertical growth of a marsh following restoration (Neckles and Dionne 2000).

Pore Water Salinity

Interstitial pore water salinity is one of the main controls on the distribution and abundance of plants in a marsh (Niering and Warren 1980; Crain et al. 2004). Monitoring pore water salinity throughout the growing season can help explain changes in environmental conditions regulating plant growth, distribution, and abundance as well as overall habitat responses to restoration activities.

Sampling locations for interstitial pore water salinity were matched with all vegetation sampling stations, excluding the heavily forested stations on transects 5 and 6 (Figure 12). At each of the sampling locations at MI and MI-R, both a shallow (15 cm) and a deep (45 cm) pore water sample were taken throughout the field season with a FieldScout EC 110 Meter[6]. Measurements were taken *in situ*, and readings recorded in the field.

Pore water salinity sampling at both locations was conducted on 30 July, 29 August, and 23 September 2013. Both "between sites" (MI vs. MIR) and "within sites" (Shallow vs Deep) comparisons of salinity levels were conducted using t-Tests (two-Sample assuming unequal variances and paired respectively). In addition, pore water salinity was mapped to assess seasonal changes across the marsh surface for "shallow" and "deep" readings. Pore water salinity is best represented spatially as a continuous surface; therefore, a kriging interpolation was used to create a series of raster grids for analysis. Kriging is a stochastic technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location and generally produces better results and smoother delineations than other commonly used methods such as IDW and spline techniques (Metternicht 2008; http://support.esri.com/en/knowledgebase/GISDictionary/term/kriging).

Sediment Accretion and Elevation

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

[5] www.solinst.com/Prod/3001/3001d2.html
[6] www.specmeters.com/brands/field-scout/ec110/

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.

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), and multiple Rod Surface Elevation Tables (RSET) and marker horizons.

Given the size of MI(R) and its location within the Tusket River Estuary system, it was decided that elevation surveys, a series of marker horizons (accretion) arrayed throughout both sites, and an RSET per site would be used. Replication of the elevation survey (years one, three and five of the monitoring program) and annual RSET and marker horizon measurements, should provide sufficient insight into any changes in overall marsh surface elevation and accretion rates following restoration. The RSETs, in combination with sediment characteristic analysis should also provide information on below ground processes and change following restoration. Installation of the RSETs will be conducted in advance of culvert replacement.

A series of marker horizons were established at points throughout MI(R) that represent the different potential habitat zones (low, mid, high marsh) on 29 July 2013 (Figure 12). The marker horizons were installed according to the methods developed by Cahoon and Lynch (USGS 2005). The marker horizons will be measured, in advance of culvert replacement, using a cryogenic corer and methods as described by Cahoon et al. (1996). The markers will be sampled (cored) annually following restoration in order to determine the annual rate of sediment accretion within the restoration site and at the reference site for comparison.

Sediment Characteristics

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.

Laboratory

Cores were processed at the In_CoaST research lab for bulk density, water and organic matter content and grain size analyses. Grain size was analyzed within using a Coulter Multiziser 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 (Figure 13) (Blott and Pye, 2001).

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 16 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 ($g \cdot cm^{-3}$) = net dry weight (g) / volume (cm^3)

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 24 hrs 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 Coulter Laser Multisizer)
The grain size sample was dried at 65 degrees 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 µm (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).

Analysis
Dr. Danika van Proosdij (SMU) conducted the sediment characteristic analysis presented in Section 4.3.

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).

Soil Chemistry (Redox Potential)

Restoration of tidal water to a previously tide restricted site has been shown to drastically alter the biogeochemistry of marsh sediments, ultimately affecting vegetation re-colonization (Anisfeld 2012). The site conditions prior to restoration will govern the soil chemistry and long-term success of the restoration project. Reddy and DeLaune (2008) define biogeochemistry as "the study of the exchange or flux of materials between living and nonliving components of the biosphere". The processes that occur within wetlands at the surface or near-surface layers of sediments govern the biogeochemical cycles, productivity of plants, microbial transformations, nutrient availability, pollutant removal, exchange between atmosphere, water and sediment, and sediment transport (Reddy and DeLaune 2008).

Oxidation and reduction reactions represent a transfer of electrons either through donating or accepting an electron respectively. For microbial communities the most preferred electron acceptor is oxygen (Craft 2001; Reddy and DeLaune 2008; Portnoy 1999); however, oxygen found within the soil is rapidly consumed leading to a high electron pressure or reduced state (Colmer and Flowers 2008; Koch and Mendelsshn 1989). Alternative electron acceptors include (in order of decreased energy provided): nitrate (NO_3^-), manganese (IV) oxides (MnO_2), iron (III) oxides ($Fe(OH)_3$), sulfate (SO_4^{2-}), and carbon dioxide (CO_2) (Craft 2001; Reddy and DeLaune 2008). The reduction of these alternative electron acceptors not only reduces the amount of energy accessible to the microbial community, but many produce phytotoxins (e.g. hydrogen sulfide) that are detrimental to vegetation growth (Koch and Mendelsshn 1989).

Redox potential can be used as an indicator for the intensity of anaerobic conditions within the sediments (de la Cruz et al. 1989; Reddy and DeLaune 2008) and represents the dominant oxidation reduction reaction occurring at the time of the measurement (Reddy and DeLaune 2008; Figure 14) Measuring redox potential of soils at representative locations throughout a restoration site reflect the interaction between hydrology, microbial activity, rhizome activity, sediment characteristics and amount of available organic matter and nutrients (Catallo 1999; Reddy and DeLaune 2008).

Field Methods

Redox potential was measured at both sites on 29 August 2014 using a series of platinum electrodes, an accument calomel reference electrode and Thermo Scientific Orion Star A221 Milivolt Meter[7] (Figure 14). Platinum electrodes (probes) were constructed based on the design by Vepraskas and Cox (2002). Probes were calibrated in a mixture of quinhydrone and pH 4.00 buffer before use in the field to ensure accurate readings. Sampling locations (six per site) were matched with sediment sample locations (Figure 12). A shallow and a deep measurement were taken at each sampling location using two probes inserted into the marsh sediment 2 cm and 20 cm respectively. Probes were deployed 30 minutes before readings were taken to allow the probes to equilibrate. The reference electrode was inserted into the soil close to the probes at the time of measurement. Measurements from the two probes were taken by individually connecting the probe to the Meter and waiting for the Meter to stabilize (max five minutes). Redox potential was determined by adding +244 mV to each field measurement to account for the potential of the reference electrode.

[7] www.coleparmer.com/buy/product/96392-thermo-scientific-orion-star-a221-ph-portable-meter-kit.html

Figure 14 Constructed platinum electrodes (top), accumet calomel reference electrode (bottom) and Thermo Scientific Orion Star A221 Milivolt Meter. Photograph by C. Skinner 2013).

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 MI on 30 July 2013 and 29 August 2013 and at MIR on 30 August 2013, 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-six plots were established at MI and MIR. 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

The vegetation data was analyzed by Dr. Jeremy Lundholm (SMU) and is presented in Section 4.4.

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 surveys were conducted on 23 September and 9 October 2013 at MI and MIR, using a combination of minnow traps and fyke net (Figure 12). Sampling of ponds and tidal creeks was conducted using a set of four minnow traps, baited with bread. The traps were anchored to the marsh surface and set by tossing the trap into the middle of the panne or channel. The minnow traps were left to fish only during the high tide (approximately three hours). Only minnow traps were used on MI and were set in available open water on site.

The fyke net construction and [modified] methodology followed those used by Dionne et al. (1999). The fyke net was set at low tide with the wings at approximate 45 degree angles and retrieved when the water drained low enough to approach the net, ensuring that the cod end of the net was still under water. All captured fish were held in buckets, identified to species using identification guides (Audubon Society 1993; Graff and Middleton 2002; Scott and Scott 1988), counted (to a maximum of 300 per species), and measured for length (15 individuals per species).

3.6 Aquatic Invertebrates

Aquatic invertebrates within the water column of select pannes/ponds within MI and MIR were sampled using Aquatic Invertebrate Activity Traps (IAT) (Figure 15). IAT were submerged and anchored within the water column of the panne or pond being sampled and allowed to passively sample over a single tide cycle (approximately 24 hour period). Four samples were taken on 30 July and 29 August 2013. Traps were set on the dates indicated and then retrieved the following day. Samples were emptied into a 0.5 mm sieve and all captured materials and organisms field-preserved in 70% isopropyl alcohol for transport to the laboratory facilities at Envirosphere Consultants Ltd. in Windsor, NS where the samples were sorted and analyzed for species composition and abundance. An ANOVA analysis was conducted comparing the effect of time (sample month) over site.

Figure 15 Disassembled Invertebrate Activity Trap. Photograph by T. Bowron 2007.

3.7 Structured Winter Site Walk

On 24 February 2014, a structured winter site-walk was conducted at MI and MIR. Landscape photographs were taken along each transect from the upland edge (transect back stakes) at each site. The structured walk included the perimeter and center of each site, with photographs being taken of key features such as the culvert, tide channel, ice/snow features, areas of erosion or deposition and other features of interest.

4.0 Results

4.1 Habitat Map and Digital Elevation Map (DEM)

The DEM and survey data statistics are shown in Table 2. The elevation survey points and completed DEM are presented in Figure 16. The wetland boundary, as delineated by elevation and vegetation, was determined to encompass a total area of approximately 8 ha. When combined with the hydrology data, the area of potential direct tidal influence (area under water or restorable area) was on the order of 1 ha.

The minimum elevation for the survey was 0.13 m, while the mean was 1.95 m (Table 2). In contrast, the minimum elevation in the DEM was 0.61 m, while the mean was 3.93 m (Table 2). One of the main reasons for this difference was the inability to complete an accurate elevation survey (decreased accuracy or poor Positional Dilution of Precision (PDOP)) towards the back of the site due to dominant vegetation (mix of spruce and maple trees: Figure 12). The elevation data obtained for the un-treed areas within the site were found to be at or near maximum flood elevations, while the elevations extending into the treed area were at or above the maximum flood elevations. These findings combined with provincial topographic and aerial photographic data, as well as field observations, rendered expanding the elevation survey further into the treed interior unnecessary.

Therefore, the areas that could be surveyed with accuracy were areas of lower elevations, while the portion of the site not surveyed were higher (above expected tide elevations). Furthermore, elevations throughout the site (particularly the areas not directly surveyed) may be lower than predicted by the DEM. This is due largely to the scale of NSTDB data (1:10,000), which can result in inaccuracy at small scales.

The elevation of the current road surface (causeway) is 3.9 to 4.0 m. The dirt road adjacent to the site ranges in elevation from 3.0 m (near the front of the site) to 4.0 m (back). Elevations at the back end (upstream end) of the site were approximately 2.1 m, while elevations of the tidal wetland beyond the site (north) were between 1.8 and 1.9 m. A natural berm (~3.5 to 4.0 m) separates the back portion of the restoration site from the tidal wetland to the north (Figure 3).

A habitat map and a description of the vegetation community assemblages at the Morris Island Restoration Site are presented in Figure 17 and Table 3.

Table 2 DEM and Survey statistics.

	DEM	Survey
Min	0.61	0.13
Max	5.50	6.58
Mean	3.93	1.95

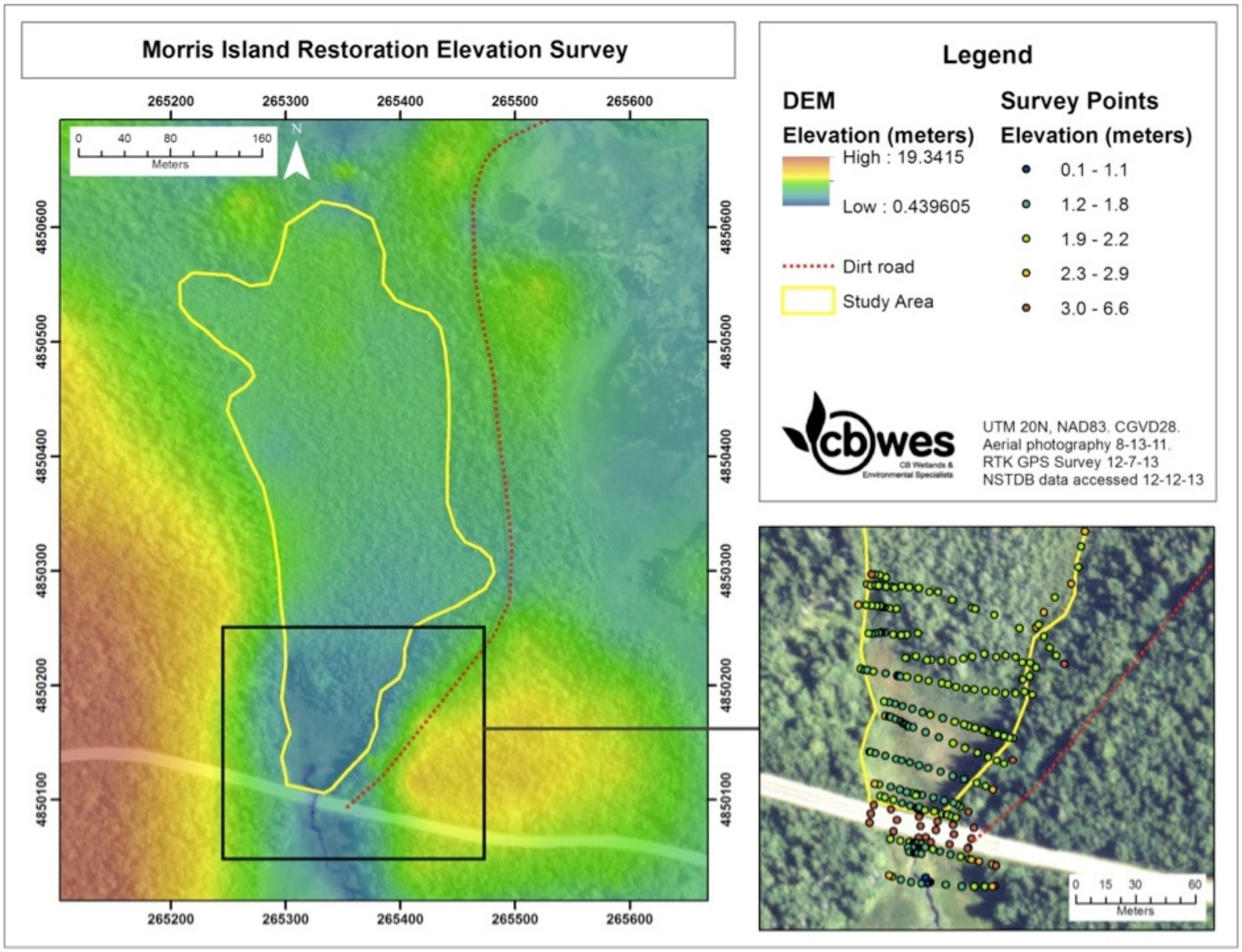


Figure 16 DEM and elevation survey points at Morris Island Restoration Site.

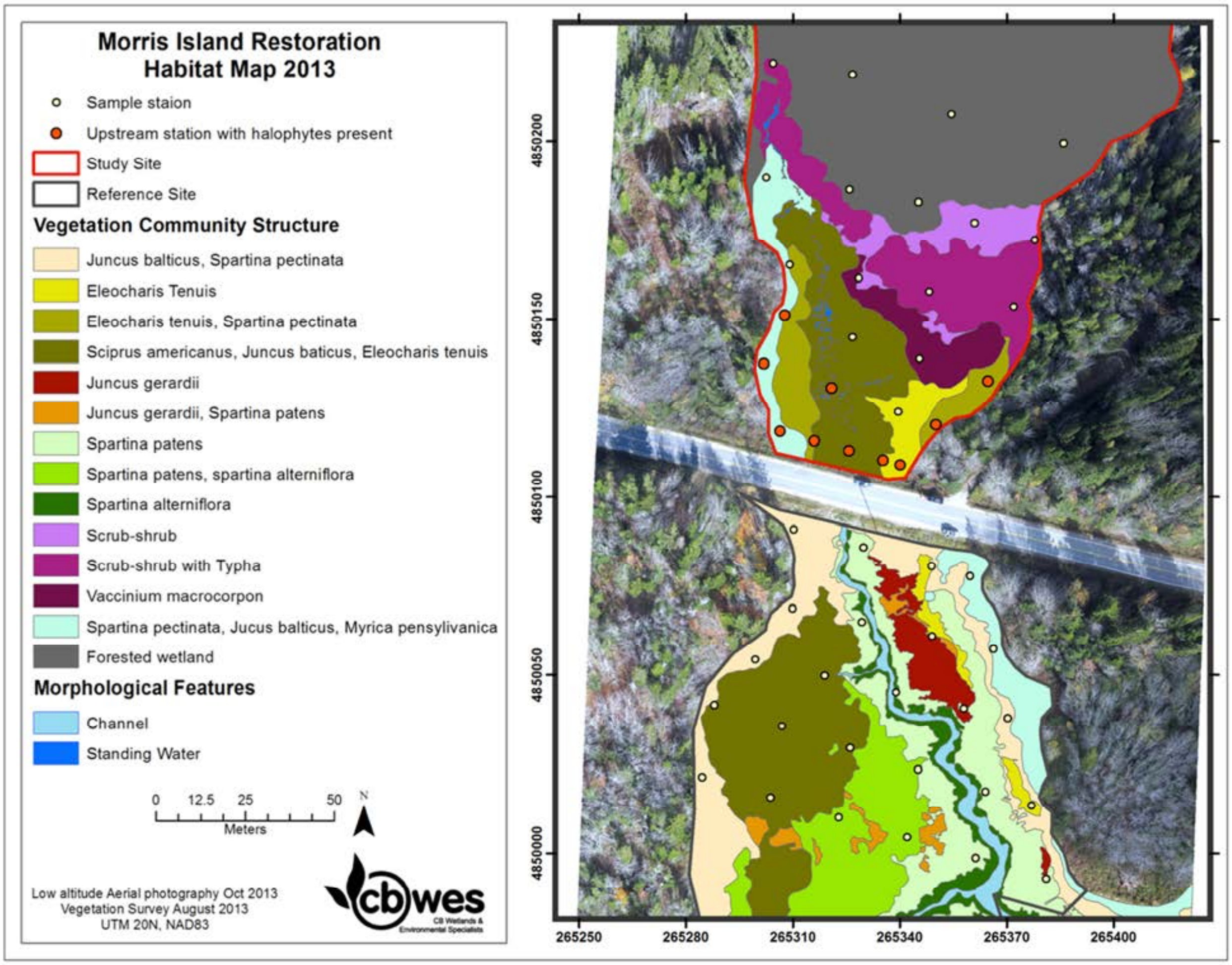


Figure 17 2013 habitat map for MI showing dominant surface cover features and vegetation community assemblages.

Table 3 Description of the dominant surface cover features and vegetation community assemblages.

Surface cover	Description	Dominant Species	Other key species	Wetland Type
Eleocharis sp.	Monocultre with few, if any, other species present. Downstream patch in burn zone.	*Eleocharis sp.*		Brackish
Eleocharis sp. community	Mixed graminoid community dominated by *Eleocharis sp.* Moderate to high representation by other key species.	*Eleocharis sp.*	*S. pectinata, Scirpus americanus, juncus balticus*	Brackish
Juncus gerardii	Monocultre with few if any other species present.	*Juncus gerardii*		Salt marsh
Juncus gerardii mixed	*Juncus gerardii* with other key halophytes present in low to moderate numbers.	*Juncus gerardii*	*S. patens, Solidago sempervirens, Potentilla anserina*	Salt marsh
Open water	Upstream open water, indicative of relict channel and current drainage path.			Open Water

Surface cover	Description	Dominant Species	Other key species	Wetland Type
Scirpus americanus community	Located primarily in zones containing water. Dominated by *Scirpus americanus* with other key graminoids present in moderate to high numbers. Some forbs present in very low numbers. Distribution of non-dominant species patchy.	*Scirpus americanus*	*Eleocharis sp, S. patens, Juncus balticus, Juncus canadensis*	Brackish
S. alterniflora	Monocultre with few if any other species present.	*S. alterniflora*		Salt marsh
S. patens	Monocultre with few if any other species present.	*S. patens*		Salt marsh
S. patens mixed	Very diverse community. Dominated by *S. patens* but with other key halophytes present in high numbers. Distribution of non-dominant species patchy.	*S. patens, S. alterniflora*	*Solidago sempervirens, Juncus gerardii, Potentilla anserina*	Salt marsh
Brackish graminoid community	Upland edge transition zone. Dominated by *Juncus balticus* and *S. pectinata* with moderate representation by other brackish graminoid and forb species. Distribution of non-dominant species patchy.	*Juncus balticus, S. pectinata*	*Festuca rubra, Symphocatrium novi-belgii, Agrostis stolonifera*	Brackish
Upland edge community	Upland edge transition zone. Dominated by *S. pectinata* and *Myrica pensylvanica* with moderate numbers of other graminoids, forbs, and shrubs.	*S. pectinata*	*Juncus balticus, Myrica pensylvanica*	Freshwater
Vaccinium macrocorpon community	Transition zone from graminoid meadow to scrub-shrub. Dominated by *Vaccinium macrocorpon* with other graminoids present in moderate numbers.	*Vaccinium macrocorpo n*	*Juncus balticus, S. pectinata, Scirpus americanus*	Brackish
Scrub-shrub community	Peat bog dominated by shrubs. Low numbers of graminoids and forbs present in understory.	*Rhododendron groenlandicum, Chamaedaphne calyculata, Myrica gale*		Freshwater
Scrub-shrub community with cattail	Peat bog dominated by shrubs and *Typha sp.* Low numbers of graminoids and forbs present in understory.	*Typha sp., Rhododendron groenlandicum, Chamaedaphne calyculata, Myrica gale*		Freshwater
Forested wetland	Forested wetland dominated by water-tolerant trees such as *Picea mariana* and alder as well as shrubs identified in scrub-shrub community. Understory community composed of *Sphaghum,* graminoids and forbs.	*Picea mariana, Sphagnum*	*Carex trisperma, Drosera rotundifolida, Eriophorum Virginicum Rhododendron groenlandicum, Chamaedaphne calyculata, Myrica gale*	Freshwater

4.2 Hydrology

Hydroperiod and Tidal Signal

No additional tide data was recorded during baseline data collection in 2013. Bowron et al (2013c) confirmed, when comparing the two tide signals (upstream vs. downstream), that the causeway-culvert (collapsed) represented a significant restriction to tidal flow (Figure 18). The mean difference (restriction) was 14 cm, with a maximum restriction of 50 cm (2.53 m downstream, 2.02 m upstream) (Bowron 2013c). The minimum, mean and maximum water levels are shown in Table 4. The maximum recorded tide (2.5 m) would flood approximately 1.12 ha (Table 6). Table 5 and Table 6 illustrate the relationship between tide height, area of marsh flooded and the percentage of tides that would flood a given area. Any storm surge or unanticipated high water event would result in larger portion of the wetland to flood. The flood map for MI can be found in Figure 19.

Table 4 Minimum, mean and maximum water levels from data loggers 12 October to 6 December 2012.

	Downstream	Upstream
Min water level	0.5	1.7
Mean water level	0.8	1.8
Max water level	2.5	2.2
Min high tide	1.2	1.7
Mean high tide	1.7	1.9
Max high tide	2.5	2.0

Table 5 Predicted flood levels and areas.

		Tide Level	Area Flooded (ha)
Recorded tides	Mean high tide	1.7	0.0
	Max high tide	2.5	1.1
Storm surge Scenario	Max high 2013 + 1 m storm surge	3.2	1.8
	Max recorded tide + 1 m storm surge	3.5	2.2

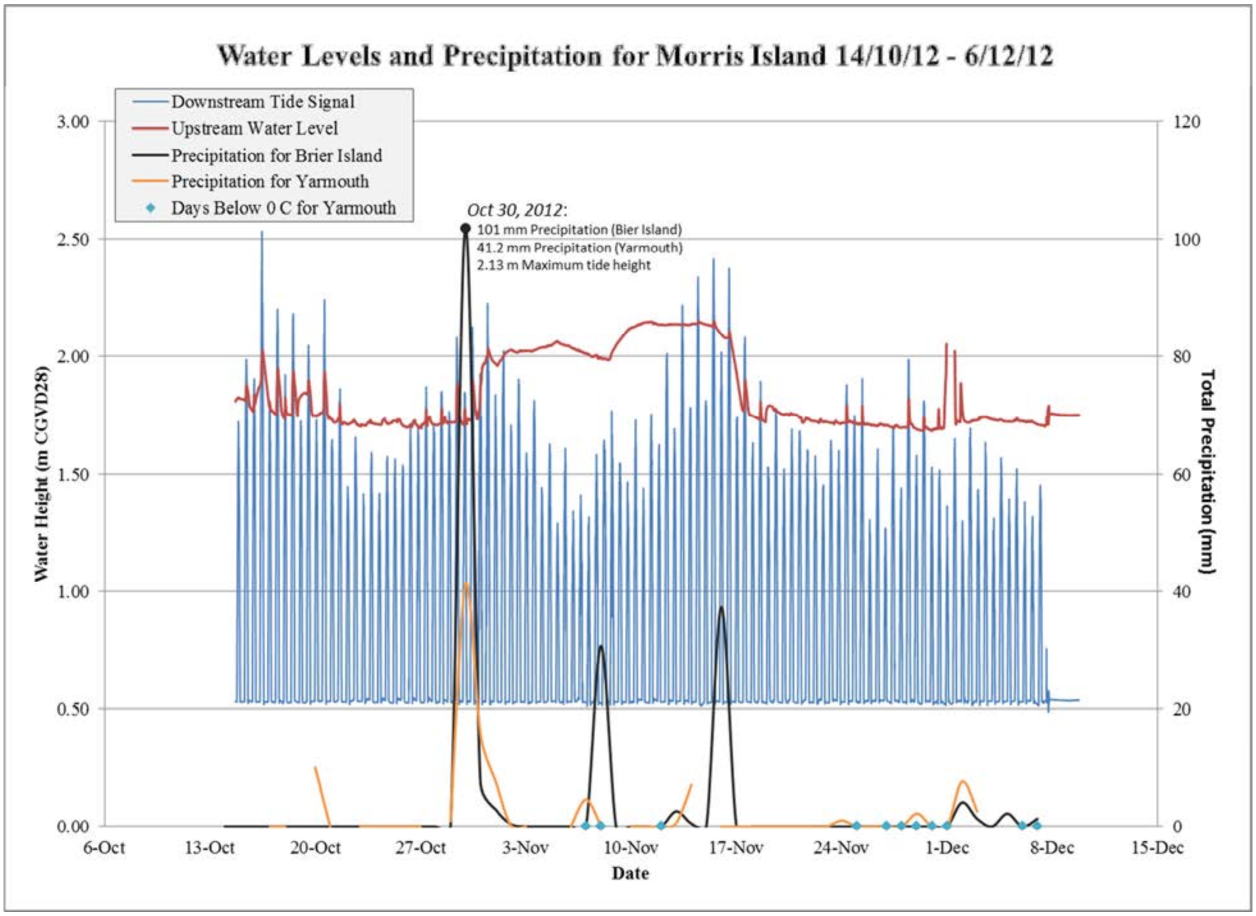


Figure 18 Water level record and precipitation for Morris Island.

Table 6 Flood extent and frequency.

Tide Height	Area (ha)	% Recorded tides
1.5	0.028	74.8
1.6	0.034	62.1
1.7	0.045	43.7
1.8	0.116	33.0
1.9	0.290	22.3
2	0.428	15.5
2.1	0.637	9.7
2.2	0.807	7.8
2.3	0.937	3.9
2.4	1.037	1.9
2.5	1.122	1.0

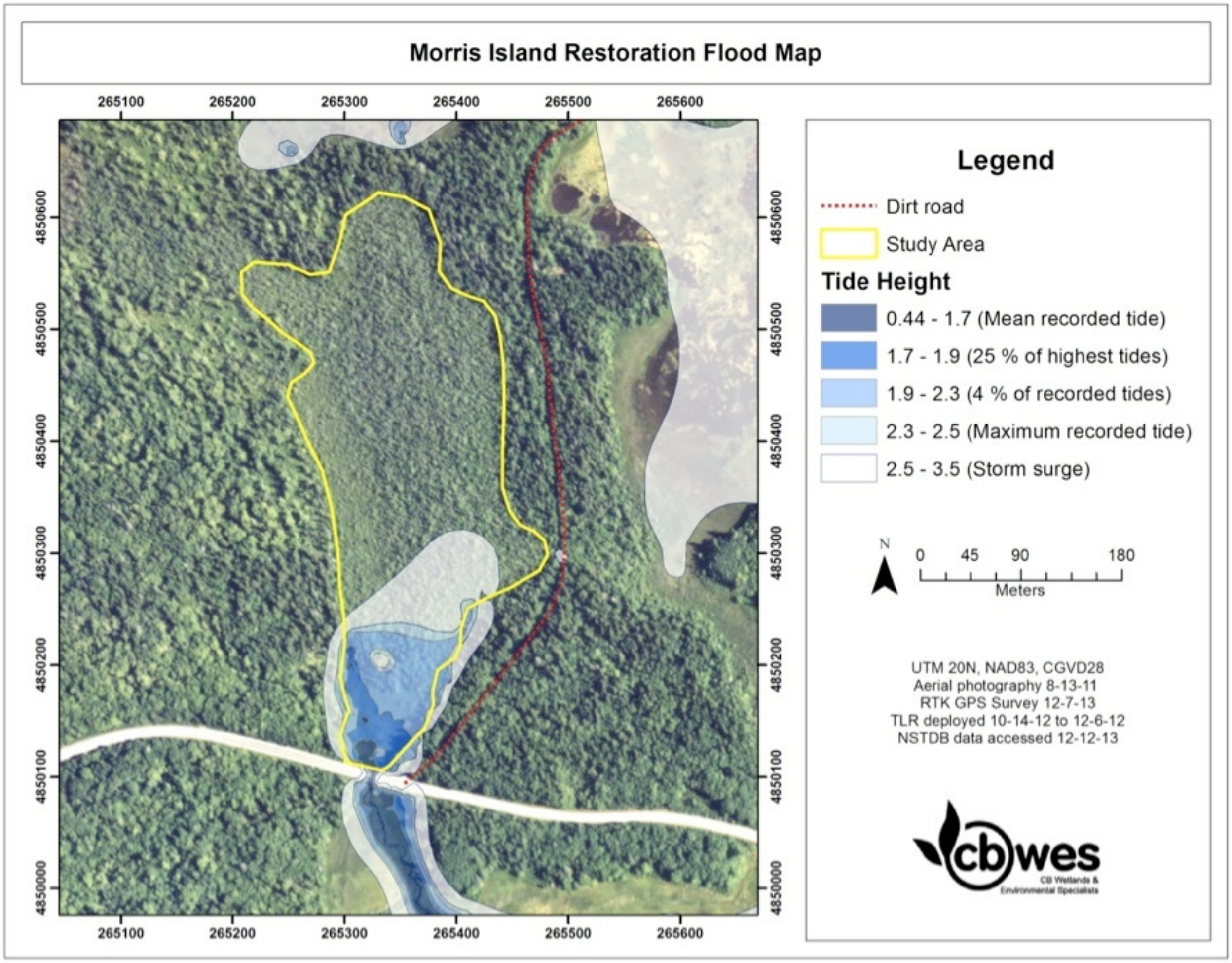


Figure 19 Flood map for MI showing unrestricted flooding under low and high tide conditions.

Water Quality

Water quality sampling of the surface floodwaters was conducted concurrently with nekton sampling. Table 7 shows the water quality readings taken at MI above and below the causeway. Sampling was conducted in this manner in order to determine if there was a gradient in water quality conditions from the downstream end of MIR to the upstream end of MI. For most of the parameters (DO, pH, temperature), there was little variation in readings within the sites or between, and the readings were within the range expected for the location and time of year (Table 7). Salinity, the parameter of most interest because of its role as a major driver of soil conditions and vegetation community structure, did show variation between the two sites. Salinity levels for the reference site were consistently at the high end of the polyhaline range of 18 to 30 ppt (Tiner 2005: Odum 1988) (Table 7). Immediately upstream of the causeway, salinity dropped from the 28/29 ppt recorded downstream to 24 ppt and continued to decline with increased distance upstream (Table 7). This rapid decline with distance from the causeway is reflective of the reduced tidal water influence due the restrictive nature of the causeway-culvert and an increase in freshwater influence.

Table 7: Water quality conditions for MI(R).

Sample Location	Temp (°C)	Sal (ppt)	DO (mg/L)	pH
MI Transect 4, relic channel	13.40	0.12	6.36	6.03
MI Transect 2, relic channel	15.22	4.75	9.20	6.54
MI 15m from culvert (relic channel)	12.38	12.70	7.01	6.84
MI Mouth of culvert	12.64	24.95	7.80	7.16
MIR Transect 1	12.86	28.16	8.25	5.85
MIR Transect 2	12.86	28.91	8.36	6.86
MIR Transect 3	12.95	29.13	8.31	7.20
MIR Transect 4 (shallow)	13.25	23.46	8.70	7.63
MIR Transect 4 (deep)	13.81	29.46	7.00	7.62

Ground Water

The water level data was analyzed both as depth to water table and water table elevation (Figure 20; Figure 21). Standing water (water above the wetland surface) was not recorded for any sample stations during the recording period. Standing water, or ponding, was observed to occur at MI following significant rain events. Water level across all sampling stations increased following a rain event, then gradually decreased until the next rainfall. Water level at the front of the marsh (wells #1, #2; Figure 12) was clearly responding to the tidal signal (tidally influenced), while the remainder of the site (wells) showed little to no correlation to the tidal conditions. Despite the limited tidal influence on water level immediately upstream of the culvert, the site is predominantly fresh water (precipitation) driven.

The depth to water table showed that the well (#5) at the back of the site had the deepest water table (water level furthest from the surface) and that the middle wells (#3, #4) had water levels shallower than the wells at the front of the site (#1, #2; Figure 12). The water table elevation data on the other hand indicated that well #4 had a higher water table elevation (east edge) than well #5 (back). This gives an indication of the drainage pattern for the site, suggesting that the eastern side of the restoration site is hydrologically isolated from the front. Meaning that water is draining from the eastern side via the back of the marsh, while the remainder of the site drains along the western edge via the remnant channel and out the front of the marsh.

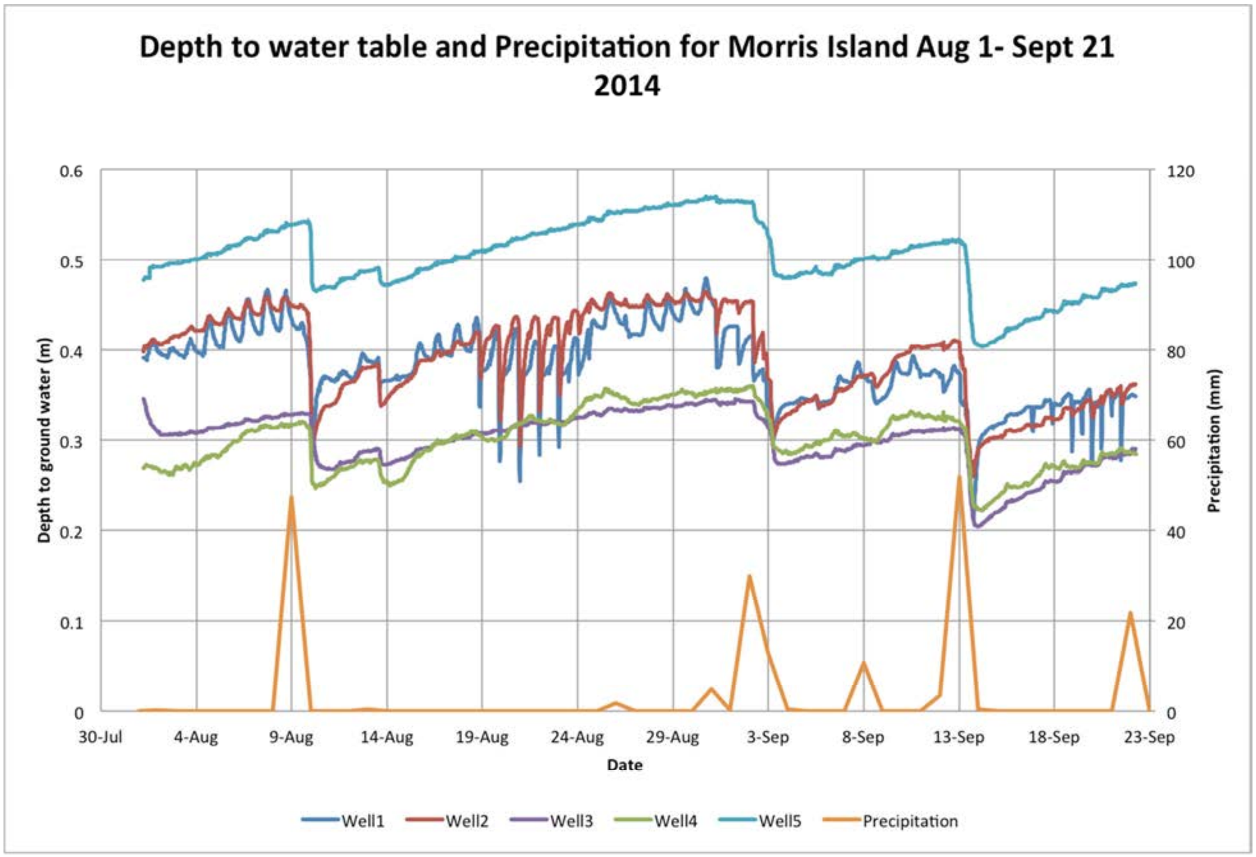


Figure 20 Water table depth and precipitation (rain fall) for MI.

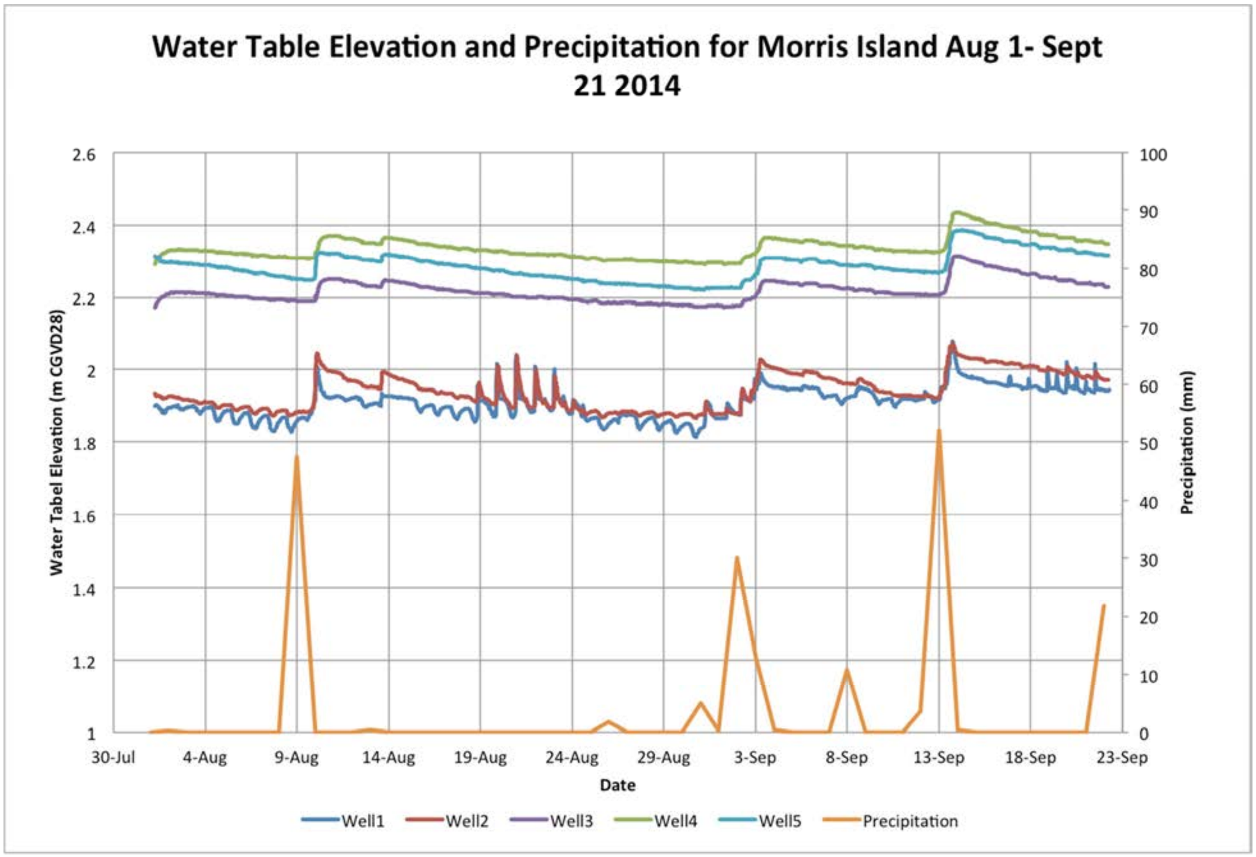


Figure 21 Water table elevation and precipitation (rain fall) for MI.

4.3 Soils and Sediments

Pore Water Salinity

Interstitial pore-water salinity was found to be both lower and less variable at MI vs MIR, reflecting the dominance of freshwater at the restoration site due to the current tidal restriction. Shallow readings were more saline and more variable than deep readings at both sites. Summary stats are presented in Table 8. Statistical analysis of pore water salinity showed significant differences between the restoration and reference sites and between deep and shallow readings at both sites. (MI vs MIR Deep - $t(97)=8.07$ $p<0.01$; MI vs MIR Shallow - $t(123)=7.98$ $p<0.01$; MI Shallow vs Deep - $t(62)=-2.8$ $p<0.01$; MIR Shallow vs Deep - $t(72)=-6.44$ $p<0.01$) (Figure 22; Figure 23).

Mapping of interstitial pore water showed seasonal and spatial trends at the site (Figure 24). As expected salinity decreased with distance upstream (north of causeway for restoration site) and increased with distance downstream (south of causeway for reference site). Also evident from the pore water salinity map are sinks and sources – locations that are higher or lower in salinity than expected based on their proximity to a channel and relationship to adjacent raster cells (Figure 24). This is likely due to topographic features such as depressions (sinks) which retain water for extended periods of time and high spots which do not. Station MI T2S2 is a prime example of this. As suggested by summary statistics, shallow pore water salinity readings are higher than deep readings in most locations. This is particularly notable within the restoration site near the causeway in the vicinity of the relic channel, where water has been observed to pool and groundwater wells indicated minimal tidal influence. Finally, the map revealed seasonal trends, with higher salinity values recorded upstream during the mid-summer period (August) than July and September. This may be a reflection of decreased freshwater (precipitation) influence, which is the primary control on hydraulics at the site, mid-summer, which allows tidal water to penetrate further upstream than at other times of the year.

Table 8 Baseline (2013) pore water salinity statistics for MI(R).

Site	Count	Minimum	Maximum	Mean	Standard Deviation
Deep Readings					
MI	63	0.05	5.64	0.86	1.22
MIR	73	0.00	12.10	3.98	3.03
Shallow Readings					
MI	63	0.08	10.33	1.32	2.03
MIR	73	0.00	12.43	4.98	3.24
All Readings					
MI	126	0.05	10.33	1.09	1.68
MIR	146	0.00	12.43	4.48	3.17

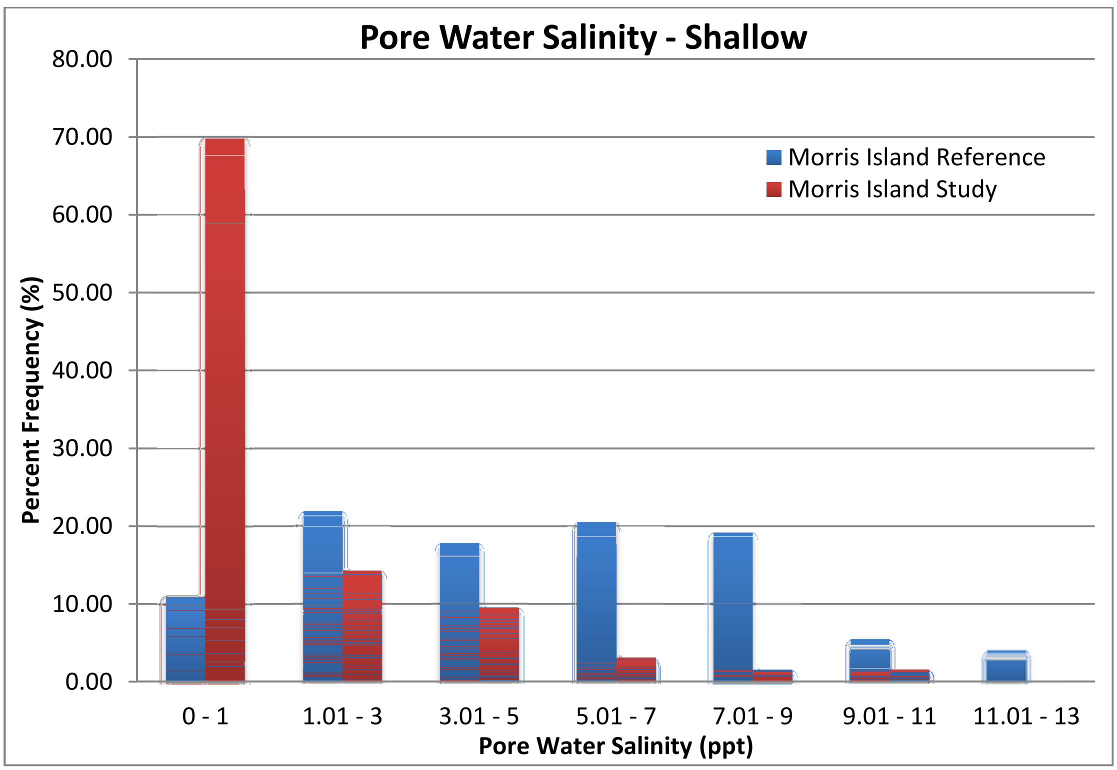


Figure 22 Salinity level frequencies for shallow readings at MI and MIR.

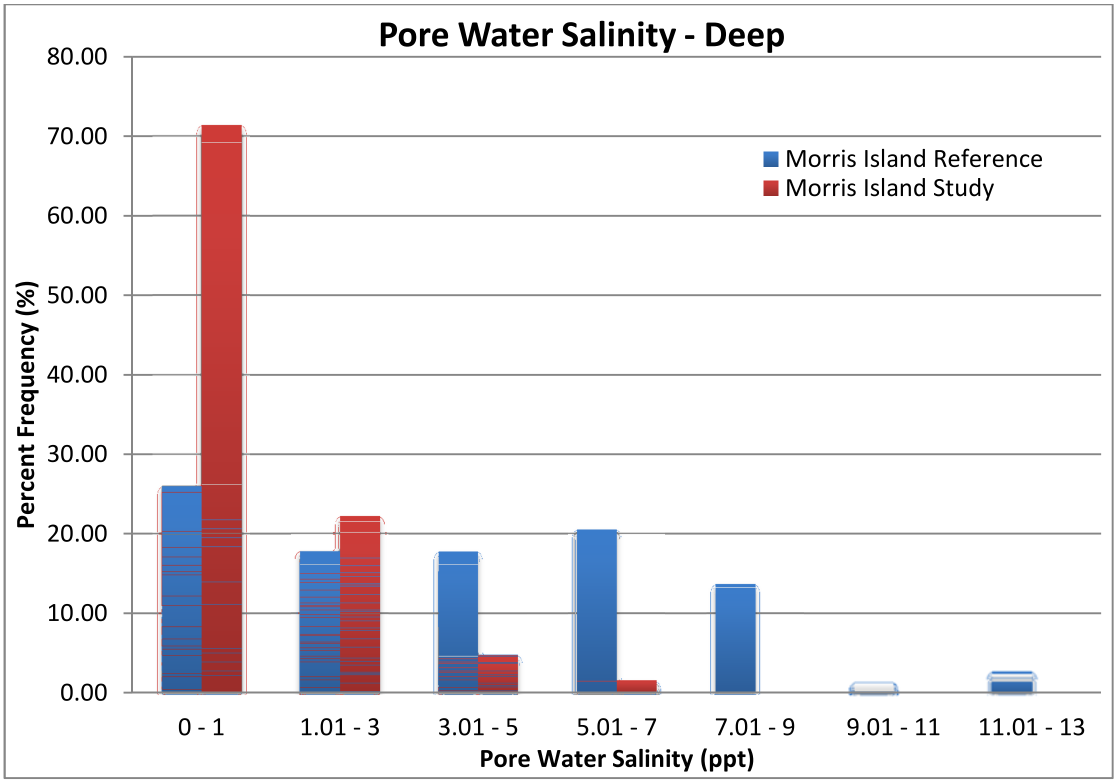


Figure 23 Salinity level frequencies for deep readings at MI and MIR.

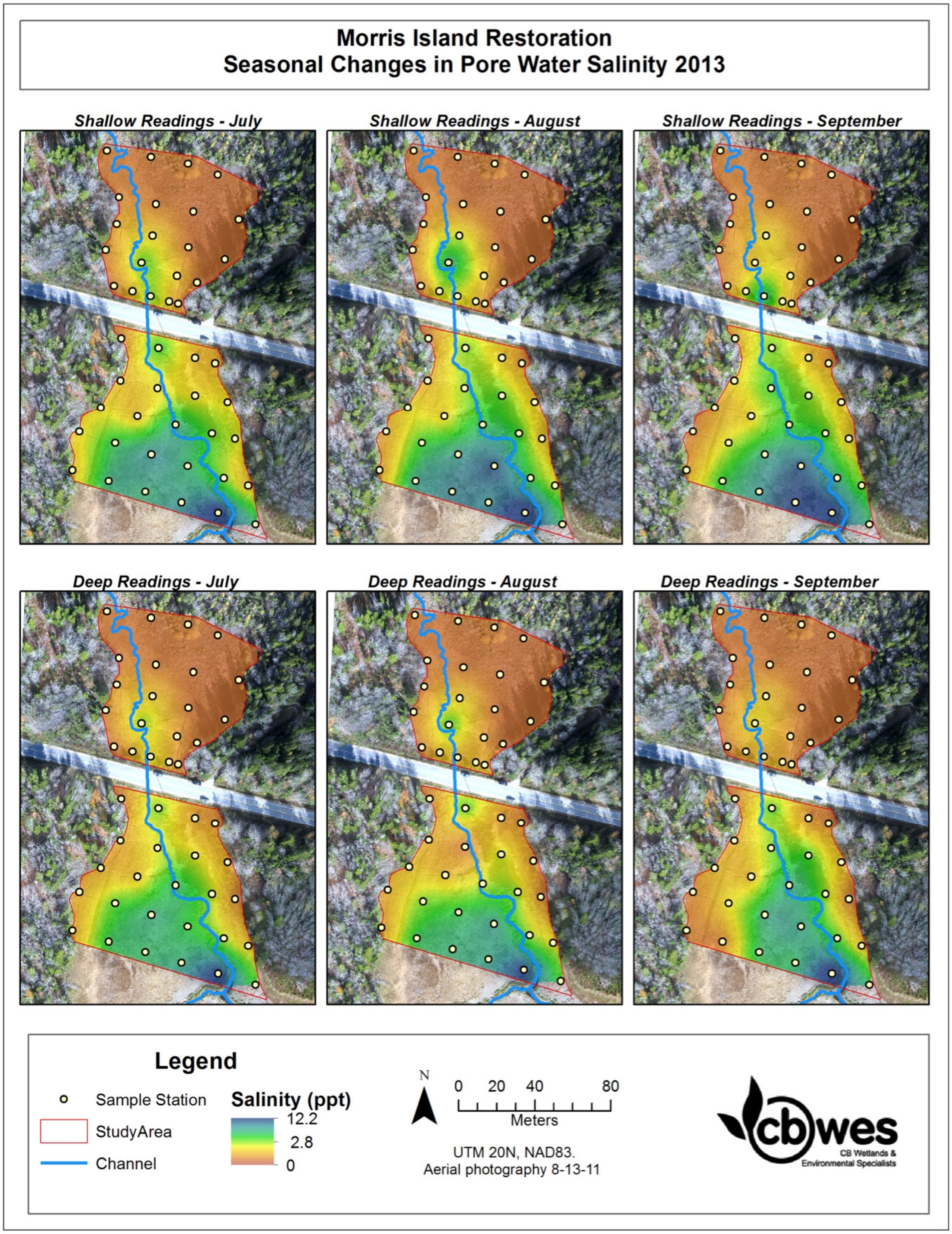


Figure 24 Seasonal changes in pore water salinity, 2013.

Soil Characteristics

Soil characteristics at each sample location are highly influenced by the source material, the site's elevation within the tidal frame, distance from the mouth of the estuary, distance from the creek bank and flow velocity. 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. Grain size spectra are controlled by the source material and current velocity (Krank and Milligan 1985).

A total of 16 cores and bulk density samples were collected at the restoration and reference sites (Table 9). All cores were processed at the In_CoaST research lab for bulk density, water and organic matter content. Grain size spectra were derived using a Coulter Multiziser 3^{tm}. Grain size statistics were derived using Gradistat (Blott and Pye 2001).

Table 9 Summary of core descriptions based on examination of the extruded cores within In_CoaST. Cores collected at a) MI and b) MIR. Observations provided by C. Skinner.

Station	Description
a) MI	
MI_T1S2	7.5 cm, large root mass, peat, black colour, water squishes out and is then absorbed back up
MI_T1S4	7.5 cm, extremely wet, peat, no large roots, fibrous, black
MI_T2S1	8 cm, extremely wet, peat, no large roots, fibrous, black colour
MI_T2S3	7 cm, extremely wet, peat, black
MI_T3S2	7 cm, roots close to bottom, extremely wet, fibrous
MI_T3S4	5 cm, mostly water, black, peat, fibrous, no large roots
MI_T4S2	5.5 cm few root masses, peat, black
MI_T4S4	7.5 cm sphagnum moss on top, no root mass, peat, plant fibers throughout
b) MIR	
MI_T1S2	7cm, large root masses, brown colour, does not look like the restoration, does not hold a lot of water
MI_T1S4	10 cm, large root mass, brown, does not hold a lot of water
MI_T2S1	9.5 cm, peat, looks like the MI cores, hold a bit more water
MI_T2S3	8cm, peat black, looks like the MI cores, holds a bit more water than other MIR cores
MI_T3S2	10.5 cm, root in middle, brown, peat but not like restoration
MI_T3S4	8cm, strong sulfur smell, extensive root system, 2cm from top is rich dark brown colour, rest is brown with roots
MI_T4S2	10 cm, root system in bottom half of core, brown
MI_T4S4	8cm, brown, fibours bright brown, root system 2 cm from bottom

Physical observations of extruded cores at both the reference and reference sites demonstrated a predominance of peaty material and the soil matrix was predominantly organogenic in nature, typical of bog habitat. Sphagnum moss was observed on the surface of some cores, mostly along transect 4, furthest upstream (Table 9). The presence of Sphagnum suggests more acidic conditions, which is often perpetuated by the uptake of cations, such as calcium and magnesium, and the release of hydrogen ions into the soil matrix (Parent and Ilnick 2003).

The water content of the sediments at both MI and MIR were very high, reflecting the more peaty nature of the matrix material. Values ranged from 86.7% to 94.1% at MI_T1S2 and MI_T4S2 respectively, indicating an increasing contribution from either groundwater or freshwater stream source further upriver in the restoration site (Table 10). Water content at the reference site was generally lower, ranging from 69.1% (MIR_T3S4) to 88.1% (MIR_T3S2) (Table 11). Organic matter content was almost twice as high in MI versus MIR. Organic matter ranged from 47.9% immediately adjacent to the highway at MI_T1S4 to 96.8% at MI_T4S2 and was relatively consistent throughout the core (Table 10). This was compared with lower values ranging from 24.5% (MIR_T3S4) to 59.6% (MIR_T2S1) at the reference site. In general, higher organic matter content promotes increased water retention and higher water content to be recorded within the cores. Bulk density values were very low at MI and showed a distinct difference between transect 1 and the remaining transects. The remaining transects recorded bulk density values ranging from 0.03 to 0.07 $g \cdot cm^{-3}$ and bulk density is inversely proportional to organic matter content. Syringe cores collected at MI_T1S2 and MI_T1S4 recorded bulk density values more comparable to the reference site with 0.14 and 0.11 $g \cdot cm^{-3}$ respectively. Bulk density of samples collected from the reference site ranged from 0.07 $g \cdot cm^{-3}$ (MIR_T1S3) to 0.21 $g \cdot cm^{-3}$ (MIR_T3S2). The lower bulk density values overall indicate a high amount of pore space, which would allow for more drainage and absorption of water. Both sites fell within the category of peat soils based on their bulk density. Bulk density of peat generally ranges from 0.02 to 0.4 $g \cdot cm^{-3}$ (Parent and Ilnick 2003) reflecting its high porosity. The pore sizes are also influenced by the degree of decomposition, with higher bulk density values associated with greater degrees of decomposition (Brandyk et al. 2003).

The grain size of the cores within the reference site were fairly consistent within the size class of poorly sorted, fine skewed, medium silt throughout the core (Table 11, Figure 32). Their kurtosis values tended to fall within the mesokurtic class, which reflects a normal distribution. The mid sections of the cores at the restoration site were also classified as medium silt, with the exception of MI_T2S1 classified as fine silt (Table 10). The top portion of the core, however, did display spatial variability ranging from 7.29 µm (fine silt) at MI_T1S4 to 19.29 µm (coarse silt) at MI_T4S2 (Table 10). In addition, numerous cores displayed platykurtic distributions, which tended to have a flatter distribution and may suggest the presence of two modes of transport. Closer examination of the distribution of grain size classes within the restoration site revealed the presence and influence of a source of very fine sand, which was rarely present within the reference site cores (Figure 27). This influx of very fine sand was present in the top of the cores at M1_T2S3, M1_T3S2 and MI_T3S4, as well as the mid-section (Figure 27d; Figure 28e,f). This signal was not present in the remaining cores along transect 4, but was very present at the mid core level (Figure 31). This pattern, as well as the absence of very fine sand in the reference site downstream (Figure 29; Figure 30), suggests an episodic freshwater source and potential erosion of a source location upstream rather than a marine storm deposit.

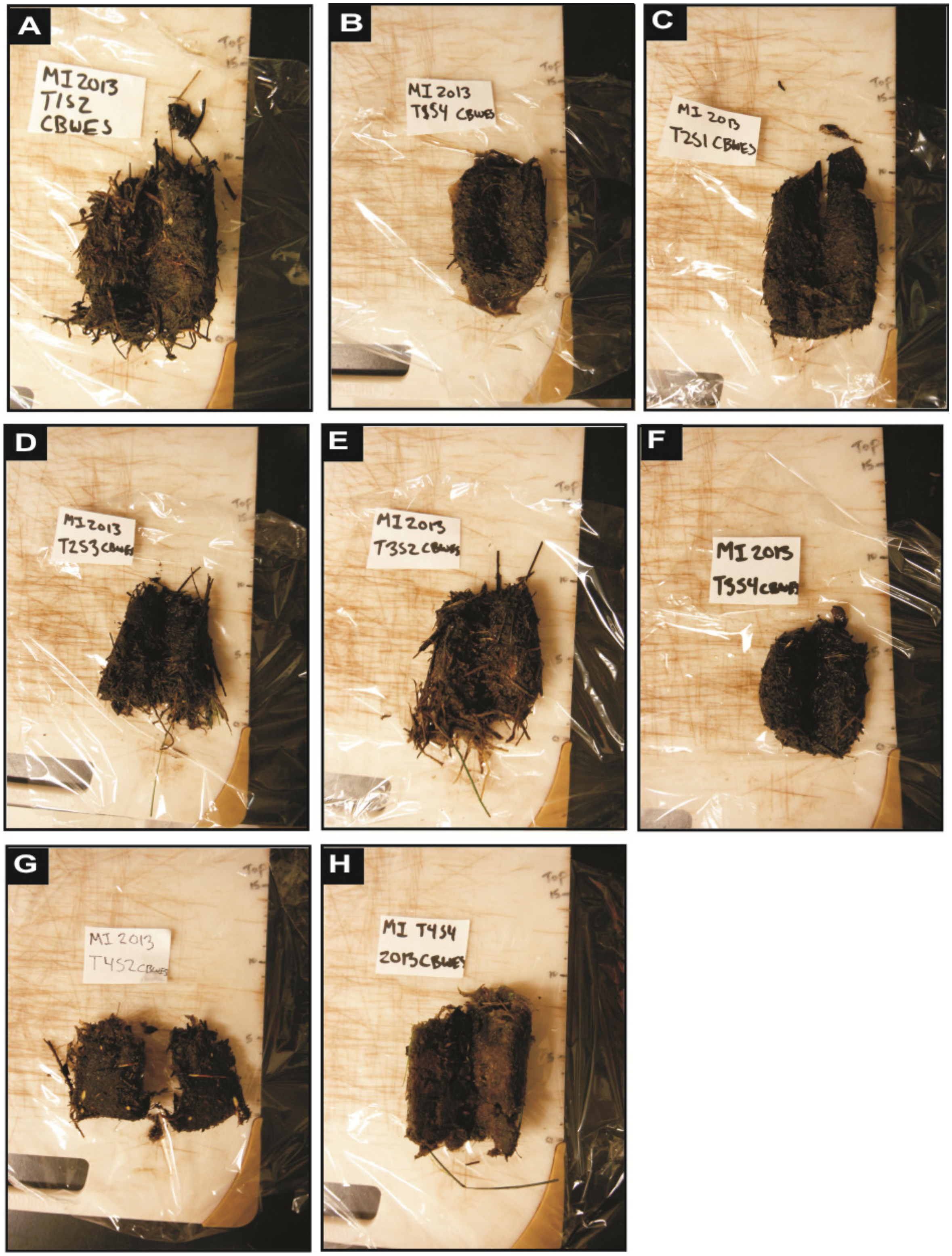


Figure 25 Split cores collected at MI in 2013 at stations a) MI_T1S2, b) MI_T1S4), c) MI_T2S1, d) MI_T2S3, e) MI_T3S2, f) MI_T3S4, g) MI_T4S2 and h) MI_T4S4.

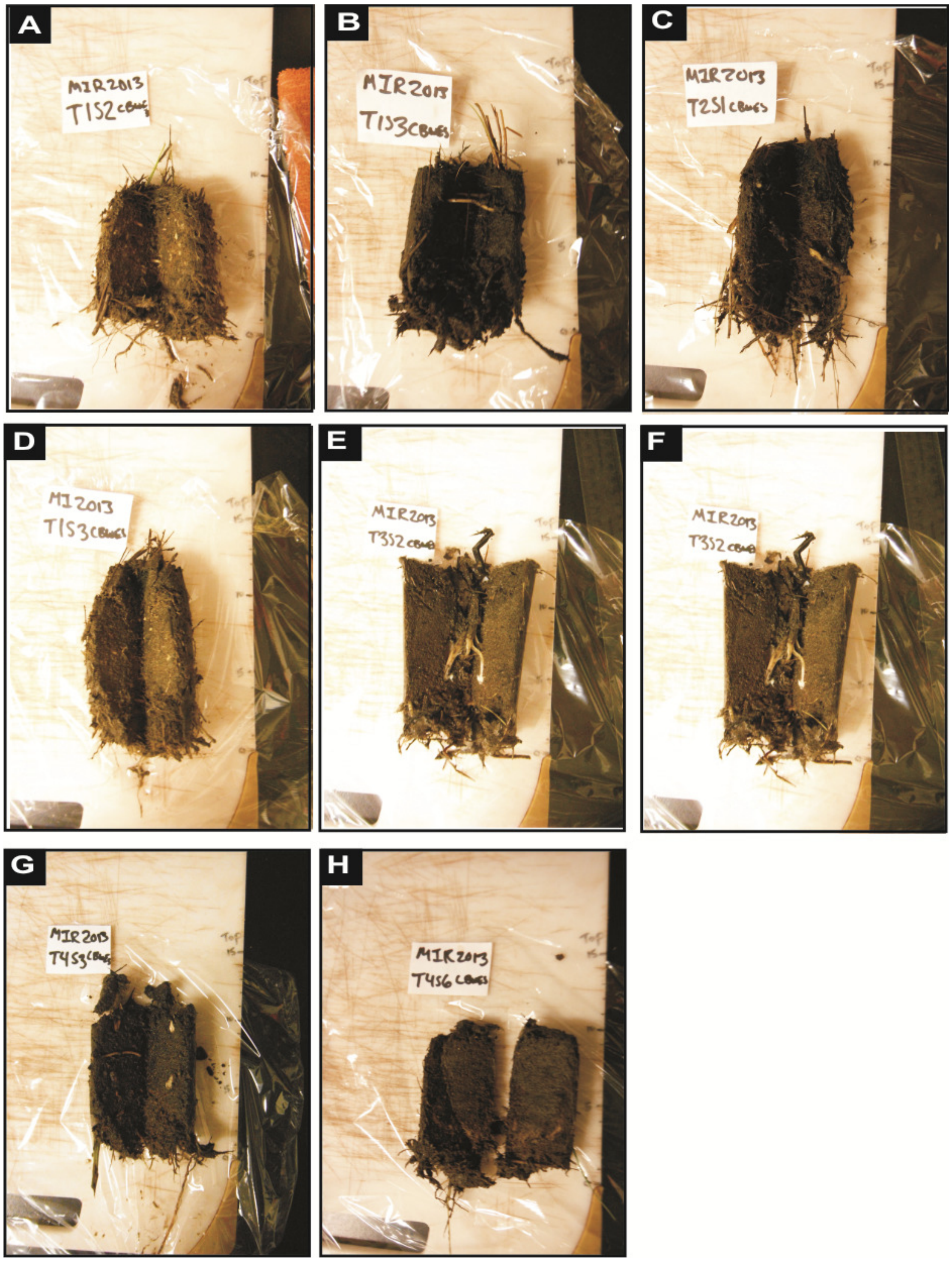


Figure 26 Split cores collected at MIR in 2013 at stations a) MIR_T1S2, b) MIR_T1S3), c) MIR_T2S1, d) MIR_T2S3 (note, label incorrect in photo), e) MIR_T3S2, f) MIR_T3S4, g) MIR_T4S3 and h) MIR_T4S6.

Table 10 Summary of sediment characteristics of cores collected at MI. Elevations are expressed relative to CGVD28 vertical datum. Grain size was assessed according to Folk and Ward descriptions. Platy = platykurtic; meso = mesokurtic.

MI station	Elev (m)	Water content (%)	Organic matter (%)	Dry bulk density ($g \cdot cm^{-3}$)*	Mean size (µm)	Sorting	Skewness	Kurtosis
Top of core								
MI_T1S2	1.94	86.7	75.0	0.14	8.62 Med silt	2.90 Poorly sorted	-0.11 Fine skew	platy
MI_T1S4	1.95	87.2	47.9	0.11	7.29 Fine silt	2.76 Poorly sorted	-0.16 Fine skew	meso
MI_T2S1	2.03	90.4	83.1	0.06	8.45 Med silt	3.06 Poorly sorted	-0.11 Fine skew	platy
MI_T2S3	1.92	89.4	50.2	0.07	7.90 Fine silt	2.64 Poorly sorted	-0.11 Fine skew	meso
MI_T3S2	1.95	89.9	82.1	0.06	11.80 Med silt	3.01 Poorly sorted	-0.15 Fine skew	platy
MI_T3S4	2.06	91.7	87.9	0.05	16.31 Coarse silt	2.96 Poorly sorted	-0.32 very fine skew	meso
MI_T4S2	2.03	94.1	96.8	0.03	19.29 Coarse silt	3.29 Poorly sorted	-0.20 Fine skew	meso
MI_T4S4	2.11	93.3	96.2	0.05	11.79 Med silt	3.32 Poorly sorted	-0.30 very fine skew	platy
Middle of core								
MI_T1S2	1.94	79.1	49.7		8.46 Med silt	2.74 Poorly sorted	-0.20 Fine skew	platy
MI_T1S4	1.95	81.9	30.8		8.67 Med silt	2.63 Poorly sorted	-0.17 Fine skew	meso
MI_T2S1	2.03	90.6	78.0		8.99 Med silt	2.99 Poorly sorted	-0.05 symmetrical	platy
MI_T2S3	1.92	86.9	43.5		7.79 Fine silt	2.55 Poorly sorted	-0.18 Fine skew	platy
MI_T3S2	1.95	89.8	75.9		10.78 Med silt	3.11 Poorly sorted	-0.14 Fine skew	platy
MI_T3S4	2.06	91.5	87.4		13.33 Med silt	3.03 Poorly sorted	-0.22 Fine skew	meso
MI_T4S2	2.03	91.3	96.6		12.99 Med silt	3.06 Poorly sorted	-0.18 Fine skew	meso
MI_T4S4	2.11	95.8	94.2		13.40 Med silt	3.02 Poorly sorted	-0.30 Fine skew	platy

Table 11 Summary of sediment characteristics of cores collected at MIR. Elevations are expressed relative to CGVD28 vertical datum. Grain size was assessed according to Folk and Ward descriptions. Platy = platykurtic; meso = mesokurtic.

MIR Station	Elev (m)	Water content (%)	Organic matter (%)	Dry bulk density ($g \cdot cm^{-3}$)*	Mean size (µm)	Sorting	Skewness	Kurtosis
Top of core								
MIR_T1S2	1.84	79.8	55.3	0.16	8.61 Med silt	2.62 Poorly sorted	-0.17 Fine skew	meso
MIR_T1S3	2.04	78.3	37.7	0.07	10.80 Med silt	2.72 Poorly sorted	-0.23 Fine skew	meso
MIR_T2S1	2.00	86.9	59.6	0.15	8.16 Med silt	2.62 Poorly sorted	-0.15 Fine skew	meso
MIR_T2S3	1.88	81.6	47.0	0.12	8.65 Med silt	2.65 Poorly sorted	-0.19 Fine skew	meso
MIR_T3S2	1.92	88.1	34.5	0.21	8.51 Med silt	2.59 Poorly sorted	-0.17 Fine skew	meso
MIR_T3S4	1.82	69.1	24.5	0.15	10.81 Med silt	2.67 Poorly sorted	-0.24 Fine skew	meso
MIR_T4S3	1.94	83.2	34.7	0.15	8.59 Med silt	2.65 Poorly sorted	-0.18 Fine skew	meso
MIR_T4S6	1.90	79.8	28.9	0.15	10.47 Med silt	2.55 Poorly sorted	-0.24 Fine skew	meso
Middle of core								
MIR_T1S2	1.84	82.6	62.8		9.21 Med silt	2.65 Poorly sorted	-0.28 Fine skew	meso
MIR_T1S3	2.04	78.4	45.4		11.92 Med silt	2.94 Poorly sorted	-0.27 Fine skew	platy
MIR_T2S1	2.00	89.9	58.5		8.50 Med silt	2.76 Poorly sorted	-0.17 Fine skew	platy
MIR_T2S3	1.88	74.4	31.3		9.50 Med silt	2.74 Poorly sorted	-0.24 Fine skew	meso
MIR_T3S2	1.92	87.6	31.6		8.71 Med silt	2.59 Poorly sorted	-0.18 Fine skew	meso
MIR_T3S4	1.82	75.4	35.9		10.03 Med silt	2.74 Poorly sorted	-0.28 Fine skew	meso
MIR_T4S3	1.94	85.9	48.8		8.94 Med silt	2.81 Poorly sorted	-0.13 Fine skew	platy
MIR_T4S6	1.90	83.3	32.9		8.78 Med silt	2.57 Poorly sorted	-0.31 very fine skew	meso

*Dry bulk density sample from syringe, not core.

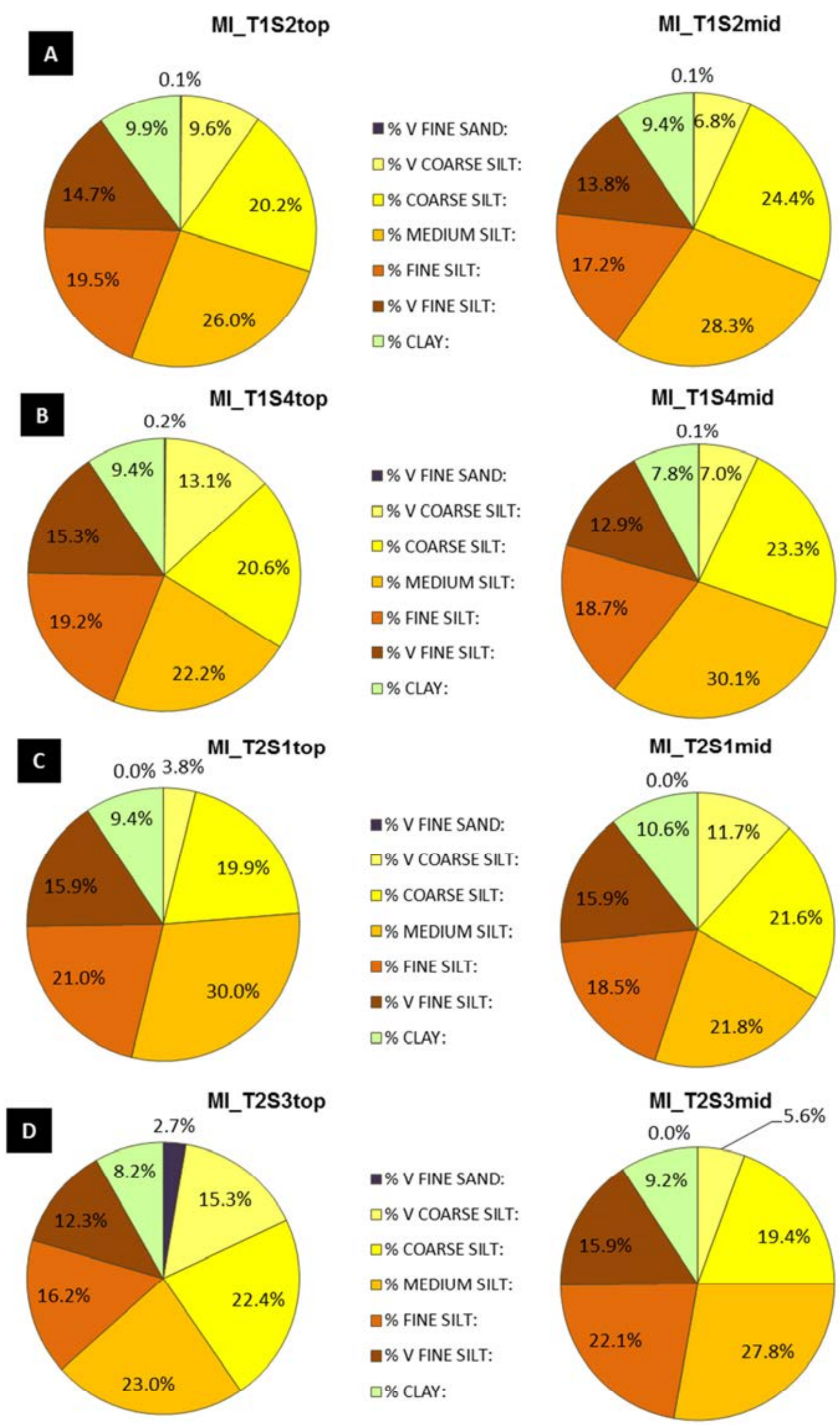


Figure 27 Distribution of grain size classes within the top 2cm and mid section of surface cores collected from MI at a) MI_T1S2, b) MI_T1S4, c) MI_T2S1, d) MI_T2S3.

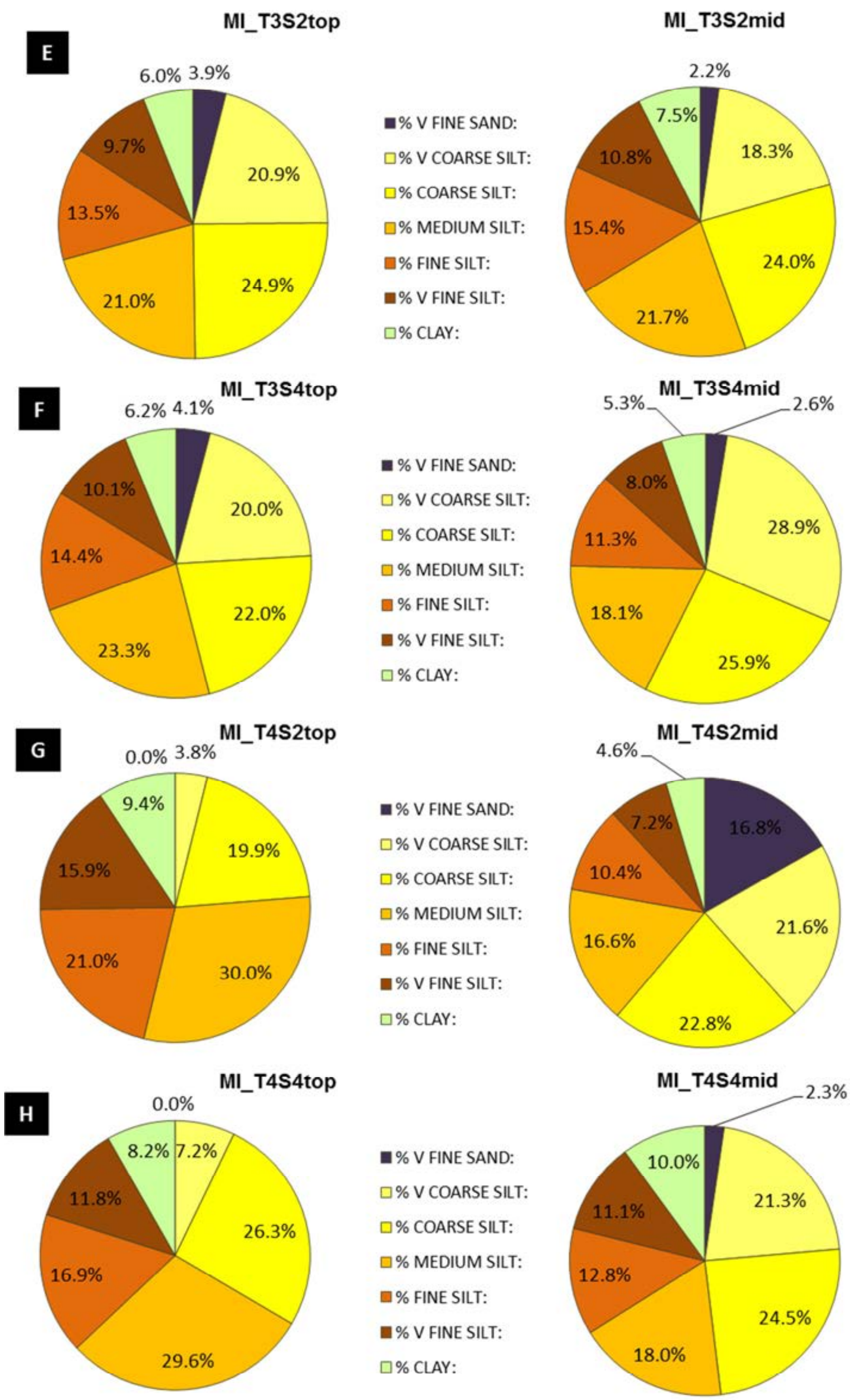


Figure 28 Distribution of grain size classes within the top 2 cm and mid section of surface cores collected from MI at e) MI_T3S2, f) MI_T3S4, g) MI_T4S2, h) MI_T4S4

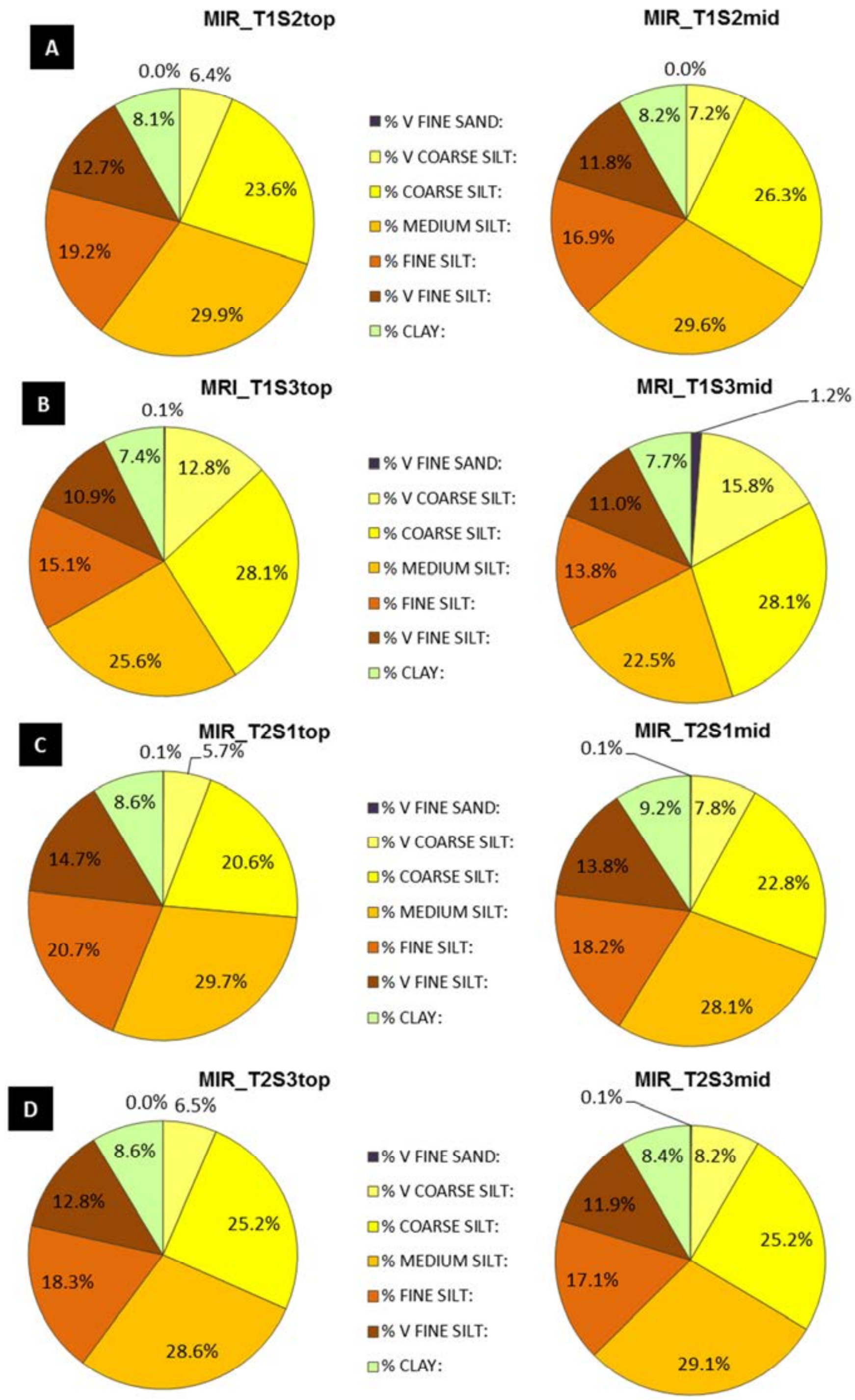


Figure 29 Distribution of grain size classes within the top 2 cm and mid section of surface cores collected from MIR at a) MIR_T1S2, b) MIR_T1S3, c) MIR_T2S1, d) MIR_T2S3.

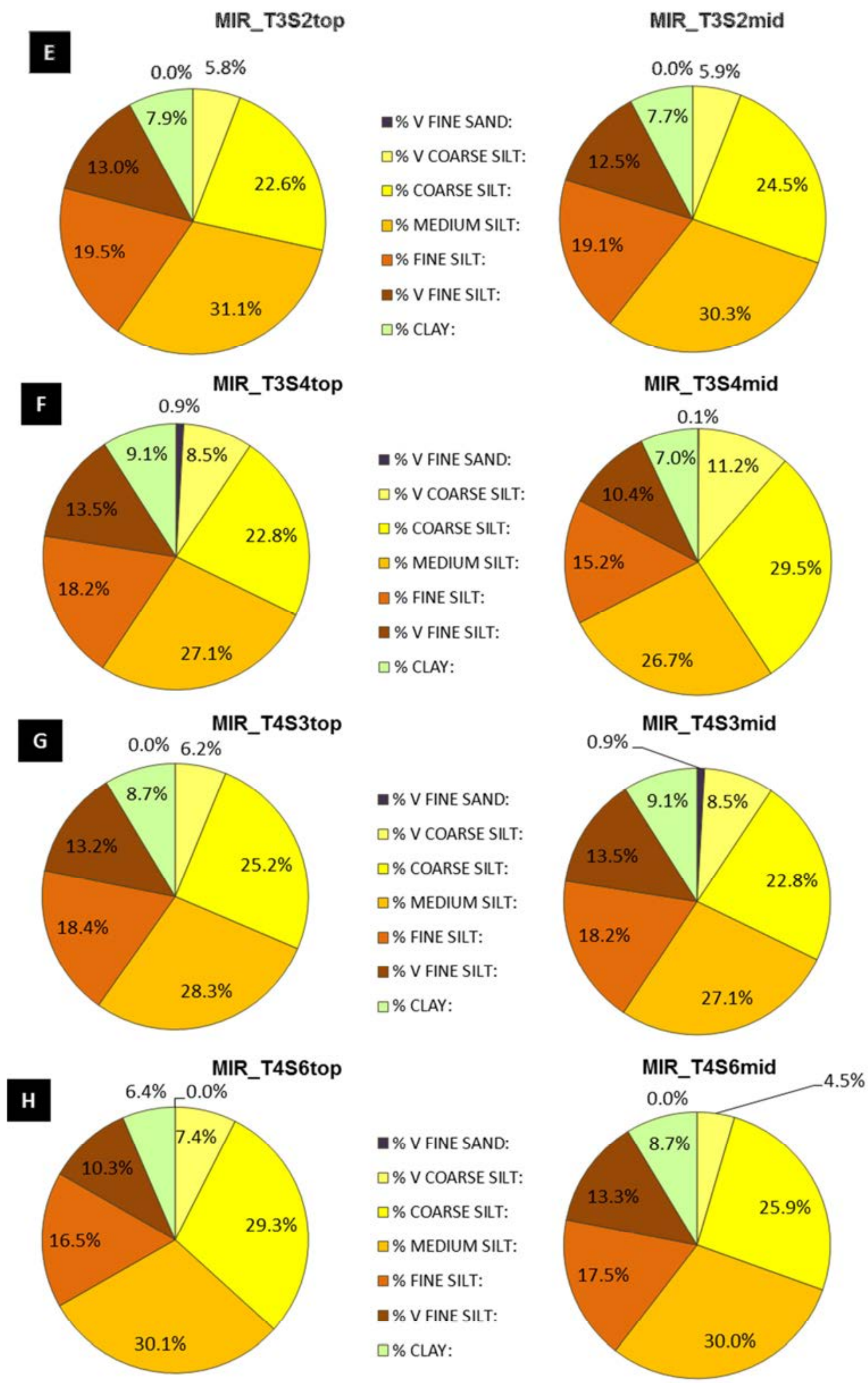


Figure 30 Distribution of grain size classes within the top 2 cm and mid section of surface cores collected from MIR site at e) MIR_T3S2, f) MIR_T3S4, g) MIR_T4S3, h) MIR_T4S6.

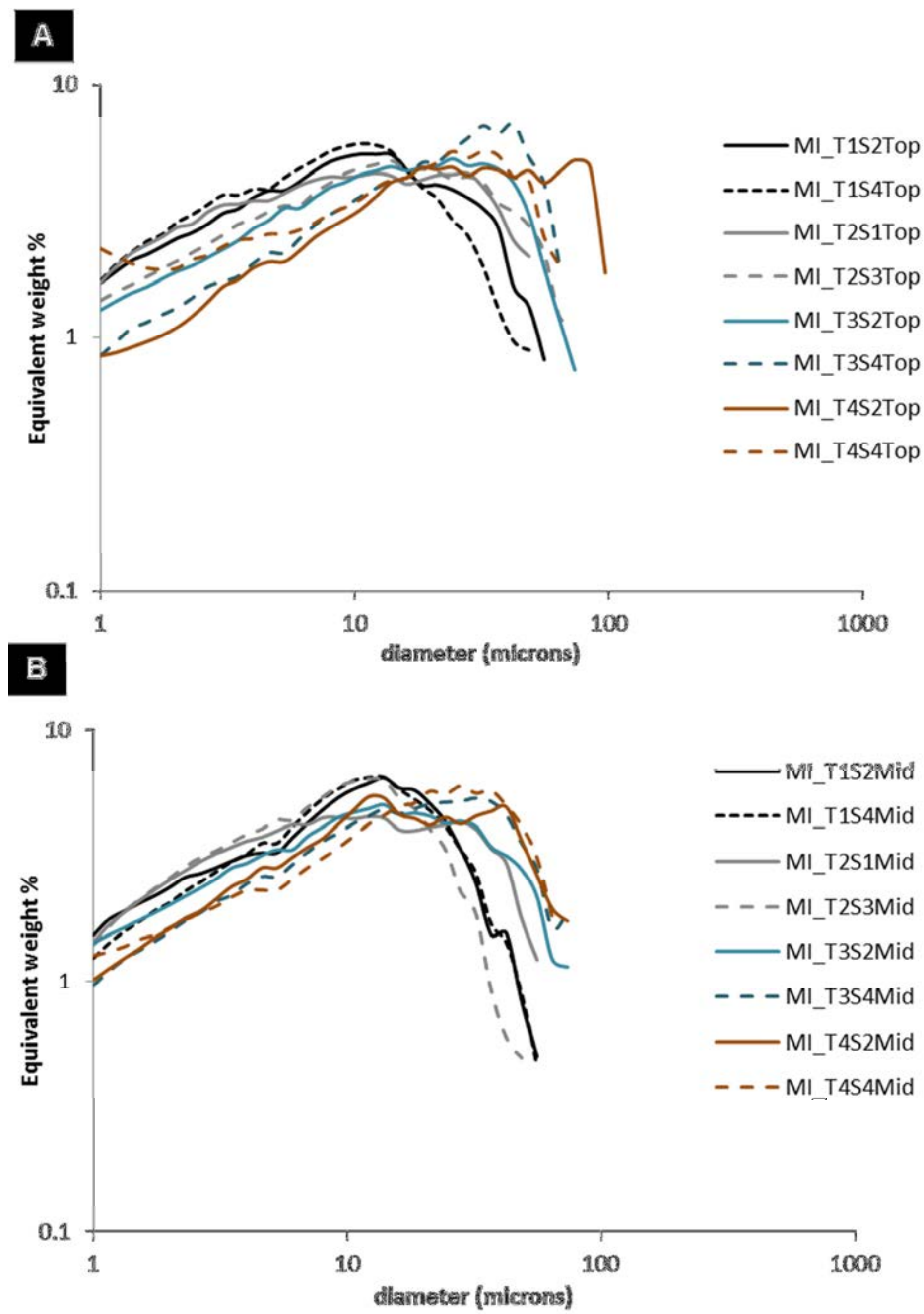


Figure 31 Comparison of the detailed grain size spectra for top 2 cm and mid section of core samples collected in 2013 at MI processed with the Coulter Multisizer 3.

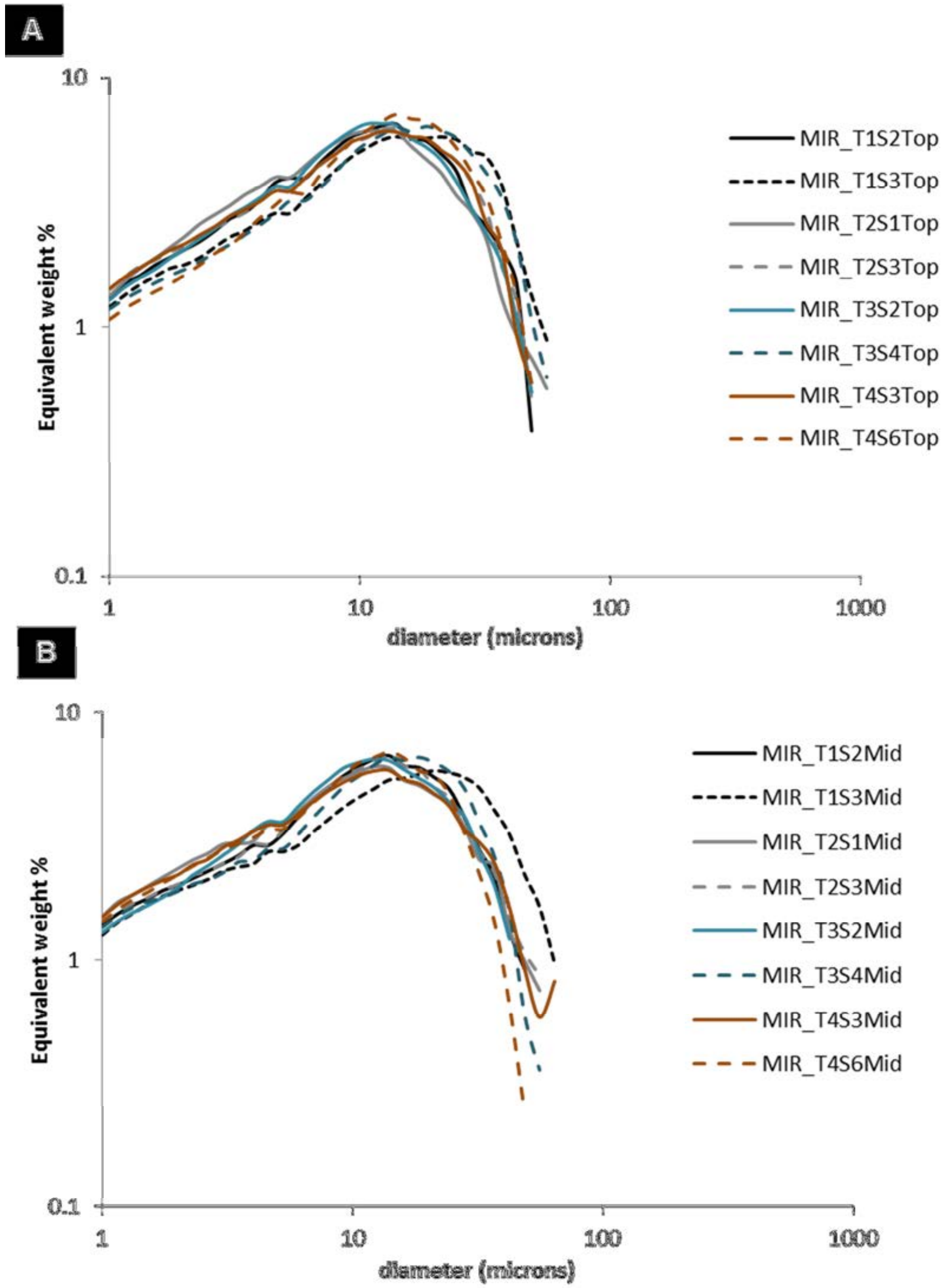


Figure 32 Comparison of the detailed grain size spectra for top 2 cm and mid section of core samples collected in 2013 at MIR site processed with the Coulter Multisizer 3.

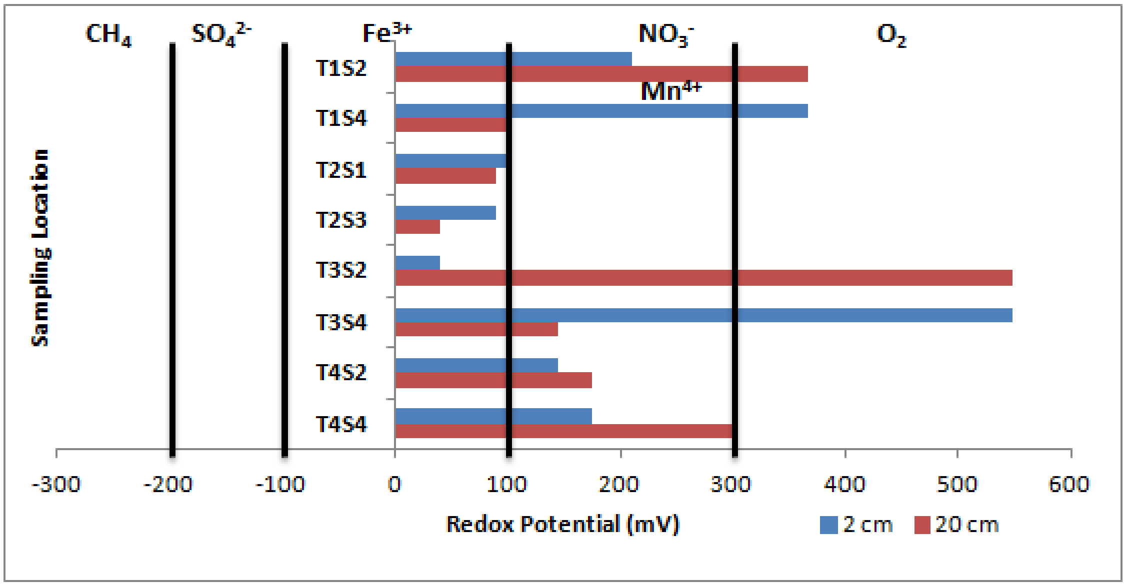
Soil Chemistry (Redox Potential)

The dominant reactions occurring within 2 cm and 20 cm depth at MI (Figure 33a) were iron (III) and nitrate/manganese (IV) as compared to only nitrate/manganese (IV) at MIR (Figure 33b). This indicates that the reference site was more oxidized (low stress on vegetation) than the restoration site (stressed conditions). At the restoration site, two sampling locations at the 2 cm depth (T1S4 & T3S4) and 20 cm depth (T1S2 & T3S2) had the dominant redox reaction as oxygen as compared to one sampling location at the 2 cm depth (T2S1) and 20 cm depth (T1S3) at the reference site. The analysis of soil characteristics indicated that bulk density was lower at MI than MIR suggesting that the soil may be better aerated because of the potential greater amount of pore space, drainage, and lower decomposition. It is interesting to note that the sampling stations on MI transect two experienced the lowest redox values at the 20 cm depths indicating the vegetation in this region were unable to oxygenate down to that depth and the soil may have less nitrate and Mn^{4+} than in other regions leading to iron (III) reduction. This also correlates with water and salinity levels in this part of the marsh (Section 4.2: Ground water; Section 4.3: Pore water salinity).

The redox potential measurements indicated moderate anaerobic stress on vegetation and potential for moderate decomposition rates within the soil under anaerobic conditions. There is potential for sulfide, a known phytotoxin, to accumulate within the soil, as the soil is heterogeneous and multiple redox reactions occur at one time. However, sulfate reduction was not the dominant redox reaction being measured at the time, and therefore high levels are not expected to accumulate. The areas that experienced oxygen reduction would allow for the oxidation of the reduced compounds (i.e. sulfide) and decrease these levels within the soil. Regular flooding by tidal waters provide large amounts of sulfate to coastal marshes. For this reason tidally restricted sites, such as MI, do not have dominant redox reactions that fall into the sulfate range.

Overall, the sites were experiencing similar dominant reduction reactions creating similar stress on the vegetation. Vegetation on the restoration site is comprised of wetland species (brackish and freshwater species compared to halophyte species at the reference) that are adapted to this kind of soil condition and stress. However, once restoration of tidal water occurs, the new hydrological regime will cause significant changes in soil conditions (water content, salinity, chemistry), which will in turn drive change in vegetation community structure.

a)



b)

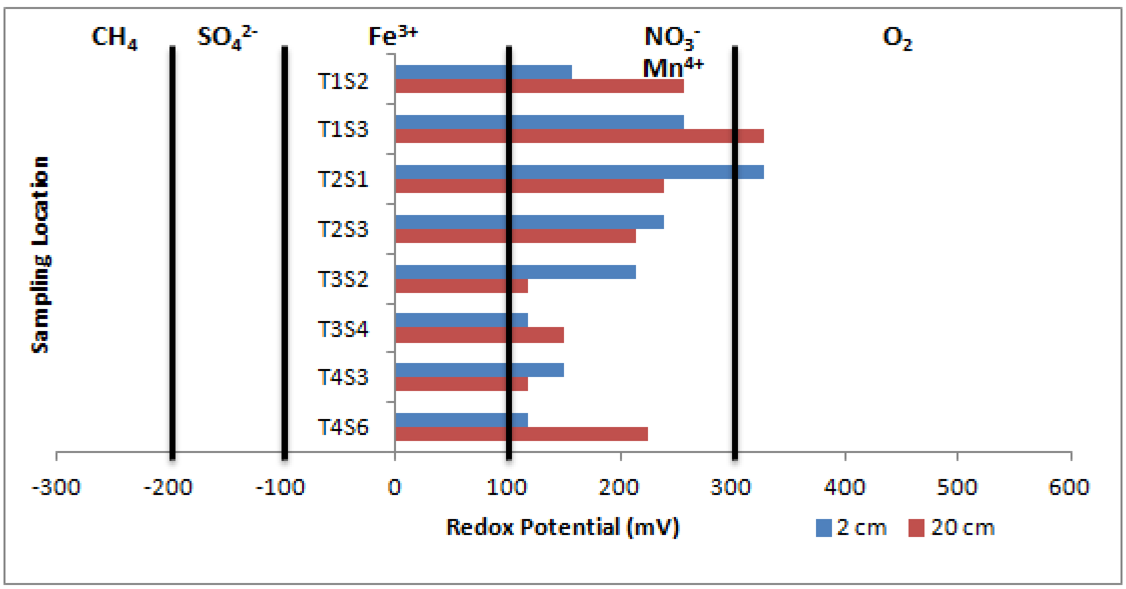


Figure 33 Mean redox potential values in relation to dominant reduction oxidation reaction occurring at 2 cm and 20 cm depth segmented into ranges of redox potential for dominant reduction reactions; a) MI, and b) MIR.

4.4 Vegetation

Community Composition

The vegetation sample plots on transects 4, 5, and 6 (Figure 12) of the restoration site contain bog vegetation, on the left of the ordination graph (Figure 34a,b). The vegetation community composition of the sample plots on the remaining (front) three transects in MI overlapped with some reference site plots, which could be characterized as brackish vegetation (*Carex paleaceae,* *Spartina pectinata, Festuca rubra, Juncus balticus* etc.) (Table 12). At MI, the spread of plots along the vertical axis (axis 2) may indicate a fertility gradient, with bog conditions at the low end (*Drosera rotundifolia, Carex trisperma, Sphagnum* spp.), and species of more productive freshwater wetlands at the upper end (Figure 34a,b). This might indicate increased groundwater influence at the upper end. The bog and other freshwater wetland species detected here are very common across the province.

In addition to some plots with brackish vegetation, MIR contained plots dominated by typical high and low salt marsh species (*S. alterniflora, S. patens* etc.) (Figure 34a,b). There were too few plots containing these species at MIR to see the evidence of clear environmental gradients, and *S. alterniflora* only occurred in plots also supporting *S. patens*, unlike the typical distribution in other areas where there was clear zonation and discontinuity between these communities (Porter et al. submitted). However, the presence of both brackish and salt marsh species at the reference site was sufficient to classify this site as a salt marsh, but with strong freshwater influence due likely to the presence of the causeway and the narrow marsh profile.

Given the lack of previous reference site characterization in this region it is not clear whether to expect the same tidal wetland plant communities as have been recorded for Bay of Fundy tidal wetlands (Porter et al. submitted). Additional sampling of intact reference marshes in SW Nova Scotia would be useful as regional botanists note substantial differences in substrate characteristics and the presence of rare species compared with Bay of Fundy and eastern shore tidal wetlands (Sean Basquill, personal communication).

Univariate indicators

The restoration site had greater average plot species richness than the reference site (1-way ANOVA: $F_{1,49}$=8.761, P=0.005) (Figure 35a). This likely reflects the different habitat types present at the sites; the reference site contains mainly salt marsh and brackish communities, which are relatively species-poor in other parts of the province (Bowron et al. 2011). The restoration site has many plots in bog, fen or other freshwater wetland habitat types, which typically have greater species richness, thus the differences do not likely represent differences in habitat quality or the influence of ecological degradation; however, the current condition of MI is clearly influenced by the presence of the causeway, reducing salt water influence and likely resulting in changes from its previous condition.

Halophytic species were found at both sites, and despite the dominance of bog vegetation, many plots at MI contained at least one halophyte species, suggesting that the site still has some salt water influence (Table 12). Neither site had substantial unvegetated areas in this pre-restoration year (not shown). Halophytic richness and abundance were both greater at the restoration site (richness: $F_{1,49}$=16.37; P=0.0002; abundance: $F_{1,49}$=19.89; P<0.0001) (Figure 35b,c).

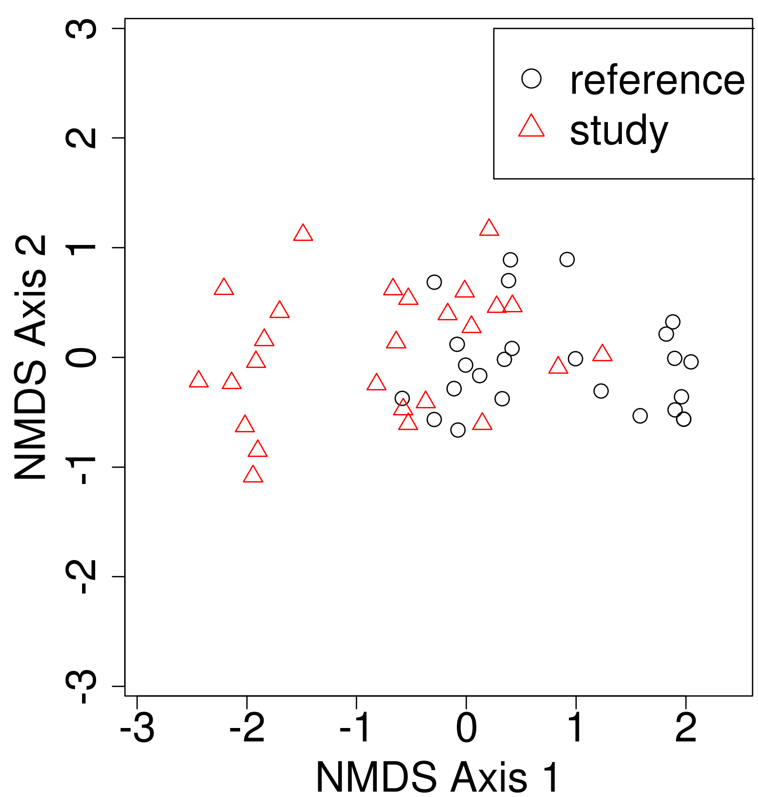
Table 12 Mean abundance and frequency of plant species at Morris Island reference and study sites. Species in bold considered halophytes for purposes of this study (MI – restoration site; MIR – reference site).

Name	Abbreviation	MI mean (av canopy density/plot)	MI frequency (#plots)	MIR mean (av. canopy density/plot)	MIR site frequency
Acer rubrum	Ace.rub	0.59	2	0.24	1
Agrostis gigantean	Agr.gig	0.16	3	0	0
Agrostis stolonifera	Agr.sto	2.08	6	5.05	10
Alnus incana	Aln.inc	0.88	1	0	0
Amelanchier sp.	Ame.sp	0.08	1	0	0
Andromeda polifolia	And.pol	0.13	2	0	0
Aster sp.	Ast.sp	0.09	2	1.08	2
Atriplex sp.	Atr.gla	0.00	0	0.01	1
Calystegia sepium	Cal.sep	0.16	3	0.25	4
Carex echinata	Car.ech	0.62	1	0	0
Carex folliculate	Car.fol	0.04	1	0	0
Carex hormathodes	Car.hor	0.23	2	0.52	2
Carex paleacea	Car.pal	0.00	0	0.04	1
Carex scoparia	Car.sco	0.01	1	0	0
Carex trisperma	Car.tri	2.35	4	0	0
Chamaedaphne calyculata	Cha.cal	2.17	8	0	0
Coptis trifolia	Cop.tri	0.08	1	0	0
Cornus canadensis	Cor.can	0.01	1	0	0
Distichlis spicata	Dis.spi	0.00	0	0.36	2
Doellingeria umbellata	Doe.umb	0.12	2	0	0
Drosera rotundifolia	Dro.rot	0.38	2	0	0
Eleocharis tenuis	Ele.ten	5.77	7	4.32	7
Elymus trachycaulis	Ely.tra	0.00	0	0.72	1
Eriophorum virginica	Eri.vir	0.27	2	0	0
Eurybia radula	Eur.rad	0.08	1	0	0
Festuca rubra	Fes.rub	2.88	8	6.16	12
Galium palustre	Gal.pal	0.15	1	0	0
Gaylusaccia baccata	Gay.bac	2.96	7	0	0
Glaux maritime	Gla.mar	0.00	0	0.01	1

Name	Abbreviation	MI mean (av canopy density/plot)	MI frequency (#plots)	MIR mean (av. canopy density/plot)	MIR site frequency
Hierochloe odorata	Hie.odo	0.36	5	0.77	8
Juncus balticus	Jun.bal	5.12	14	6.32	11
Juncus canadensis	Jun.can	0.08	2	0.25	2
Juncus gerardii	Jun.ger	0.15	2	2.32	8
Kalmia angustifolia	Kal.ang	0.86	5	0	0
Larix laricina	Lar.lar	0.15	1	0	0
Lichen	Lic.sp	0.12	1	0	0
Limonium nashii	Lim.nas	0.04	1	0.08	1
Lonicera cerulean	Lon.cer	0.12	1	0	0
Lysimachia terrestris	Lys.ter	0.00	0	0.16	1
Maianthemum trifolium	Mai.tri	0.27	2	0	0
Fern	fern1	0.01	1	0	0
Unknown	fl1	0.04	1	0	0
Unknown	mis2	0.19	1	0	0
Myrica gale	Myr.gal	1.52	9	0	0
Morella pensylvanica	Myr.pen	0.69	3	1.12	2
Oclemena acuminata	Ocl.acu	0.13	3	0	0
Picea mariana	Pic.mar	1.77	3	0.48	1
Potentilla anserina	Pot.ans	0.00	0	1.01	7
Rhododendron canadense	Rho.can	1.15	4	0	0
Rhododendron groenlandica	Rho.gro	2.43	7	0	0
Rosa virginiana	Ros.vir	1.88	7	0.4	3
Rubus idaea	Rub.ida	0.00	0	0.01	1
Rubus pubescens	Rub.pub	0.47	7	0	0
Salicornia europea	Sal.eur	0.00	0	0.16	2
Sarracenia purpurea	Sar.pur	0.08	1	0	0
Scirpus americana	Sci.ame	5.08	10	5.72	9
Solidago sempervirens	Sol.sem	0.08	1	1.1	8
Solidago uliginosa	Sol.uli	0.04	1	0	0
Spartina alterniflora	Spa.alt	0.19	2	3.16	9
Spartina patens	Spa.pat	1.42	2	11.2	14
Spartina pectinata	Spa.pec	4.97	12	4.96	8

Name	Abbreviation	MI mean (av canopy density/plot)	MI frequency (#plots)	MIR mean (av. canopy density/plot)	MIR site frequency
Sphagnum sp.	Sph.mos	7.77	13	0	0
Spirea latifolia	Spi.lat	0.19	2	0	0
Sueda maritime	Sue.mar	0.01	1	0	0
Symphotrichum novi-belgii	Sym.nov	1.01	6	2.96	11
Symphocarpus foetidum	Sym.foe	1.01	6	0	0
Thalicrum pubescens	Tha.pub	0.05	2	0.16	2
Toxicodendron radicans	Tox.rad	1.99	9	0.36	2
Triglochin maritima	Tri.mar	1.43	8	1.01	7
Typha latifolia	Typ.lat	0.85	4	0	0
Unknown	sp	0.29	5	0.2	1
Vaccinium macrocarpon	Vac.mac	2.69	10	0.24	2
Vaccinium myrtilloides	Vac.myr	0.15	1	0	0
Vaccinium oxycoccus	Vac.oxy	0.31	4	0.04	1
Viburnum nudum	Vib.nud	0.12	1	0	0

a)



b)

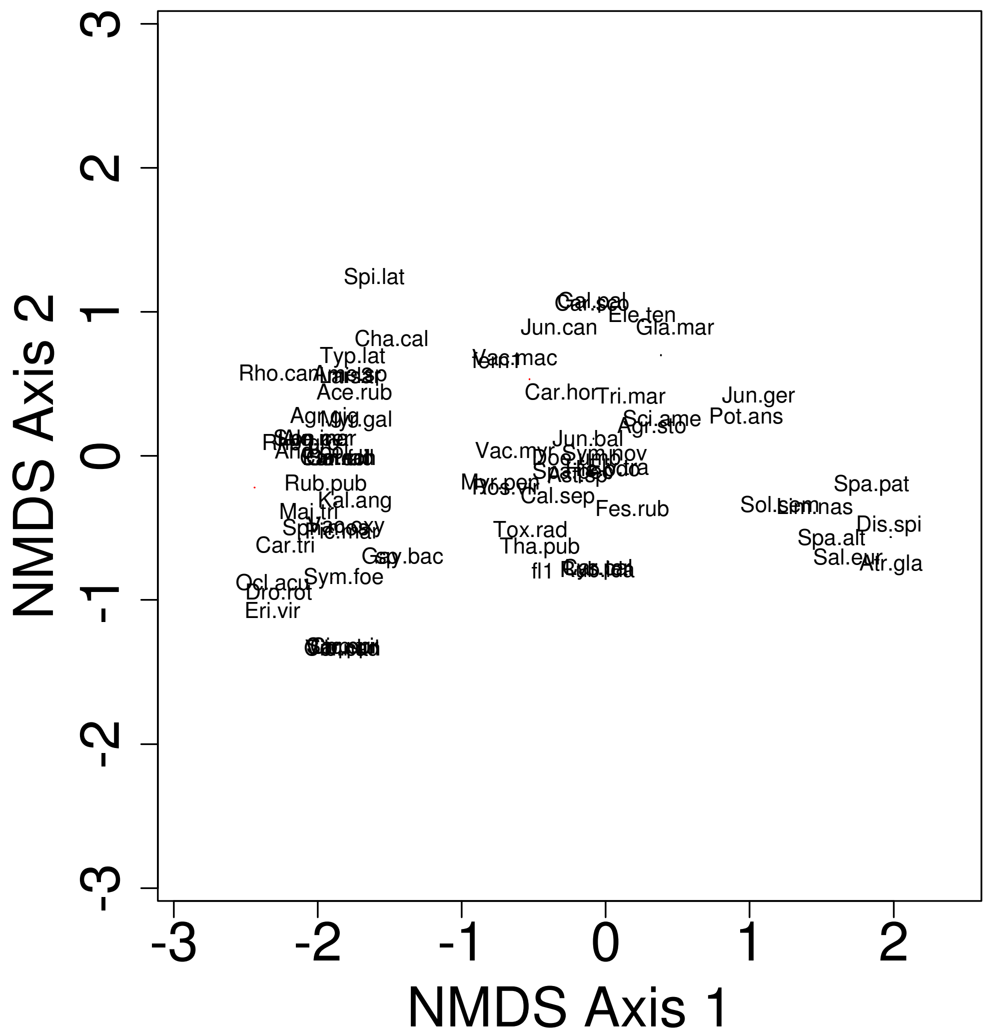


Figure 34 Non-metric multidimensional scaling analysis of vegetation composition (abundances are canopy densities in each plot, sampled by pin-frame). a) plots only; b) species only. Stress=0.109

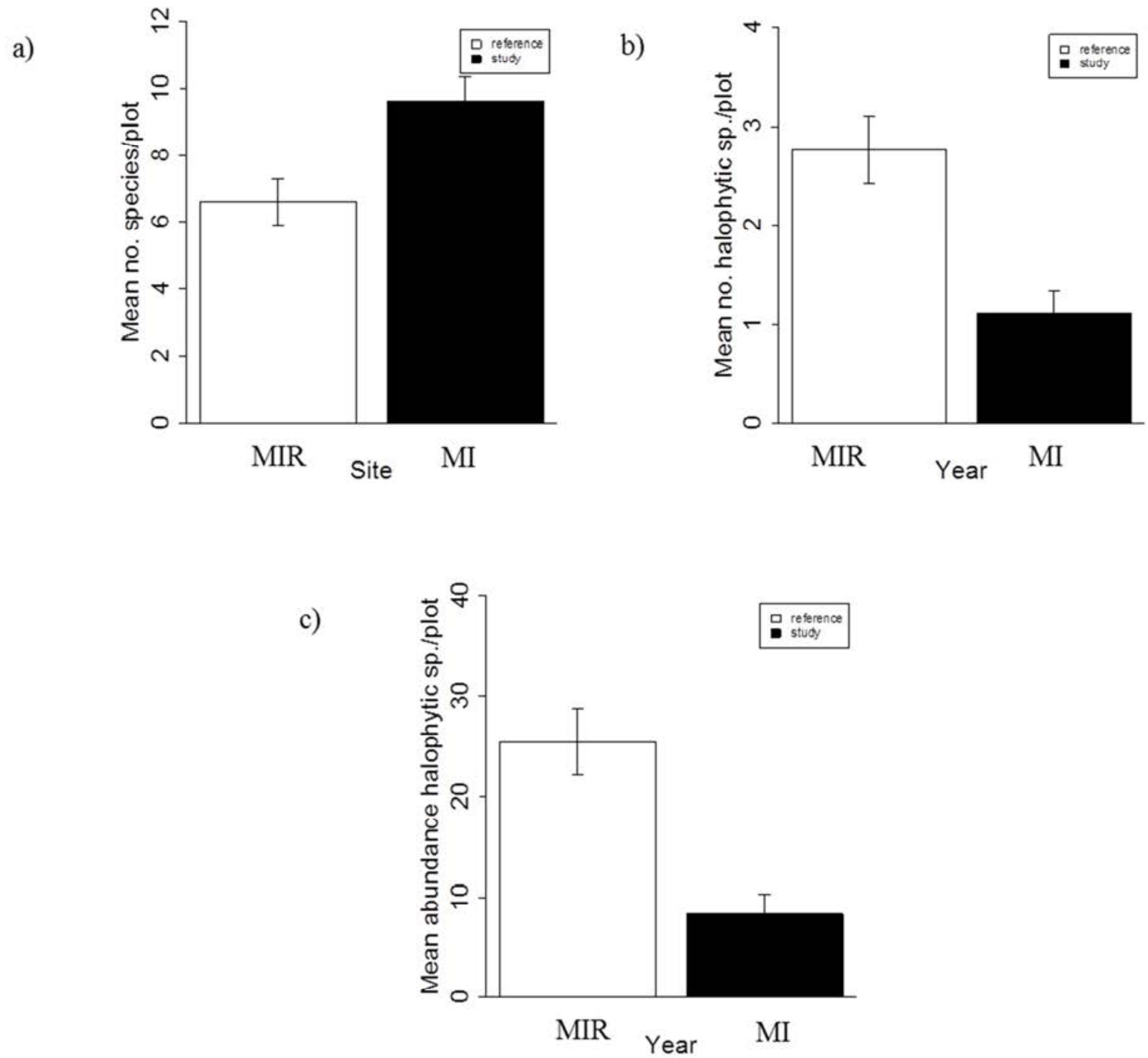


Figure 35 Species richness (a), halophytic species richness (b), and halophytic species abundance (c) for Morris Island study and reference sites.

4.5 Nekton

Only one trap set in the restoration site contained fish. The trap set immediately upstream of the culvert caught ten mummichogs and a single *Gasterosteus aculeatus* (three-spined stickleback) (Table 13). The mummichog was also the dominant species in both fyke net and minnow traps at MIR (Table 13). The mummichog was the only species captured in the minnow traps at MIR. The fyke net samples however, contained five different species of fish including the three-spined stickleback and the green crab (*Carcinus maenas*). The other species captured in the fyke nets set within the main tidal channel were *Alosa pseudolarengus* (alewife; gaspereau), *Anguilla rostrata* (American eel), *Microgadus tomcod* (Atlantic tomcod), and *Gasterosteus aculeatus (three-spined stickleback).* These species are migratory estuarine species known to access both the lower elevation portions of tidal wetlands and the vegetated surface during high tide.

Faunal response to restoration is dependent on access to the shallow intertidal marsh surface and intertidal and subtidal creeks (Able et al. 2008). The response of fish can be rapid following hydrological restoration (Roman et al. 2002; Able et al. 2008, Konisky et al. 2006), as has been the case at other coastal wetland restoration project sites throughout the province (Bowron et al. 2011; van Proosdij et al. 2010; Roman et al. 2012). *Fundulus heteroclitus* (mummichog) has typically been the most commonly encountered species, often in large numbers, in tidal creeks, pannes and on the marsh surface of both reference and restoration sites throughout the province. It is a species that is known to be a resident salt marsh species found in both natural and impacted systems (Konisky et al. 2006). Diversity has been greater in fyke net samples due to sampling location and broader range of size class selection. The presence of species, such as the American eel, Atlantic tomcod, and gaspereau, are indicative of higher order species within the reference site that would likely be accessing the restoration site if not for the tidal restriction.

Table 13 Fish species, and abundance, observed during monitoring at MI(R).

Species (common name)	2013 (pre)	
	MI	MIR
Alosa pseudolarengus (alewife; gaspereau)	0	10
Anguilla rostrata (American eel)	0	1
Fundulus heteroclitus (Mummichog)	10	349
Gasterosteus aculeatus (three-spined stickleback)	1	25
Microgadus tomcod (Atlantic tomcod)	0	1
Species Richness (n=x)	2	5
Abundance (total # of individuals)	11	386

4.6 Aquatic Invertebrates

IAT samples contained organisms from a cross-section of 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.

The MIR samples were numerically dominated by small copepod crustaceans and nematodes. The greatest numbers of these organisms were captured in the July 2013 samples, although they were still dominant in the August samples. The MI samples were numerically dominated by chironomidae larvae, an isopod species (*Caecidotea* sp.) and copepods. The number of species (richness) for each of the sites was not statistical different, with MIR samples ranging from 7 to 9 and 2 to 9 at MI (ANOVA = 0.19, DF = 1, F = 2.45) (Figure 37). There was a statistical difference in abundance between the two sites, with the reference site being the more productive (34 to 185 compared to 2 to 79 for MI) (ANOVA 0.02, DF = 1, F = 13.9).

Fish were present in two of the MIR samples, however, none were found in the MI samples. Within the restoration site, the transect 5 sampling location captured the greatest number of species and had the greater abundance, compared to the traps located at transect 2. As was seen in the water quality (salinity), groundwater level, soil salinity, and fish data, these two areas were quite distinct from each other, which was also reflected in the invertebrate community.

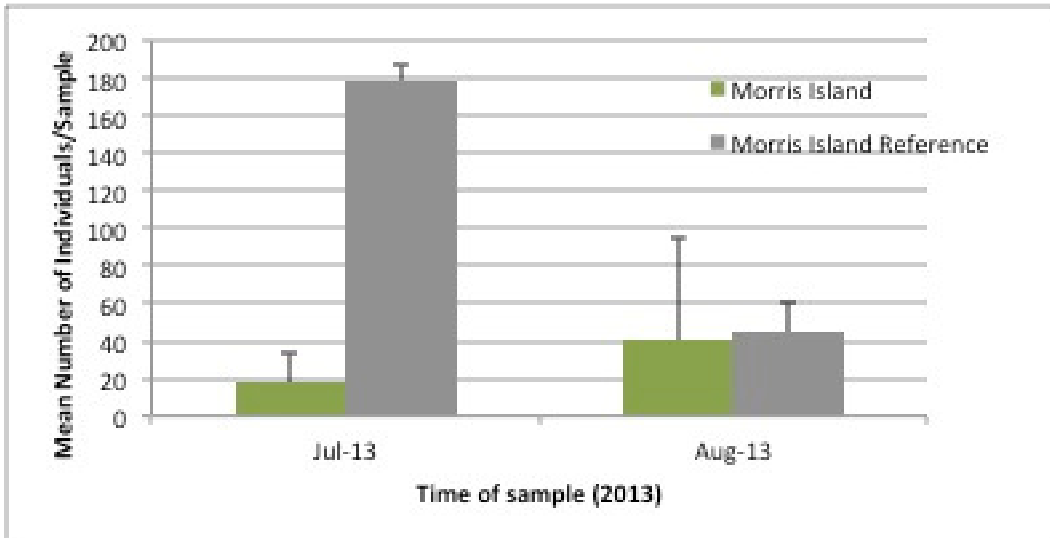


Figure 36 Aquatic invertebrate mean abundance for MI(R), 2013.

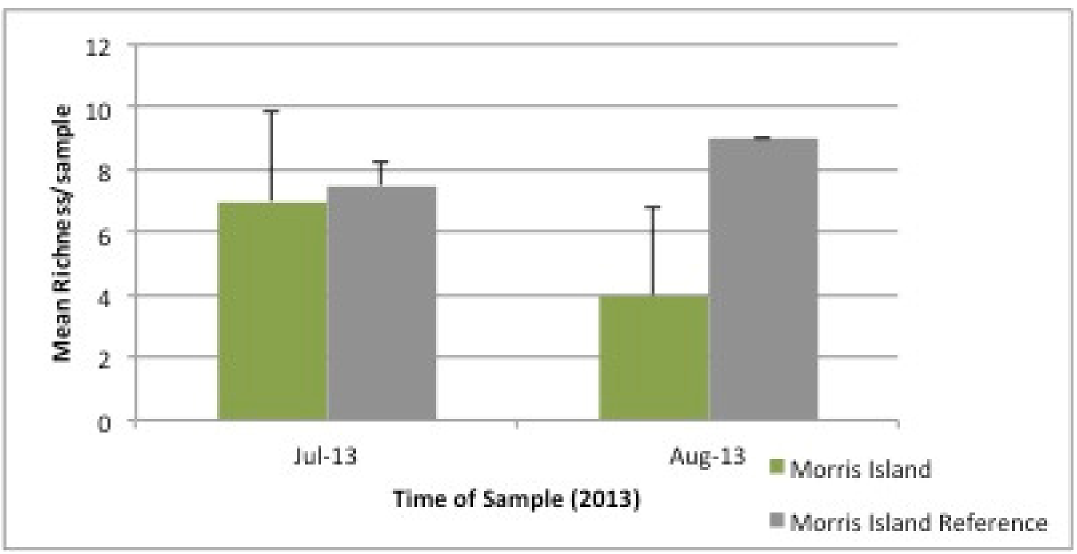


Figure 37 Aquatic invertebrate diversity for MI(R), 2013.

4.7 Structured Winter Site Walk

The period of December 2013 through early February 2014 was marked by extended periods of cold temperatures, numerous snowfall events and both fast and sea ice formation on coastal areas throughout much of NS. A warm period that included rainfall events in advance of the winter site visit on 24 February 2014 resulted in very little ice and snow being present. The site visit was conducted at low tide, however, water level within the restoration site was higher than observed during the summer monitoring activities. This was indicative of increased precipitation (higher freshwater inputs) and the restrictive nature of the causeway-culvert. The earlier presence of sea ice (ice blocks) on the reference site was evidenced by sediment deposits (Figure 38). A selection of landscape photographs from the MI and MIR winter walk are provided in Appendix B.

Figure 38 Sediment deposits on the marsh surface of the reference site. 24 February 2014. Photograph by CBWES Inc.

5.0 Summary and Restorable Area

The results of the 2013/14 pre-restoration baseline monitoring of the Morris Island tidal wetland restoration project were presented in this report. Post-restoration monitoring is planned to occur after one, two, three and five years. 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 current causeway-culvert structure at MI represents a significant barrier to tidal flow and fish passage, has resulted in an alteration of the natural hydrological regime and a loss of halophytic species and tidally influenced wetland habitat conditions. Pre-restoration monitoring confirmed MI to be a freshwater wetland environment with a mix of bog, fen and brackish wetland 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 downstream of the causeway, and marsh surface elevations within the site indicate that the site would experience increased 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 size and 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 will enable the documentation of early stages of the wetland recovery process and verification of an acceptable restoration trajectory.

Restorable Area

With the elimination of the hydrological restriction, the potential area of the restored tidal wetland habitat at MI would be approximately 1.12 ha (based on observed tide elevations and marsh surface elevation; Section 4.1 and 4.2; Figure 39). Factors such as sea level rise, a decrease in marsh surface elevation due to improved drainage, and storm events may result in a larger than predicted area being directly influenced by tidal flooding. The actual restored area (area under water) will be determined on the ground by the post-restoration monitoring program. The elimination of the tidal restriction at MI would result in the restoration of a more natural hydrological regime, further diversifying the current wetland complex and allowing for improved transport of materials and species between upstream and downstream habitats.

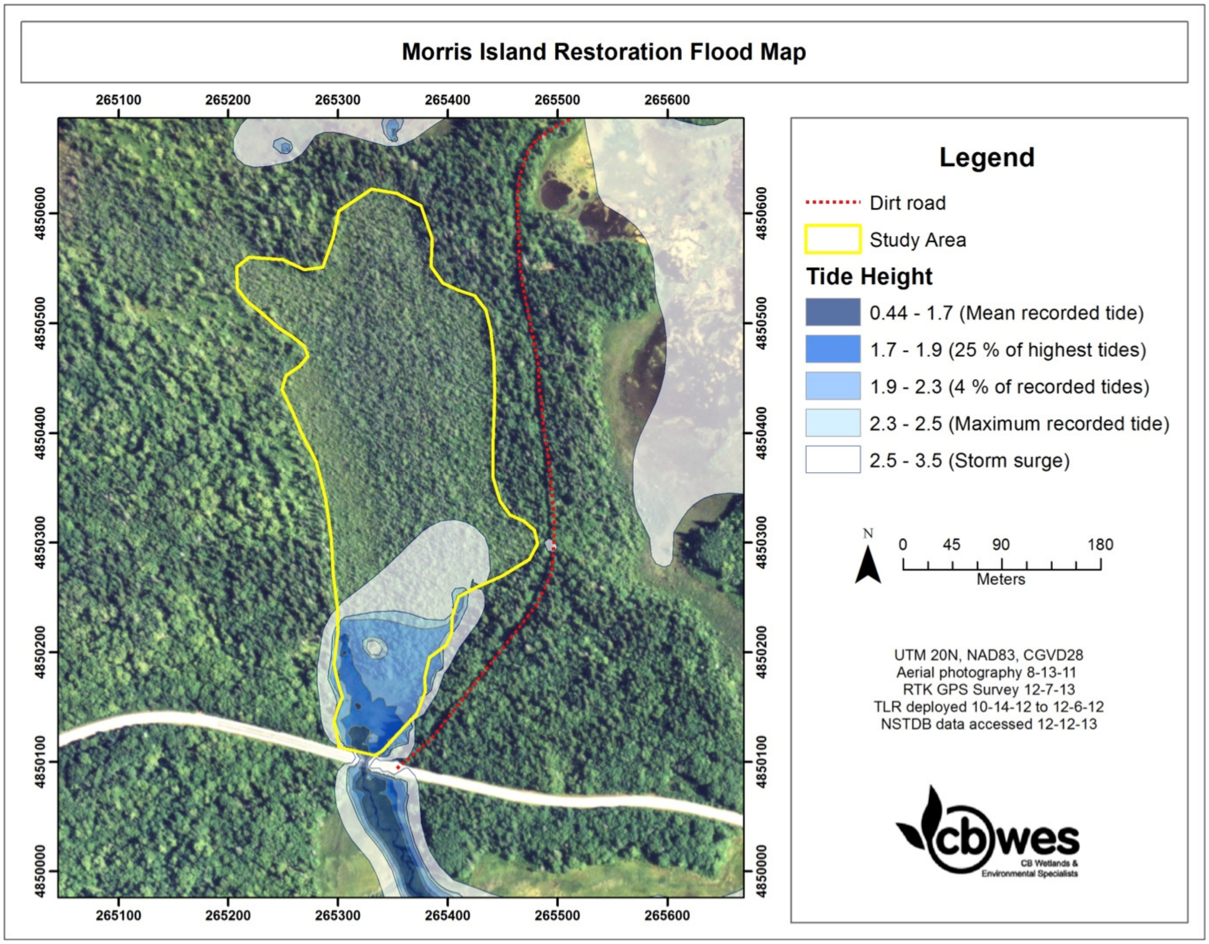


Figure 39 MI flood map for showing unrestricted flooding under low and high tide conditions.

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 by providing valuable information: on the ecological condition of the restoration and reference sites; the response of physical and biological elements; and 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 for the MI project are outlined in Table 1 (Section 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, in advance of culvert replacement (construction; anticipated in 2015/16), that the marker horizons that were installed in 2013 be measured in order to determine the pre-restoration sediment deposition rate for the two sites. As well, a pair of RSETs should be installed and measured (one per site).

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, groundwater, water quality, and winter conditions should also be sampled at this time. The post-restoration monitoring program, as outlined in Table 1, will involve monitoring activities conducted one, two, three, and five years following culvert replacement.

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Appendix A - CBWES Supported Student/Research Projects

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

Current Projects:

Masters of Applied Science
Department of Environmental Science
Saint Mary's University
Christa Skinner
2013-2015

Temporal and Spatial Patterns of Soil Chemistry and Primary Productivity in a Restored Salt Marsh

Salt marshes are highly productive ecosystems that provide a variety of ecosystem services. These ecosystems have been hindered by human alteration for hundreds of years and now provide opportunities for restoration. Salt marsh restoration of a previously tide-restricted site creates alteration to biogeochemical cycles within the sediment that have implications for vegetation recolonization and expected timeline for marsh development. Restoring appropriate hydrology to the previously tide-restricted site is extremely important to ensure proper drainage and minimize pooling of water on the marsh surface. Biogeochemistry is the study of the exchange of materials between living and nonliving components of the biosphere. Tidal water brings large amounts of salt and sulfate into coastal systems that can influence the productivity of vegetation. The sulfur cycle has been found to be the dominant oxidation-reduction cycle within coastal systems due to the large volume of sulfate available. Sulfate is used as an electron acceptor when conditions are favorable to assist in the oxidation of organic matter and subsequent production of sulfide. High levels of sulfide and salinity have been found to influence the productivity of vegetation within salt marshes and is influenced by the hydrologic network of the site. This study strives to determine the temporal and spatial pattern of sulfide, salinity and redox potential and related primary productivity and hydrology. It is hypothesized that the highest concentrations of sulfide and salinity will be found in areas of poor drainage during neap tides. An understanding of the temporal and spatial patterns of biogeochemical factors within a macro-tidal salt marsh will assist in the development and planning of future restoration projects.

Directed Study
Environmental Science
Saint Mary's University

Carly Wrathall
2014

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

The purpose of this directed studies course is to develop a proof of concept for the use of a created (engineered) salt marsh to reduce erosion along the Lawrencetown Lake section of the Trans Canada Trail. Project will include a thorough review of the scientific and technical literature on the use of engineered salt marshes (living shorelines) to control erosion; the development of a rationale for the use of this technique as part of a shoreline management strategy for Lawrencetown Lake salt marsh restoration project and trail system; a site design proposal (techniques, materials, timelines, cost estimates, etc.); and the presentation of this "proof of concept" to provincial and federal regulatory agencies in order to identify regulatory requirements and obstacles. This course will involve literature review; consultation with restoration practitioners, material supply companies, and provincial & federal regulatory agencies; development of a project design using a geographical information system.

Completed Projects:

Directed Study

Environmental Science
Saint Mary's University
Carly Wrathall
2013

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

The purpose of this directed studies course is to examine above and below ground productivity of salt marshes in Nova Scotia's Bay of Fundy macro-tidal environment, and and the potential for carbon sequestration. This will include examining the physiological, chemical, sedimentological, environmental and anthropogenic factors that could be potentially be influencing productivity. Along with field research and data collection, this course will also include a major research project including statistical analysis of field samples and geospatial analysis using a geographical information system.

Peer-review Publication (submitted)

Caitlin Porter, Jeremy Lundholm, Danika van Proosdij, Tony Bowron, Nancy Neatt, Jennie Graham, Ben Lemieux
Saint Mary's University & CBWES Inc.
2013

Classification and environmental correlates of tidal marsh vegetation in Nova Scotia, Canada.

Tidal wetland vegetation of eastern North America shows conspicuous zonation attributable to biotic interactions between plant species and differential tolerance of salinity and flooding. Tidal wetlands are a conspicuous feature of the coastline in Nova Scotia, and previous descriptions suggest that many of the plant communities are similar to those found in New England, which have been extensively studied. The goal of this study was to perform a numerical classification of tidal wetland vegetation in Nova Scotia, and to determine the relationships between variation in plant species composition and environmental factors. Sampling was conducted from vegetation communities of eight tidal wetland sites along a range of tidal magnitudes (micro- to macro-), designated as reference (intact) sites for paired tidal wetland restoration projects. Cluster analysis revealed seven distinct plant communities related to gradients of inundation duration and salinity. Plant community types were usually dominated by a single graminoid species. Communities detected were similar to those found in New Brunswick Bay of Fundy and Northumberland Strait wetlands, and to those farther south in Maine and New England, but three brackish communities were also identified within this study, of which the Juncus balticus/Festuca rubra and Spartina pectinata communities have not been previously described. Redundancy analysis shows continuous variation among these community types and highlights key environmental variables related to plant community patterns. These analyses provide a baseline for restoration work and identify environmental correlates of plant communities, allowing for better predictions of ecological restoration trajectories in tidal wetlands.

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; van Proosdij et al. 2010).
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.

References

Bowron, T.M., N.C. Neatt, J.M. Graham, J. Lundholm and D. van Proosdij. 2009. Post-Construction Monitoring (Year 3) of the Walton River Salt Marsh Restoration Project. Report Prepared for Nova Scotia Department of Transportation and Infrastructure Renewal. CBWES Inc. Publication No.12

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

Analysis of the Relationship Between Vegetative Community Structure and Geodetic Elevation for Salt Marsh Restoration in Hypertidal Systems

Monitoring of salt marsh restoration sites is critical to the success of current and future projects but may also lead to costly projects. The distribution of vegetation across the marsh surface is highly influenced by soil salinity, duration of tidal flooding and competition between plant species. Focus has been placed on vegetation regeneration in post restoration activities and the role vegetation plays in sediment deposition within the Bay of Fundy. The influence that geodetic elevation has on the distribution of vegetation across the marsh has not been studied within restoration salt marshes in the Bay of Fundy. This study analyzes the relationship between vegetation community structure and geodetic elevation within restoration and reference macrotidal salt marshes in the Bay of Fundy.

This reseach was conducted within three newly restored salt marshes (and associated reference site(s)) in the upper Bay of Fundy currently being monitored as a compensation project. Dominant vegetation and geodetic elevation was determined at sampling stations arranged in transects running from the main tidal creek to the upland for each of the study sites in 2010. Five similar salt marsh species were found in both the reference and restoration sites. These include *Carex paleacea, Juncus gerardii, Spartina patens, Spartina pectinata*, and *Spartina alterniflora*. Of these five species, *Juncus gerardii, Spartina pectinata,* and *Spartina alterniflora* were found to have significantly different means and ranges of elevation within the restoration sites as compared to the reference sites. This is due to soil salinity, frequency and duration of inundation, and competition. All of these factors are influenced by geodetic elevation and time since beginning of restoration.

Undergraduate Honours

Environmental Science
Saint Mary's University
Alisha Glogowski
2012-2013

Information From the Wrack: Viability of Halophytic Vegetation within Tidal Wetland Wrack Mats

Nova Scotia's coastal wetlands are under various anthropogenic pressures that can cause destruction or degradation to these ecosystems. Many of these valuable systems have not been protected in the past and have been lost. An important stage in the overall knowledge of coastal wetlands is figuring out how these systems can recolonize without planting. Wrack is understudied in the Minas Basin, Bay of Fundy and determining if there is viable halophytic plant material within the wrack in this area could be a clue to understanding how these systems function. In order to gain a better understanding of the role of wrack mats, 18 samples were analyzed from 6 study areas (3 sample locations per study area). A characterization of the wrack mat was completed and seed material was determined viable. Target species *Spartina patens* and *Spartina alterniflora* did not germinate at all, while target species *Plantago maritima* and *Juncus gerardii* did germinate from seed and rhizome material found within the wrack. This information complements ongoing studies within the Minas Basin, Bay of Fundy, and increases the overall knowledge of relationships between wrack and colonization within coastal wetlands.

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 Class Research Project

Department of Biology
Saint Mary's University

by Shawn Adderley, Alison Bijman, Lydia Ephraim, Kristen Gallant, Robert Hicks, Sebastien Letourneau-Paci, Lori Miller, Chantal Pye, Benjamin Royal-Preyra, Shayna Weeks

Edited by Dr. Jeremy Lundholm, Department of Biology/Environmental Science, Saint Mary's University

Phragmites australis at Cogmagun Restoration Site

A population of *Phragmites australis* was discovered at the salt marsh restoration site at Cogmagun Creek in summer 2011. As this species includes native and invasive subspecies, we undertook several analyses to determine a) the extent of colonization at the site; b) whether other nearby sites have also been colonized by *Phragmites*; c) environmental and vegetation characteristics of colonized areas. We found that *Phragmites* has colonized an area of 885 m^2 and has been present for at least two growing seasons (CBWES pers. comm 2011). However, there was no evidence of the species further upstream at the restoration and reference sites, nor on any adjacent marshes.

This population has morphological characteristics suggesting that it belongs to the native subspecies, but several of the measurements overlap with those from other populations from central Nova Scotia known to be non-native. Existing *Phragmites* stands contain a mixture of other species, mostly natives. The presence of many species coexisting within *Phragmites* stands provides more evidence to suggest that the plants at Cogmagun are representatives of the native strain of *Phragmites*, which is known to grow in less dense stands and to coexist with other native species. The elevation range of current populations suggests that much of the restoration site and upstream coastal marshes have similar elevation ranges to the area occupied by current populations, however, soil salinity values suggest that much of the site cannot be colonized by the native subspecies of *Phragmites*. We recommend that the most important next step in assessing the site would include a genetic analysis of the *Phragmites* populations to obtain a definitive genetic identity and to better estimate potential spread on the site.

Based on experiments conducted in other parts of North America, appropriate control measures for non-native *Phragmites* at Cogmagun could include mechanical and/or chemical control.

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 and Askins 2002, Shriver et al. 2004, Hanson and 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.

References:
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

Hanson, A.R. and W.G. Shriver. 2006. Breeding birds of Northeast saltmarshes: habitat use and conservation. *Studies in Avian Biology*. 32:141-154.

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.

STRUCTURED WALK PHOTOGRAPHS - MI (select images):

Figure 1 Transect one.

Figure 2 Transect three.

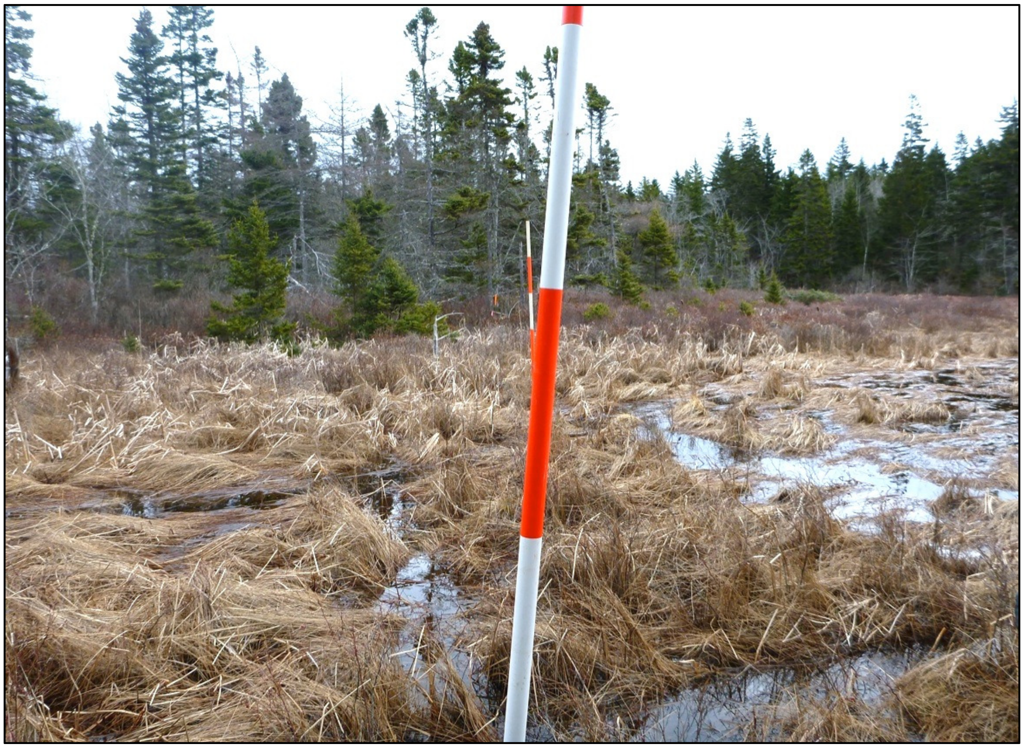

Figure 3 Transect five.

Figure 4 Upstream end of the culvert

Figure 5 Landscape photograph of MI taken from the causeway above the culvert looking (north) towards the back of the site. Note the amount of standing water on the site which was not present during the summer month.

STRUCTURED WALK PHOTOGRAPHS - MIR (select images):

Figure 6 Transect one. Note the ATV tracks in the foreground. Trail was not in use during summer months.

Figure 7 Transect three.

Figure 8 Transect five.

Figure 9 Downstream end of the culvert and tidal channel.

Figure 10 Landscape photograph of reference site taken from the causeway above the culvert looking (south) downstream towards the mouth of the estuary.