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

Post-Restoration Monitoring (Year 5) of the Lawrencetown Lake Salt Marsh Restoration Project

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Executive Summary

In the fall of 2006, the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR) began the process of restoring tidal flow and fish passage to a tidally restricted component of the Lawrencetown Lake tidal lake and salt marsh system. The earthworks component of the restoration project took place in November 2007 and involved the installation of an appropriately sized and placed culvert within the trail bed in order to restore a more natural tidal regime to the site. The primary goals of the Lawrencetown Lake Salt Marsh Restoration Project were to:

- Significantly reduce the tidal restriction caused by the Trans Canada Trail (former railway bed - causeway);
- Improve hydrological conditions within the study site;
- Improve fish passage to and within the wetland area as well as nutrient exchange;
- Improve wetland habitat conditions to increase the number of halophytic vegetation species and their abundance; and
- Re-establish a more typical low-mid-high marsh habitat zonation pattern as observed at the reference site.

CBWES Inc. was commissioned by NSTIR to develop and implement the pre- and post-restoration ecological monitoring component of the project. The feasibility and pre-restoration portion of the monitoring program was conducted in 2006, with additional baseline data collected in 2007 in advance of construction. The fifth year of post-restoration monitoring took place during the period of May 2012 through December 2012 with a structured winter site walk in February 2013. The purpose of the monitoring program, and this year's phase of it, was to:

- Document the efficacy of the compensation being undertaken to restore the Lawrencetown Lake salt marsh system;
- Determine the nature, extent and direction of change, in the physical, chemical and biological indicators being studied, as a result of the restoration activity; and
- Track 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 those of an adjacent reference site.

Data were collected for geospatial attributes, hydrology, soils and sediments, vegetation, nekton (fish) and benthic invertebrates at both the salt marsh restoration site (LT) and adjacent reference area (LT-R). The information collected will not only provide insight into the changes at the site as a result of the restoration activities, but will also contribute to our collective understanding of salt marsh ecology, and the effectiveness of restoration efforts in the region (Bowron et al. 2011a,c,d; Bowron et al. 2012a,b,c; Bowron et al. 2013a,b,c,d; Neatt et al. 2013; van Proosdij et al. 2010)[1]. The results for the fifth and final year of post-restoration monitoring are detailed in the following report and summarized below.

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[1] www.gov.ns.ca/tran/enviroservices/enviroSaltMarsh.asp

Geospatial Attributes:
The DEM for LT and LT-R was updated in 2012 to include the additional survey data collected. The statistics taken from the DEM for LT have a mean of 1.04 m with a range of 0.17 to 3.73 m and a standard deviation of 0.63. For LT-R the mean was 0.67 m with a range of 0.34 to 1.96 m and a standard deviation of 0.25. When comparing the DEM means for LT pre-restoration and Years 3 and 5, there were only slight differences. These changes overtime were well within the survey error (±10 cm). There were, however, changes at specific locations that have been occurring over the past few years post-restoration. The end of Line 2 has been consolidating and has been lengthening into the edge of the pond. Also of note was the elevation increase illustrated on Line 4, although this increase could be attributed to erosion of the adjacent drumlin more so than sediment deposition from tidal waters. A vegetation dominance map was constructed comparing 2007 (pre-restoration) to 2012 (post-restoration) vegetation. There were no large shifts in vegetation dominance at either site during the monitoring program. The most notable changes were found on Line 3 with a change from *Calamagrostis canadensis*/*Myrica gale* to *Juncus balticus* and on Line 2 with a change from *Agrostis stolonifera* to *Spartina alterniflora*.

Hydrology
Hydroperiod and Tidal Signal: Tide level data was collected from 24 May to 14 June 2012 in LT and Lawrencetown Lake. The maximum water level at LT during the 2012 data collection was 0.9 m (CGVD28) with a maximum of 1.0 m (CGVD28) at LT-R. The majority of LT would be covered on a mean tide (0.6 m: CGVD28). The area covered at LT by the maximum recorded tide in 2012 was 1.79 ha, which is less than the total restored area of 2.0 ha. The peak tide occurred in the lake before peak tide within LT 60% of the time during data collection and 24% of the time the peak tide occurred within LT first. This would be expected since there are times when tide waters do not drain completely out of the site; therefore, the peak within the site would occur sooner. Although the temporal delay could be large, the tide height differences are small (1 – 3 cm). The hypsometric curve for LT and LT-R (based on tide signal and DEM) illustrated the change of flow into LT with the addition of the new culvert. There was no change in the hypsometric curve in 2012.

Water Quality: The comparison of the 2007 (pre) and 2008 (post) data showed that there was little difference between the abiotic factors at LT and LT-R (lake), indicative of the elimination of the tidal restriction. This has been shown for each year post-restoration (2008 – 2012). Prior to restoration, the average salinity reported at LT-R was 15.7 ppt and 8.6 ppt at LT. The average salinity for all years post-restoration at LT-R was 25.5 ppt and 25.7 ppt at LT with the highest salinities found in 2010 and 2012. The trend of decreasing water temperature into the fall was apparent, particularly during sampling in years 2009 to 2011, with a subsequent increase in dissolved oxygen (DO) levels. This trend was not as apparent in year five data. The pH levels ranged from 7.0 to 8.2, all years post-restoration included, with the normal range of pH for seawater being 7.5 to 8.5.

Soils and Sediments
Pore Water Salinity: The 2012 mean salinity value for LT-R was 8.74 ppt with a range of 0.26 to 15.15 ppt and a standard deviation of 4.26. The 2012 mean salinity value for LT was 6.92 ppt with a range of 0.18 to 17.28 ppt and a standard deviation of 4.95. The lowest mean salinity

readings for LT were found at the sample stations along Line 1, with the highest mean salinities found at Line 4 and 5. Line 2-site LT_L2S3, situated on the edge of the pond in *Spartina alterniflora* dominated vegetation community, also showed a higher mean salinity than those stations on Line 1. In 2012, both LT-R and LT experienced a decrease in the frequency of lower salinity values (0-3.00 ppt range) compared to pre-restoration levels for shallow readings. There was also an increase in the frequency of the higher salinity values (12.10–16.00 ppt range) in 2012 for the shallow readings at both sites. For 2012 deep readings at LT the opposite trend was found, with an increase in frequency of the lower salinity readings (0-3.00 ppt), as well as an increase in frequency of the higher salinity values (16.10-18.00 ppt), which were not found at LT-R. No significant difference was found between years at LT ($t = 1.23$; $p = 0.22$). T-tests (95% CI) performed between LT-R and LT in 2012 showed no significant differences when shallow ($t = 0.99$; $p = 0.33$) and deep ($t = 1.06$; $p = 0.29$) readings were tested separately, nor when all readings ($t = 1.45$; $p = 0.15$) were tested together.

Sediment Accretion: Overall sediment accretion in 2012 was lower than in 2011, particularly at LT. The station that continued to have the highest rate of accretion (also the lowest organic matter and largest mean grain size) was LT_L4S2, likely from erosion of the adjacent drumlin. In 2009 and 2012, storm deposits, evidenced by discrete sediment layers overtopping vegetation, were found along the back of LT in an area which also experiences fine sediment deposits from the eroding drumlin. There were large storms in 2012, but the main impact of these storms has been heavy rain, whereas in the past, storms have brought over-wash material onto the sites from the adjacent road, beach and dune system.

Soil Characteristics: The water content was higher at LT-R than LT for all years. The water content increased at LT in Year 1, but the changes were within the range of natural variability. In 2010 (year 3), water content decreased compared to previous years (Year 1 and pre) and in 2012 most sampling locations recorded higher water content values than previous years. Organic matter at LT-R increased with distance from the lake for 2006, 2008 and 2010. In 2012, one of the low marsh stations had the highest organic matter values due to wrack deposits. Generally, the organic matter values at LT decreased at almost all stations post-restoration and were lower than LT-R. In 2012, values at almost all stations were greater than 2010 and pre-restoration. The bulk density values at LT-R were slightly higher in 2012 than previous years post-restoration, but still lower than pre-restoration values. At LT the bulk density values decreased in year one post-restoration, decreased further in Year 3 and then at five years (2012) have increased at a few stations. The highest values were at LT_L4S2 (near drumlin) and the lowest at LT_L2S2 (near panne). Pre-restoration LT and LT-R consisted mostly of silt and sand and in 2012, five years post-restoration, both sites have become medium to fine silt. In 2010 and 2012 there was an even distribution at LT of fine to medium silt. Small grain sizes and similarity to LT-R suggests deposition of suspended sediment from tidal flooding rather than storm or ice deposits.

Vegetation

Immediately following restoration at LT there was a decline in average plot species richness, followed by an increase over the longer term. This would suggest that species have been lost with the return of tidal influence and more salt tolerant species have colonized. LT-R had significantly more halophyte species pre-restoration compared to LT and in the last three years of post-restoration monitoring LT has become more similar to LT-R. The average halophyte abundances were initially lower at LT, but have been increasing towards LT-R numbers since 2010 (Year 3). The vegetation present at LT has been largely unchanged over the monitoring program. The plant community evidence for effects of the restoration of tidal flow was consistent; however, the overall effect seemed to be confined to a few plots. There were distinct differences in the overall species composition between the two sites. LT still contained more plots with upland or freshwater species, which were likely too high in elevation to be influenced by the increased tidal flow post-restoration.

Nekton

Twenty different nekton species were encountered during the monitoring program. LT-R had a greater species diversity (9-12 species) compared to LT (6-8 species) every year during the seven years of monitoring. LT-R also had a greater total catch than LT for all years except 2009 (year 2) and 2012 (year 5). However, the total catch average for the post-restoration monitoring program at LT-R was 766 and at LT 687. Over the five years of post-restoration monitoring, the dominant species caught at LT has been a combination of Mummichogs (*Fundulus heteroclitus*), Atlantic silversides (*Menidia menidia*), and Three-spine sticklebacks (*Gasterosteus aculeatus*). This was similar to LT-R, although crabs, mainly *Carcinus maenas* (green crab), were also dominant at this site in 2009 and 2011. For the seven years of pre- and post-restoration monitoring, the relative abundance average for the minnow traps was similar at LT (23.41) and LT-R (24.76), with a similar sample size. This illustrates the fish habitat value of LT, especially considering its small size compared to other restoration sites being monitored in the region. Although the methods used for LT-R and LT differed, the standard length average showed that juveniles and adults were represented at both sites.

Benthic and Aquatic Invertebrates

Benthic Invertebrates: In 2012, the benthic samples at LT had 14 species, compared to 16 species at LT-R, typically consisting of marine/estuarine species. Mean species richness for the samples from LT was higher in all years post-restoration compared to pre-restoration. There was no clear trend for species richness when LT and LT-R (panne and lake samples separated) were compared over time. In 2012, LT had the highest abundance for all years pre- and post-restoration. It appeared that abundance was increasing each year post-restoration at LT, but 2011 saw a very low abundance of species. The baseline condition at LT was mostly Diptera species and *Hydrobia totteni*. Through all years post-restoration *Hydrobia totteni* continued to be present, but there was also C*orophium insidiosum*, *Garmmarus*, Ostracoda, other Diptera species and Oligochaeta. LT-R was mostly Diptera and *Hydrobia totteni* species similar to LT. The species found in the LT Ekman samples over the five years of post-monitoring more closely resembled that of the LT-R panne samples.

Aquatic Invertebrates: In 2012, the activity trap samples at LT had 12 species, typically a mix of estuarine and freshwater-associated, compared to 12 species at LT-R. For all years post-restoration, LT had a higher species richness compared to the baseline condition. Most years the mean species richness was higher at LT, except for 2012. Mean abundance pre-restoration and year one values were highest at LT compared to other years post-restoration. Generally, for all years post-restoration, LT-R had higher mean species abundance, especially during Year 5. At LT-R, over the duration of the monitoring program, samples mainly contained Corixidae and *Gammarus mucronatus*. At LT, baseline and Year 1 saw greater numbers of Corixidae and

Gammarus species, although *Gammarus* species were still present most years post-restoration. After Year 1 post-restoration, other species emerged such as Ostracoda and Copepoda (larger numbers) and *Hydrobia totteni*, as well as Corixidae larvae.

Summary:

The 2012/13 field season was the fifth and final year of post-restoration monitoring required for the Lawrencetown Lake Salt Marsh Restoration Project.

The installation of a more appropriately sized and placed culvert in 2007 has resulted in a more natural hydrological regime in the LT system, restoring 2.0 ha of tidal wetland area. The observed changes over the five years of post-restoration monitoring included improved water quality and pore water regime, expansion of halophytic vegetation and improved fish passage and usage. These changes were positive responses to the intervention at LT and were not observed at LT-R.

While it is difficult to predict how successful this restoration will be in the long term, it is clear that the major objectives (significantly reduce the tidal restriction caused by the Trans Canada Trail (former railway bed); re-establishment of a more natural hydrological regime to the site; improve fish passage; increase the extent, distribution and abundance of halophytic vegetation) were achieved. Although there are still differences in the habitat zonation pattern between LT and LT-R, the restoration activities undertaken at LT in 2007 have resulted in the restoration of a self-sustaining and resilient salt marsh and tidal wetland system.

Acknowledgments

We would like to extend our thanks to Dr. Bob Pett (Nova Scotia Department of Transportation and Infrastructure Renewal), Dr. Danika van Proosdij (Saint Mary's University - SMU) and Dr. Jeremy Lundholm (SMU) who have been and continue to be strong supporters of CBWES and partners on this project.

We wish to also thank Greg Baker (Maritime Provinces Spatial Analysis Research Centre (MP_SpARC - SMU), Emma Poirier (In_CoaST-SMU) and Envirosphere Consultants Limited for their assistance with sample processing and analysis this year.

This project would not have been possible without the support of the adjacent property owners who gave their consent to allow this project to move forward and for us to access the areas within and surrounding the restoration site, as well as the Nova Scotia Department of Natural Resources and the Cole Harbour Parks and Trails Association for the use of the trail.

Financial and in-kind supporters of this project include: Nova Scotia Department of Transportation and Infrastructure Renewal; Fisheries and Oceans Canada; Saint Mary's University (MP_SpARC; In_CoaST; Community-Based Environmental Monitoring Network); Nature Sciences and Engineering Research Council of Canada (NSERC); Nova Scotia Department of Economic and Rural Development; Human Resources and Skills Development Canada.

1.0 Introduction

The Lawrencetown Lake salt marsh restoration site was originally identified as a potential restoration project by T. Bowron in 2004 during an inventory of tidally restricted coastal wetland systems conducted in the area in collaboration with Nova Scotia Transportation and Infrastructure Renewal (NSTIR). The site was approved by Fisheries and Oceans Canada (DFO) as a fish habitat compensation (restoration) project in 2006.

The restoration of tidal flow, and ultimately of salt marsh habitat, to this site fulfills a compensation requirement (like-for-like estuarine habitat) noted in NSTIR's Harmful Alteration Disruption or Destruction (HADD) Compensation Proposal and Fisheries Act-Section 35(2) HADD Authorization for the Lawrencetown Lake Bridge Replacement Project. Restoration activities consisted of the installation of an appropriately sized and placed culvert in the trail bed, and the implementation of a pre- and post-restoration monitoring program in order to ensure and document project success. The new culvert was installed by NSTIR during the period of 1-6 November 2007.

The monitoring program that was utilized for this project, and a requirement of the HADD Authorization, was adapted from the monitoring programs employed as part of the Cheverie Creek and Walton River Restoration Projects (Bowron et al. 2011a; Bowron et al. 2013a; Neatt et al. 2013; van Proosdij et al. 2010; and based on the set of regional (GPAC) protocols developed for use as part of tidal wetland restoration projects in the Gulf of Maine and Bay of Fundy (Neckles and Dionne 2000; Neckles et al. 2002). Key elements of the program were developed in association with DFO staff and researchers at Saint Mary's University (SMU). The feasibility and baseline ecological studies were conducted over the 2006 (November – December) and 2007 (June – November) field seasons, and the five years of post-restoration monitoring was conducted between 2008 (Year 1) and 2012 (Year 5).

All aspects of the feasibility and pre- and post-restoration monitoring for this project were conducted and supervised by CBWES Inc., under contract to NSTIR. The 2012 field and laboratory work was carried out by: Tony M. Bowron, Nancy C. Neatt, Jennie M. Graham, Ben Lemieux, Amy Lawrence, Christa Skinner and Michelle Whidden (CBWES Inc.); Greg Baker (MP_SpARC), Brenden Blotnicky (In_CoaST), Dr. Jeremy Lundholm, and Dr. Danika van Proosdij (SMU); and Patrick Stewart and Heather Levy (Envirosphere Consultants Ltd.).

1.1 CBWES Inc.

Since 2005, CBWES has been involved in the feasibility, design, restoration and monitoring of ten salt marsh restoration projects in NS in collaboration with NSTIR[2]. 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

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[2] Cheverie Creek, Walton River, Lawrencetown Lake, Smith Gut, St. Croix River, Cogmagun River, Antigonish Landing (collaboration with CBCL Ltd.), Three Fathom Harbour, Tennycape and Morris Island (Bowron et al. 2011a,c,d; Bowron et al. 2012a,b,c; Bowron et al. 2013a,b,c,d; 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)

conferences[3]. Please contact CBWES for more information on these presentations. CBWES is committed to continuing to participate in important events such as these in order to share our experience and to stay well-informed of current trends, techniques and the science of wetlands and restoration.

CBWES has a strong research partnership with SMU. Through this partnership, a number of undergraduate and graduate level research projects involving the restoration project sites have been supported. As a recognized Industrial Partner with the Natural Sciences and Engineering Research Council of Canada (NSERC), CBWES Inc. received NSERC grants for four of these projects. In 2009, an Industrial Undergraduate Student Research Award (IUSRA) enabled CBWES to hire a SMU undergraduate student to conduct a research project titled “The influence of soil seed bank on the colonization and restoration of a macro-tidal marsh”. The resulting undergraduate thesis is available from the SMU library (Lemieux 2012). In 2010, CBWES secured two two-year NSERC Industrial Postgraduate Scholarships to support post-graduate student research projects that examined how surface morphology contributes to vegetative re-colonization following restoration, and developed GIS-based tools for use in the creation of hydraulic networks in salt marsh restoration projects. A second IUSRA was received in 2011 to support a project exploring the influence of tidal creek networks on wetland vegetation colonization in a macro-tidal system. Summaries of these salt marsh restoration research projects, as well as the non-NSERC funded current and completed projects are provided in Appendix A.

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. 2011a) 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 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 and Burdick 2012). Presently, work is proceeding on additional peer-reviewed publications to continue to share the lessons learned from these projects.

1.2 Purpose and Rationale of 2012 Study

The purpose of the 2012 post-restoration monitoring of this project was to conduct the fifth and final year of the post-restoration monitoring program for the Lawrencetown Lake Salt Marsh

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[3] BoFEP’s 9th Bay of Fundy Science Workshop (BoFEP 2011); Coastal and Estuarine Research Federation’s 21st International Conference (CERF 2011); Restore America’s Estuaries 5th National Conference on Coastal and Estuarine Habitat Restoration (RAE 2010); Atlantic Reclamation Conference (ARC 2008; 2009, 2010); Coastal and Estuarine Research Federation’s 2009 International Conference (CERF 2009); BoFEP’s 8th Bay of Fundy Science Workshop (BoFEP 2009); Maritime Water Resources Symposium (CWRA 2008); Atlantic Canada Coastal and Estuarine Science Societies’ 2008 conference (ACCESS 2008); Estuarine Research Federations’ 2007 International Conference (ERF 2007); Canadian Land Reclamation Associations National Conference (CLRA 2007, 2012); Ecology Action Centre’s “Six Years in the Mud – Restoring Maritime Salt Marshes: Lessons Learned and Moving Forward” workshop (EAC 2007).

Restoration Project. The intent of this program was to document and determine the nature of the changes at the restoration site (LT) in response to the restoration activities and the return of salt marsh features and functions (re-activation of the central pond; fish access to the marsh surface; establishment and expansion of halophytic vegetation) and the re-establishment of a self-sustaining system over time.

In order to document the restoration trajectory and determine project success (restored marsh exhibits similar physical, chemical and biological characteristics as the reference site), a suite of ecological indicators representative of the structure, function and composition of natural salt marshes were monitored. The suite of indicators were drawn primarily from a tidal wetland restoration monitoring protocol for assessment of tidal restoration of salt marshes in the Gulf of Maine and Bay of Fundy, and included hydrology, soils and sediments, vegetation, fish, and invertebrates (Neckles and Dionne 2000; Neckles et al. 2002; Weldon et al. 2005). The changes in physical, chemical and biological indicators over time (following construction) were tracked against the conditions exhibited by the site prior to construction and those of the adjacent reference site (LT-R) in order to determine restoration success.

1.3 Structure of Report

The focus of this report was to describe the 2012 monitoring activities, concluding the process of comparing the post-restoration habitat conditions to the conditions that were present prior to culvert replacement and to those exhibited by the reference site, and to summarize the changes that have occurred over the past five years at LT.

Information on LT and LT-R is provided in Chapter 2. An overview of the monitoring program and the parameter specific sampling techniques are given for each indicator category in Chapter 3. The results of the fifth year of post-restoration data collection and analysis, along with a discussion of these results are presented in Chapter 4. Chapter 5 is a summary and integration of the results and the implications of these findings for project progression. Chapter 6 contains any remaining recommendations for LT moving forward. Appendices in the 2012 report provide: (A) CBWES supported student research project descriptions; and (B) photographic documentation of 2012/13 winter conditions.

2.0 Description of Restoration and Reference Sites

2.1 Lawrencetown Lake Restoration Site (LT)

Located along NS Route 207 (Marine Drive) in Lawrencetown (Halifax County), the restoration site is part of the Lawrencetown Lake tidal wetland system (Figure 1). Adjacent to the restoration site (west) is a drumlin, on which there is a gravel quarry, and to the south of Route 207 is a beach and dune system (Figure 1). This site was originally identified as a potential salt marsh restoration project by T. Bowron in 2004 during an inventory of tidal restricted coastal wetland systems conducted in the area in collaboration with NSTIR.

LT is a 26,354 m^2 (6.51 acres, 2.6 ha) salt marsh that was significantly restricted (tidal flow and fish passage) from the greater Lawrencetown Lake tidal system by the presence of the Trans Canada Trail (former bed – causeway of the Musquodoboit Railway built in 1912-1914[4]) (Figure 1 to Figure 9). A misplaced and undersized concrete culvert is located at the north end of the system (Figure 12) and was the only location for tidal water to enter the site prior to restoration. Restoration construction, which consisted of the installation of an appropriately sized and placed culvert in the trail bed (Figure 12), took place in November 2007 and re-established a larger more direct connection between LT and the broader Lawrencetown Lake system (Figure 6 and Figure 7).

Prior to restoration, salt marsh plant species (*Spartina alterniflora*, *S. patens*) and freshwater/brackish (*Calamagrostis canadensis, Juncus balticus*) were found at the site, but to a limited extent. This site has seen an increase in halophytic species and is currently a mixture of freshwater and salt marsh species. Various species of waterfowl and coastal bird species (Great Blue Heron, Willet (breeding), Egret, American black duck (breeding) and Greater Yellowlegs) have been frequently observed at this site and adjacent salt marsh during the monitoring program.

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[4] http://www.rocarchives.com/Articles/Othen-MusquodoboitRailway.htm

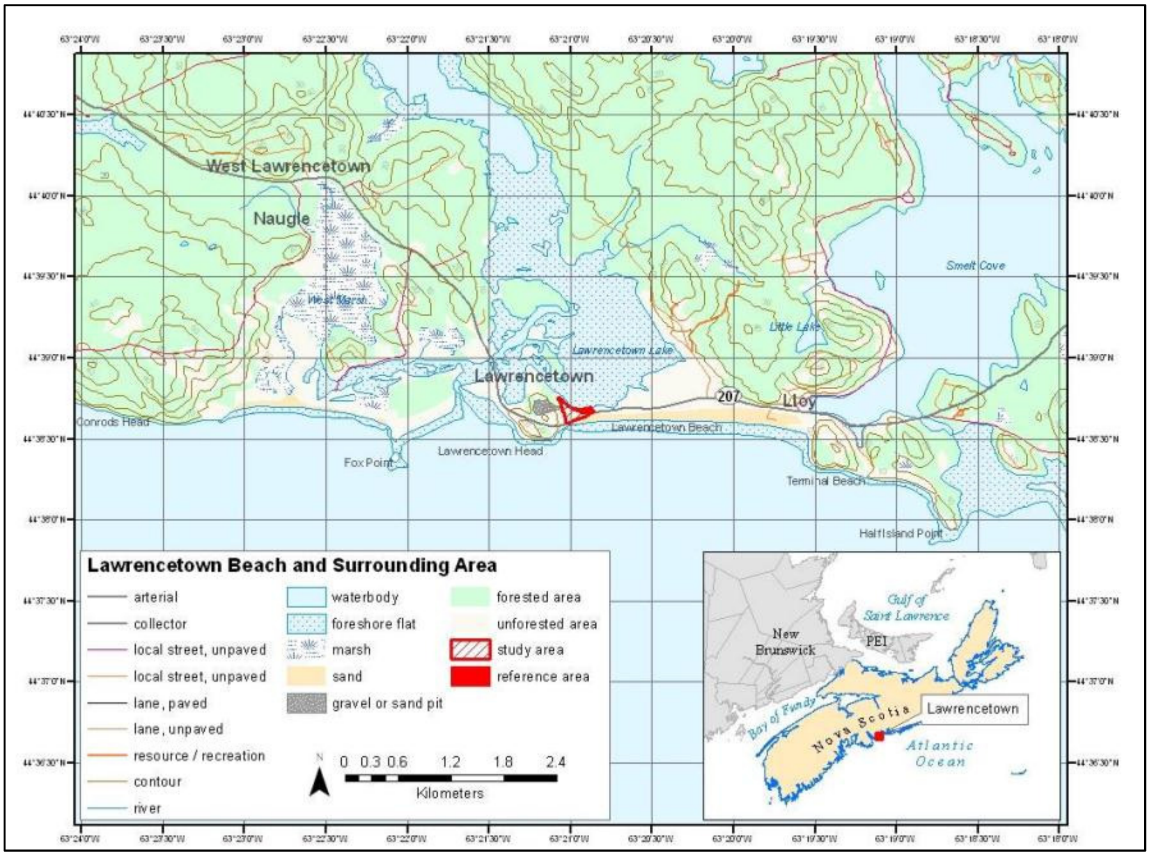

Figure 1 Location of Lawrencetown Lake restoration and reference sites, Halifax County, NS**.**

Figure 2 Aerial photograph (2002; 1:10,000) of Lawrencetown Lake restoration site (indicated by black box).

Figure 3 Low-altitude aerial photograph of LT. Photograph taken by CBWES Inc., November 2010.

Figure 4 LT from trail during a high tide. Photograph by N. Neatt, August 2011.

Figure 5 LT from the road during a spring high tide on 21 December 2010. Photograph by T. Bowron.

Figure 6 Downstream (lake side) end of the new culvert installed in the Trans Canada Trail to reconnect LT to the greater Lawrencetown Lake tidal system. Photograph by T. Bowron 2007.

Figure 7 Upstream (LT side) end of the new culvert. Photograph by T. Bowron 2007.

Figure 8 Change along the upland near Line 3 at LT: A) area in November immediately post-restoration and B) area in August 2012, five years post-restoration. Photograph by CBWES Inc.

Figure 9 Upstream (A) and downstream (B) ends of the original concrete culvert at LT. Photograph by CBWES Inc. 2006.

2.2 Lawrencetown Lake Reference Site (LT-R)

The reference site, located east of the LT site on the lake side of the Trans Canada Trail, is an 8,305 m^2 (2.0 acres; 0.8 ha) (Figure 10) salt marsh. This marsh is part of the tidal marsh system that extends around much of the perimeter of the Lawrencetown Lake tidal system. The restoration site was part of that tidal marsh complex prior to the construction of the rail line (Figure 11). LT-R follows a typical zonation expected of a salt marsh with low, mid and high marsh zones and has an extensive panne system. Salt marsh plant species found at this site include *S. alterniflora*, *S. patens*, and *Carex paleacea*. Waterfowl (adult and ducklings) and breeding Willets have been observed at this site as well as Herons and Egrets.

Figure 10 Low-altitude aerial photograph of LT-R. Photograph by CBWES Inc., November 2010.

Figure 11 LT-R from the trail during a storm high tide event. Photograph by N. Neatt, 9 August 2011.

3.0 Monitoring Program and Methods

3.1 Monitoring Program

CBWES was commissioned by NSTIR to develop a monitoring program to document the changing habitat conditions following the installation of the new culvert at LT in order to evaluate the impacts of restored tidal flow, and to determine the ecological benefits of restoration. The program being used for this project is similar to the one used on the Cheverie Creek and Walton River Salt Marsh Restoration Projects (Bowron et al. 2011a; Bowron et al. 2013a; Neatt et al. 2013; van Proosdij et al. 2010). It makes use of a suite of salt marsh indicators and data collection methods, tailored to the project site, that characterize salt marsh ecosystem components. These indicators (geospatial attributes, hydrology, soils and sediments, vegetation, fish and invertebrates) are measures of wetland structure that when applied pre- and post-restoration, collectively provide fundamental information on ecosystem condition and response to intervention. Each indicator category contains a set of core and additional indicators and associated data collection methods. A complete list of indicators and data collection methodology used is provided in Table 1.

Table 1 The Lawrencetown Lake salt marsh restoration monitoring program, including core and additional ecological indicators, methodologies, and sampling frequency (X - completed sampling event at both sites).

Category	Parameters	Sampling Method	Annual Sampling Frequency	Pre (2006/07)	Post-Restoration (2008-2012)				
					1	2	3	4	5
Hydrology	Tidal Signal	Continuous (5 minute intervals) water level recorders (Solinst Levelogger: Model 3001)	29/09/06 – 11/10/06; 21/10/08 – 14/11/08; 02/12/10 – 22/12/10; 23/05/12 – 14/06/12	X	X		X		X
	Water Quality	YSI 650 MDS and YSI 556 MPS pH Handheld Dissolved Oxygen Instruments	11/06; 06/07; 10/07; 11/07; 7/08; 10/08; 07/09; 09/09; 10/09; 9/10, 10/10; 07/11, 10/11; 06/12, 09/12	X	X	X	X	X	X
Soils & Sediments	Marsh Surface Elevation	Digital elevation model (DEM). Total Station (TS); Differential GPS (DGPS); Trimble R8 GNSS RTK (RTK)	Once per required sampling year.	X	X		X		X
	Pore Water Salinity	Sipper; Refractometer; FieldScout EC 110 Meter	LT & LT-R: 11/06; 6/07 to 10/07; 7/08 to 10/08; 6/09 to 09/09; 07/10 to 09/10; 06/11 to 09/11; 06/12 to 09/12	X	X	X	X	X	X
	Sediment Accretion	Marker horizons sampled using a cryogenic corer (Cahoon et al., 1996).	LT: 6 MH, 09/08; 10/09; 11/10 LT-R: 7 MH, 09/08; 10/09; 11/10; 12/11; 08/12	Installed	X	X	X	X	X
	Sediment Characteristics (bulk density, organic matter content, sediment type)	Sediment cores (soil samples): Paired samples: (30 ml cut syringe w/ 5 cm x 15 cm core).	LT: 8 paired samples LT-R: 6 paired samples 11/06; 8/08; 8/10; 07/12	X	X		X		X
Vegetation	Composition Abundance Height	Point Intercept method (1 m^2 plots)	LT: 15 plots; LT-R: 21 plots Annually 11/06; 8/07; 8/08; 8/09; 8/10; 8/11; 07/12	X	X	X	X	X	X
	Habitat Map	Aerial photograph, DGPS, TS, RTK, Low-altitude aerial photography (blimp)	Elevation survey – 20&22/11/10; 12/11/12 Blimp – 15/10/10	X	X		X		X
Nekton	Composition Species richness Density Length	Minnow traps in pannes and Lake (small fish); beach seine (30 m x 1 m; 6 mm mesh) and fyke net (30 m x 1 m; 6 mm mesh) on marsh surface (all sizes). All sites on Spring tide.	LT & LT-R: 23/11/06; 24/11/06; 14/06/07; 1/10/07; 30/10/07; 23/07/08; 21/10/08; 27/07/09; 24/09/09; 21/10/09; 30/06/10, 13/09/10, 12/10/10; 06/07/11, 31/10/11; 22/06/12, 14/09/12	X	X	X	X	X	X

Category	Parameters	Sampling Method	Annual Sampling Frequency	Pre (2006/07)	Post-Restoration (2008-2012)				
					1	2	3	4	5
Benthic & Other Aquatic Invertebrates	Abundance and species richness (benthic)	Ekman Dredge (bulk samples)	LT & LT-R: 4 samples each 23/11/07; 18/10/07; 23/09/08; 31/08/09; 21/09/10; 23/09/11; 29/08/12	X (07)	X	X	X	X	X
	Abundance and species richness (aquatic)	Invertebrate Activity Traps (IAT) –set for 24 hours over a neap tide.	LT & LT-R: 2 traps each 10-11/08/07; 11-12/07/08; 15-16/07/09; 27-28/08/09; 23-24/07/10, 23-24/08/10; 11-12/07/11, 12-13/08/11; 12-13/07/12, 10-11/08/12	X (07)	X	X	X	X	X
Winter Conditions	Ice/snow conditions	Structured winter walk; photographs along each transect	Once per year: 08/01/08; 30/01/09; 09/03/10; 09/03/11; 7/3/12; 06/02/13	X	X	X	X	X	X

3.2 Methods

Sampling was conducted at both the restoration and reference site using transects (Lines) established in a non-biased, systematic sampling design. Five Lines, 50 m apart and running perpendicular to the trail bed, were established at the restoration site (Figure 12). Lines extend from the terrestrial edge of the restoration site to the trail bed along a compass bearing of 80° in order to produce straight, reproducible Lines. Four Lines, using the NS Power/Telephone Poles as upland markers and running perpendicular to the lake, were established at the reference site along a compass bearing of 170° (Figure 12). The first two Lines at LT-R were 22 m apart, while the remaining Lines were 50 m apart. A combination of 100 m field tape, compass and Leica TCR-705 Total Station[5] were used to produce straight, reproducible Lines. Data collection was conducted at sampling stations established at equal intervals along the lines at each site.

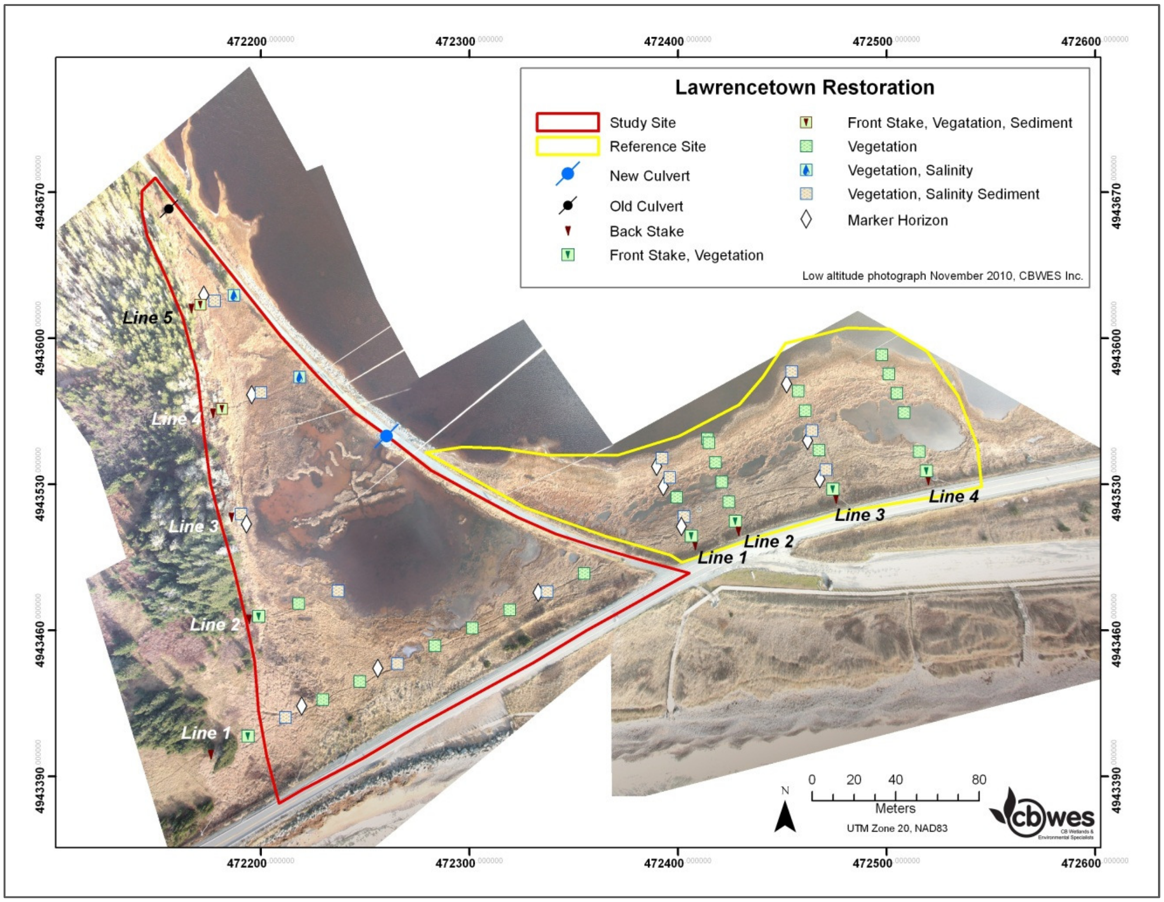

Figure 12 Location of transects and main sampling stations at LT and LT-R.

3.2.1 Geospatial Attributes

Digital Elevation Model (DEM) and Habitat Map

The DEM for a site contributes to an estimate of restorable area, inundation extent and duration, and assists in tracking changes in elevation along surveyed transects. The habitat map provides a foundation for the monitoring activities and a baseline against which changes in habitat

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[5] www.leica-geosystems.com/corporate/en/lgs_405.htm

conditions post-restoration can be compared. The habitat maps and DEMs for LT and LT-R were developed and improved during the monitoring program as conditions at the respective sites changed and additional mapping activities were undertaken. The original DEM and baseline habitat map for LT and LT-R were produced using survey data collected in 2006/2007, as well as contour and spot elevations obtained from the Nova Scotia Topographic Database (NSTDB) 1:10000 series (Bowron et al. 2008). DEM's were created using the "Topo to Raster" command in ArcGIS 10.1[6] which uses an iterative finite difference interpolation technique to produce a hydrologically correct DEM. They were updated in 2010 (Year 3) with the addition of new data using a Trimble R8 GNSS RTK surveying system and low-altitude aerial photography as described in Bowron et al. (2011b). Five years post-restoration the DEM and habitat map for each site was updated with new data gathered with the Trimble R8 GNSS RTK surveying system, however, no aerial photographs were taken in 2012. Helium shortages and technical difficulties with other formats prevented a successful aerial photograph deployment at the sites.

3.2.2 Hydrology

The fundamental control on the structure and function of salt marsh habitat is flooding with salt water (Mitsch and Gosselink 2007; 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. Surface water quality (temperature, salinity, dissolved oxygen, and pH), typically sampled concurrently with fish and aquatic invertebrate sampling, can 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) for LT and LT-R (lake) were modeled using the tidal signal data (pattern of water level change with reference to a fixed point) and DEMs for the two sites. The tidal signal at each site was measured using a set of Solinst Model 3001 Levelogger Golds[7] (water elevation and temperature) and a Solinst Barologger (atmospheric pressure and temperature).

The Leveloggers were installed within the central pond at LT and in the lake at LT-R using a pair of still wells in order to determine the tidal signal each site and to enable a comparison of tide levels (Figure 13). The Barologger collects atmospheric pressure and temperature data, which was required for post-processing of the Levelogger data. The instrument was installed in the upland above the restoration site to avoid submergence by water.

The Leveloggers were deployed on 23 May 2012 and retrieved 14 June 2012 to capture tide levels throughout at least one neap to spring tide cycle. The timing of data collection occurred earlier in the season than in previous years. The Leveloggers and Barologger were programmed to take measurements at five-minute intervals throughout the sampling period. The positions (elevation) of each of the units were surveyed using a Trimble R8 GNSS RTK surveying system.

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[6] http://resources.arcgis.com/en/home/

[7] www.solinst.com/Prod/3001/3001.html

Following retrieval, the data from the loggers were downloaded into the Solinst Software Version 3[8] for post-processing and analysis.

Using the tidal elevation information from the Leveloggers, a set of tide signal graphs were created in Microsoft Excel by creating line graphs, placing the date and time on the x-axis and tide height on the y-axis. The hypsometric curves for the LT and LT-R were created using the flood metrics extension in ArcGIS. The extension calculates the area of marsh flooded at a given tide height using a DEM provided by the user. In this case increments of 10 cm were used and a scatter plot was created in Excel with area on the x-axis and tide height on the y-axis. Inundation frequency (the percent of tides flooding a given sample station during the recording period) was calculated in excel by determining the number of tides equal to or greater than the stations elevation.

Figure 13 Solinst Levelogger (Model 3001) on the left and still well on the right. Photographs taken by N. Neatt, 2007.

Water Quality

A YSI 650 MDS Handheld Dissolved Oxygen Instrument[9] 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 minimum of two readings were taken per nekton sampling event within 30 minutes of peak tide (spring tide). Salinity readings were matched in time and location with beach seine sampling for nekton: 22 June and 14 September 2012. The YSI probe was submerged approximately at mid-depth in the vicinity of the nekton sample area.

3.2.3 Soils and Sediments

Monitoring pore water salinity, sediment accretion rates, sediment elevation and soil characteristics can provide insight into the processes controlling vegetation type, cover and productivity and the vertical growth of marsh following restoration (Neckles and Dionne 2000). Soil salinity (interstitial pore water salinity) is one of the main controls on the distribution and abundance of plant species in salt marshes (Niering and Warren 1980). Measuring pore water salinity throughout the growing season and in conjunction with depth to water table monitoring

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[8] www.solinst.com/Downloads/

[9] www.ysi.com

can help to explain changes in environmental conditions regulating plant growth, distribution and abundance and habitat responses to restoration activities.

Accretion of inorganic and organic material deposited onto the marsh surface by flood waters and vegetation is one of the main processes that allow marshes to build vertically over time, offsetting increased tidal flooding. Failure to keep pace with increased flooding could result in the loss of salt marsh features and functions important to fish (loss of productivity and extent of habitat). Monitoring sediment accretion rates, elevation and determining organic content of marsh soils, prior to engaging in restoration activities can provide an understanding of pre-restoration conditions on the marsh (subsidence due to oxidation of organic matter in sediments) and the process of recovery following restoration. Determining sediment accretion rates, sediment elevation and soil characteristics leads to a gain in knowledge of the processes controlling vegetation type, cover, and productivity and the vertical growth of the marsh following construction.

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.

During the 2007 to 2010 monitoring seasons, shallow and deep pore water samples were taken using a soil probe (sipper; Roman et al. 2001) and a handheld temperature compensated optical refractometer (nearest 2 ppt). For the 2011 and 2012 monitoring seasons a FieldScout EC 110 Meter, which uses electrical conductivity, was used to collect the data on pore water salinity (shallow and deep readings). Data was collected using both methods for at least one sampling event. Using the soil probe, measurements were formulated by sequentially inserting the probe into the soil to a depth of 15 cm and 45 cm, and drawing out a water sample. The water drawn into the tube and syringe was then expunged into a labeled (site name, sample station ID, sample depth) sample bottle. Sample bottles were then returned to the lab and allowed to rest for a 24 to 48 hour period, giving any suspended sediment and/or particulate matter time to settle out. Using a fresh syringe, a small water sample could then be taken from the individual bottles and tested for salinity using the optical refractometer. When using the FieldScout EC 110 Meter, measurements were taken *in situ*, and readings recorded in the field.

Pore water sampling was conducted monthly from June to September 2012 at both LT and LT-R. Sampling locations were matched with a subset of vegetation and sediment sampling stations (Figure 12). At each of the nine sampling stations at LT and six stations at LT-R, both a shallow and a deep pore water sample were taken.

For LT and LT-R, descriptive statistics (mean, range, and standard error) were calculated for shallow and deep samples. These values were used to create histograms to illustrate temporal patterns. In addition, t-tests were used to determine statistically significant changes in salinity, either spatially or over the course of the monitoring program. All t-tests were run at a 95% Confidence Interval ($p<0.05$) using Microsoft Excel software.

Sediment Accretion and Elevation

For larger salt marshes and marshes directly exposed to tidal influence (i.e., Cheverie Creek, Walton River, St. Croix River, and Cogmagun River), changes in marsh surface elevation and sediment accretion were monitored using a combination of Total Station survey (DEM), Rod Surface Elevation Tables (RSET) and marker horizons. Given the smaller size of LT, its location within the Lawrencetown Lake system and distance from the main tidal inlet, it was decided that only elevation surveys (completed with survey equipment) and marker horizons (accretion) would be used. Replication of the DEM, during years one, three and five of the post-restoration monitoring program, and annual marker horizon measurements, would provide sufficient insight into any changes in overall marsh surface elevation and accretion rates following restoration.

Seven marker horizons were established at locations throughout LT representing the habitat zones (low, mid, high marsh) (Figure 12) that were expected to develop post-restoration. Six markers were established at LT-R in zones representing low, mid and high marsh zones as determined by vegetation communities (Figure 12). The marker horizons were established according to the methods developed by Cahoon and Lynch (USGS 2005) in November 2006. Measurements were taken using a cryogenic corer (Figure 14) as described by Cahoon et al. (1996) on 23 November 2008, 23 October 2009, 22 November 2010, 6 December 2011 and 29 August 2012.

Figure 14 Marker horizon sampling with the cryogenic corer (with stainless steel tubing and copper "bullet") at LT-R. Photograph by B. Lemieux, December 2011.

Figure 15 Core or "marsh-cicle" on copper bullet showing feldspar clay. Top of the core is on the left. Photograph by C. Skinner.

Analysis

Dr. Danika van Proosdij (SMU) conducted the sediment elevation and accretion analysis and prepared the results and discussion presented in Section 4.3.

Soil Characteristics

Marsh soil characteristics are determined by the sediment source and tidal current patterns (Mitsch and Gosselink 2007). 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 2007). Sediment type and particle size greatly influences soil aeration and drainage (Packham and Willis 1997). Silt, clay and sand are the different soil textures typical of salt marshes. Silt and clay materials tend to retain more salt than sand, and clay is the most absorptive (Mitsch and Gosselink 2007). Clay and silt are expected to dominate high marsh soils, while the low marsh is expected to have a higher proportion of sand (Packham and Willis 1997).

Field Methods

Soil samples were collected on 31 August 2012 at both LT and LT-R. Samples were taken at eight locations at LT and six locations at LT-R (Figure 12). Sampling locations were chosen to represent the different target habitat zones (low, mid, high marsh) at the two sites and were matched with vegetation and pore water salinity sampling stations.

At each sampling station two sediment samples (cores) were taken. A small (30 ml) sample was taken using a 60 ml plastic syringe (1" diameter) (with the end cut off) and a larger sample taken with a metal tube (4" long and 1½ " diameter). Samples were taken by pressing the syringe into the soil to the 30 ml depth and removed by cutting around the syringe with a knife and lifting out with a metal trowel. The metal tubes were pressed into the ground until the top of the tube was level with the marsh surface and removed using a knife and trowel.

The syringes were placed individually into re-sealable plastic storage bags, sealed, labeled and transported in a cooler with ice back to the lab where they were placed in a freezer and frozen.

Some soil compaction did occur during the coring process, but every attempt was made to avoid further compaction of the samples during transport and storage prior to freezing. The metal tubes were capped on both ends using plastic caps and immediately labeled. Some compaction did occur during the sampling process but no further compaction/disruption should have occurred prior to the samples freezing. All cores were carefully labeled and sealed using duct tape.

Laboratory Methods

For the 2007 and 2008 monitoring years, cores were processed at the In_CoaST research lab for bulk density, water and organic matter content and at the Coastal Wetlands Centre at Mount Allison University for grain size analyses using a Coulter Laser instrument. The 2010 and 2012 cores were analyzed within the In_CoaST research lab using a Coulter Multisizer 3^{tm} which is based on electrical resistance and is more accurate for the analysis of fine sediments (McCave et al. 2006). Grain size statistics were derived using Gradistat (Blott and Pye 2001).

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/ml) = net dry weight (g) / volume (ml)

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

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

Sediment Type:

Sediment size (using laser diffraction):

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

Sediment size (using Coulter Laser Multisizer)

The grain size sample was dried at 65°C to prevent fusing of clays and crushed using a mortar and pestle. A small subsample were 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 electrolyte 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 organic matter content, water content and bulk density analysis and prepared the results and discussion presented in Section 4.3.

3.2.4 Vegetation

Plants are the primary food source in salt marshes, with the majority of plant material consumed as detritus (dead plant material) by decomposers and invertebrate consumers. It is through the production and export of plant material that salt marshes help to sustain commercial and non-commercial fish species by forming the base of the coastal food web. 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 the salt marsh, along with the physical conditions (hydrology, geology and chemical) that create the template for self-sustaining salt marshes and which enable the biological components of the broader ecosystem (invertebrates, fish, birds and animals) to benefit from these habitats.

Field Methods

Vegetation was sampled within LT and LT-R using 1 m^2 plots positioned at intervals along each Line on 29 July 2012 (Figure 12). The first vegetation plot of each Line was located at the front stake, with subsequent plots positioned at 10 m intervals. LT Line 1 was an exception to this set-up with vegetation plots at 20 m intervals given the length of this Line. There was a front stake plot at LT Line 3, and only three plots on Line 2, due to the location of the large central panne. Sampling stations were marked with bamboo stakes and flagging tape and digitally mapped using the Total Station. This arrangement of Lines and sampling stations yielded a total of 21 plots for LT-R and 15 plots for LT.

Sampling at each plot was conducted using a modified version of the point intercept method (Roman et al. 2001; Roman et al. 2002). Plots consisted of a 1 m^2 quadrat, offset 1 m to the left of the Line (facing the lake) and orientated towards the upland end of the Line. The 1 m^2 quadrat was divided into a grid of 25 squares (20 cm x 20 cm) and each intersection was used as a sampling point giving 25 intercept points. All plant species present in the quadrat were recorded. Samples of each species encountered during the survey were collected to confirm the identification. A 3 mm x 750 mm wooden dowel was lowered vertically through the vegetation to the ground at each intercept. All species that touched the rod were recorded as a hit for that point and the process was repeated for all 25 points. Categories other than plants, such as water, bare ground, rock or debris was also recorded if hit by the dowel. Photographs were taken along each Line from the front stake, as well as close-ups of each vegetation plot.

Statistical Analysis

Plant species richness, halophytic species and abundance, and unvegetated area in 1 m^2 plots were compared between LT and LT-R across seven years (2006-2012) using repeated measures ANOVA. Halophytic species abundance was estimated as the total number of contact points by halophytic species per plot. Because the total number of hits was counted, this can result in a halophytic abundance of greater than 25 (the number of points sampled in each quadrat) when more than one halophytic species were present in the plot. The species encountered at these sites that were classified as halophytes are: *Atriplex glabrisculata*, *Cakile edulenta*, *Carex paleacea*, *Juncus gerardii*, *Limonium nashii*, *Plantago maritima*, *Potentilla anserina*, *Ruppia maritima*, *Salicornia europea*, *Spartina alterniflora*, *S. patens, Spergularia canadensis, Sueda maritima* and *Triglochin maritima*. Non-metric multidimensional scaling ordination was used to compare species composition and abundance between plots. Differences in overall vegetation composition and species abundance were assessed using non-parametric multivariate ANOVA. In order to confirm patterns detected in whole-site analyses and to identify any changes not picked up in the other analyses, species composition in individual plots at the restoration site were compared over the seven years.

The vegetation data was analyzed by Dr. Jeremy Lundholm (SMU) and the results and discussion are presented in Section 4.4.

3.2.5 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).

Nekton (fish) sampling was conducted in the salt pannes and lake edge of LT-R and within the large (now tidal) central panne at LT to examine the fish assemblage accessing the marsh and the potential for secondary production (Figure 16). Surveys were carried out on the 22 June, and 14 September 2012, using a combination of minnow traps, beach seine and fyke net (Figure 17 and Figure 18).

Minnow traps were baited with bread, anchored to the marsh surface (5 m length of rope tied to a wooden stake) and set by tossing the trap into the panne or channel. Minnow traps were set in advance of high tide and allowed to fish over the high tide period (approximately three hours).

Sampling with the beach seine (30 m x 1 m; 6 mm mesh size) was conducted according to the methodology developed and used by the Community Aquatic Monitoring Project (CAMP; Weldon et al. 2005). This method allowed for the sampling of an area approximately 225 m^2 per draw, achieved by walking the beach seine out 15 m perpendicular to the shore, then 15 m parallel to the shore and then returning the entire net to the shore. Fish sampling with the beach seine was limited to LT-R due to the hydrological conditions and unconsolidated nature of the substrate within LT.

The fyke net design and [modified] sampling methodology used for this monitoring program was developed by estuarine researchers at the Wells Estuarine Research Reserve in Wells, Maine (Dionne et al. 1999). The inclusion of the fyke net allowed fish sampling to occur over the full high tide cycle (not just the peak) within the restoration site, which was not accessible to the established sampling method. The fyke net was deployed at the desired location on the marsh surface in the pond area of LT, at low tide and in advance of the same spring tide event as beach seine and minnow trap sampling were conducted.

All captured nekton 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 individuals per species), and measured for length (15 individuals per species). All nekton were then returned to the site of capture.

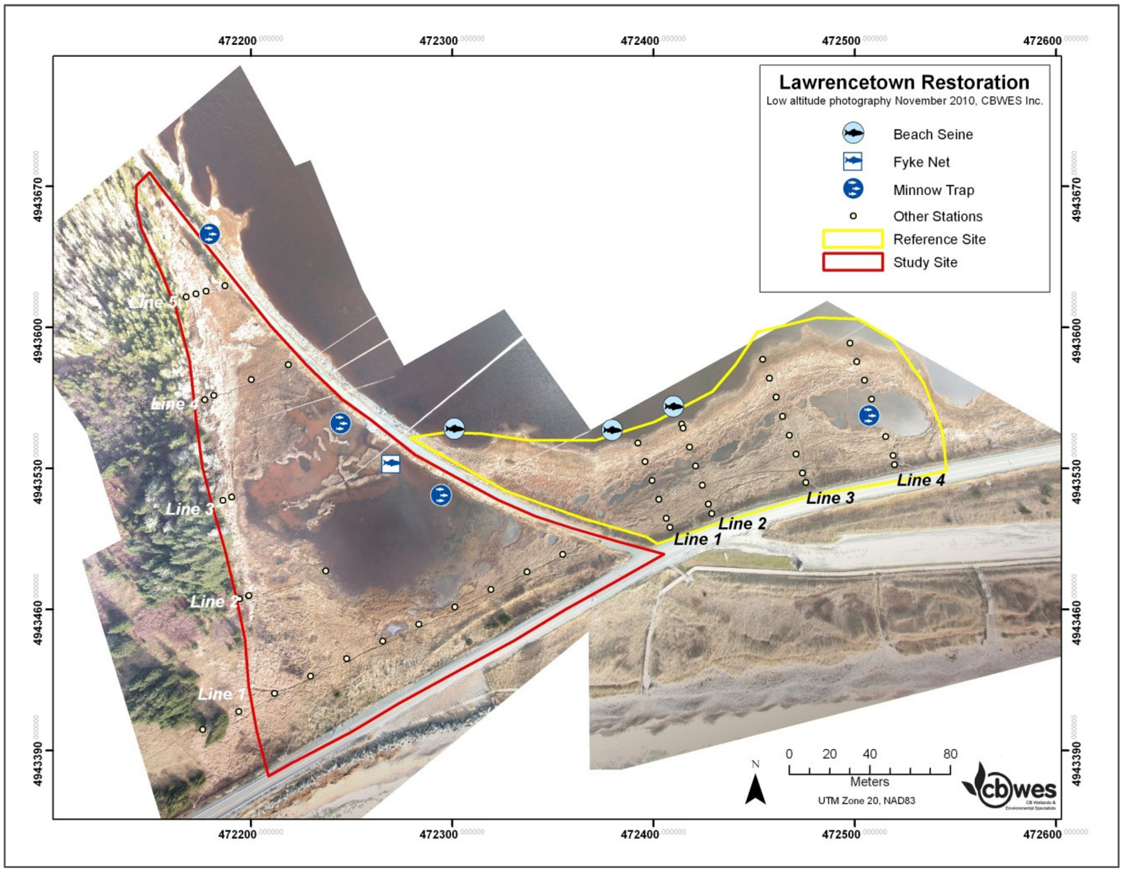


Figure 16 Locations of minnow trap, fyke net and beach seine sampling at LT and LT-R.

Figure 17 Deployed beach seine used in the fish survey at LT-R. Photograph by N. Neatt, 2010.

Figure 18 Fyke net set up for the fish survey at LT. Photograph by N. Neatt, July 2011.

3.2.6 Benthic and Other Aquatic Invertebrates

Benthic invertebrates, in association with benthic microbial communities, are largely responsible for providing the food resources that help fuel coastal and offshore marine ecosystems. As described in the section on vegetation, invertebrates are often the link between the primary producers of the salt marsh (plants) and the higher order secondary consumers/producers, namely fish. In addition to directly being consumed by fish and birds for food, these organisms perform the important task of converting the rich productivity of salt marsh plants into a form (detritus) that is more palatable to other species (see the Canadian Aquatic Biomonitoring Network (CABIN) program website for more information on the use of aquatic invertebrates to monitor the health of aquatic ecosystems - www.ec.gc.ca/rcba-cabin/).

Benthic Invertebrates

Field Methods

Benthic invertebrate samples were taken using a standard 6” x 6” Ekman Dredge (0.023 m^2 sediment sample) (Figure 19). Samples were analyzed for biological species composition and abundance. Four samples were taken at each site on 29 August 2012. Sampling locations at LT-R were divided between the lake (2 samples) and two of the larger pannes intersected by sample lines (Figure 12). The lake samples were obtained by wading into the lake aligned with Lines 2 and 4, to a depth of approximately 0.5 m and deploying the Ekman Dredge. The panne samples were taken in the middle of the panne at the point where the sample line intersected the panne. The LT samples were all located in the large central panne, with two samples located along the trail bed and two along the upland edge. These samples were taken by wading into the panne approximately five meters from the water’s edge aligned with Lines 2 and 3. Each sample was individually bagged, labeled and placed in a cooler containing ice for transport to the laboratory facilities at Envirosphere Consultants Ltd. in Windsor, NS.

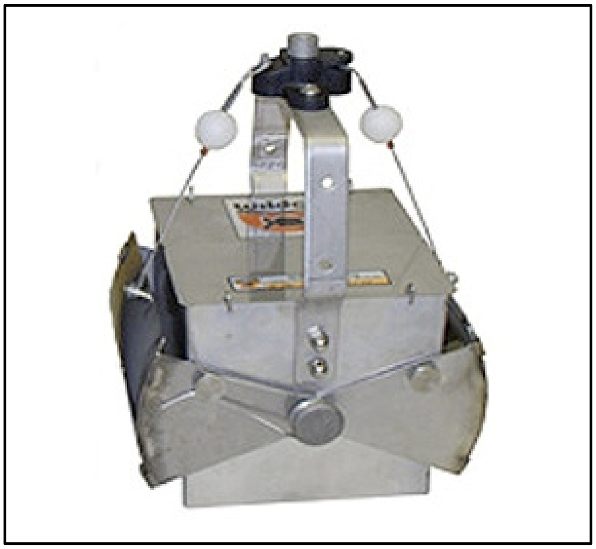


Figure 19 Ekman Dredge**.**

Aquatic Invertebrates

Aquatic invertebrates within the water column of the central tidal panne at LT and two representative pannes at LT-R were sampled using Aquatic Invertebrate Activity Traps (IAT). The lake samples were taken at LT-R for the first two years, but it was difficult to obtain a sample due to wave action, so the lake traps were moved into a panne on the marsh surface. IATs were constructed from clear plastic 2 L pop bottles with the tops removed, inverted and replaced (Figure 20). IATs were submerged and anchored within the water column of the panne being sampled and allowed to passively sample over a single tide cycle (approximately 24 hour period). Only one sample was taken at each site on 12 July 2012, as the dry state of the sites would only allow one IAT to be set, and two samples were taken at each site on 10 August 2012. The traps were set on the dates given and then retrieved the following day. Samples were emptied into a 0.5 mm sieve and all captured materials and organisms were field-preserved in 70% isopropyl alcohol for transport to the lab for processing. Species identification was conducted by Envirosphere Consultants Ltd.

Figure 20 Invertebrate Activity Trap (IAT). Photograph by T. Bowron 2007.

3.2.7 Structured Winter Site Walk at LT and LT-R

On 6 February 2013, a structured winter site walk was conducted at LT and LT-R. Landscape photographs were taken along each Line from the associated front stake as well as any features such as ice or areas of erosion. The structured walk was conducted along the upland edge of LT and LT-R.

4.0 Results of the 2012 Monitoring Program

4.1 Geospatial Attributes

Digital Elevation Model (DEM) and Habitat Maps

The DEM for LT and LT-R was updated in 2012 to include the additional survey data collected (Figure 21). The DEM and survey statistics for LT and LT-R for the years 2006, 2010 and 2012 can be found in Table 2. The statistics taken from the DEM for LT have a mean of 1.04 m with a range of 0.17 to 3.73 m and a standard deviation of 0.63. For LT-R the mean was 0.67 m with a range of 0.34 to 1.96 m and a standard deviation of 0.25. When calculating DEM statistics for LT the pond was excluded as field conditions prohibited the collection of survey data within the area. When comparing the DEM means, maxima and minima for LT and LT-R pre-restoration and Years 3 and 5, there were only slight differences. These changes over time were well within the survey error (±10 cm) and hence do not indicate a true change in elevation.

There were, however, changes at specific locations that have been occurring over the past few years post-restoration, as shown by the transect comparison (Figure 22). The end of Line 2 has been consolidating, with a subsequent vegetation change, and has been lengthening into the edge of the pond (Figure 22). Also of note was the elevation increase illustrated on Line 4 (Figure 22). This area has been increasing during the post-restoration monitoring program, although this increase in elevation could be attributed to erosion of the adjacent drumlin, as alluded to in *Section 4.3: Soils and Sediments*, more so than sediment deposition from tidal waters. The changes that appeared in the transect comparison for Line 1 (approximately 100 m) at LT were located at a low point where pannes were located; therefore, much of this change could be attributed to changes in panne formation. Changes along this Line, particularly towards the upland, could also be attributed to storm over-wash (*Section 4.3: Soils and Sediments*).

A habitat map for LT and LT-R from 2010 has been included to illustrate the morphological features of these sites (Figure 23). Additional aerials could not be obtained during the 2012 monitoring season; therefore, a vegetation dominance map was constructed to compare 2007 (pre-restoration) to 2012 (post-restoration) vegetation (Figure 24). There were no large shifts in vegetation dominance at either site during the monitoring program. At LT the dominant species found mostly along Line 1 (closest to the highway), in 2012 was *Festuca rubra*, although the difference between the numbers for this species and *Juncus balticus* was slight, if any (Figure 23). Both of these species have been found in all years. Therefore, this was not a shift in species in this location. This was also the situation for the upland plots of LT-R closest to the road (Figure 23). The most notable changes were found on Line 3 with a change from *Calamagrostis canadensis*/*Myrica gale* to *Juncus balticus* and on Line 2 with a change from *Agrostis stolonifera* to *Spartina alterniflora* (*Section 4.4: Vegetation).*

Table 2 DEM and survey statistics for pre- (2006), year three (2010) and year five (2012) post-restoration. Units are elevations in metres. * Indicates a slightly different start point for elevation measurements and does not reflect a significant elevation change within the marsh.

DEM and Survey Stats		2006	2010	2012
Study	DEM Mean	1.08	1.05	1.04
	DEM Max	3.87	3.95	3.73
	DEM Min	-0.05	0.26	0.17
	DEM Standard Deviation	0.64	0.60	0.63
Reference	DEM Mean	0.71	0.75	0.67
	DEM Max	2.14	2.01	1.96
	DEM Min	0.07	0.34	0.34
	DEM Standard Deviation	0.35	0.26	0.25
Study	Survey Mean	1.00	0.86	0.81
	Survey Max	6.06*	3.21	3.50
	Survey Min	-0.29	0.14	0.17
	Survey Standard Deviation	0.80	0.80	0.58
Reference	Survey Mean	0.62	0.71	0.50
	Survey Max	2.19	1.69	1.10
	Survey Min	0.07	0.34	0.23
	Survey Standard Deviation	0.32	0.30	0.13

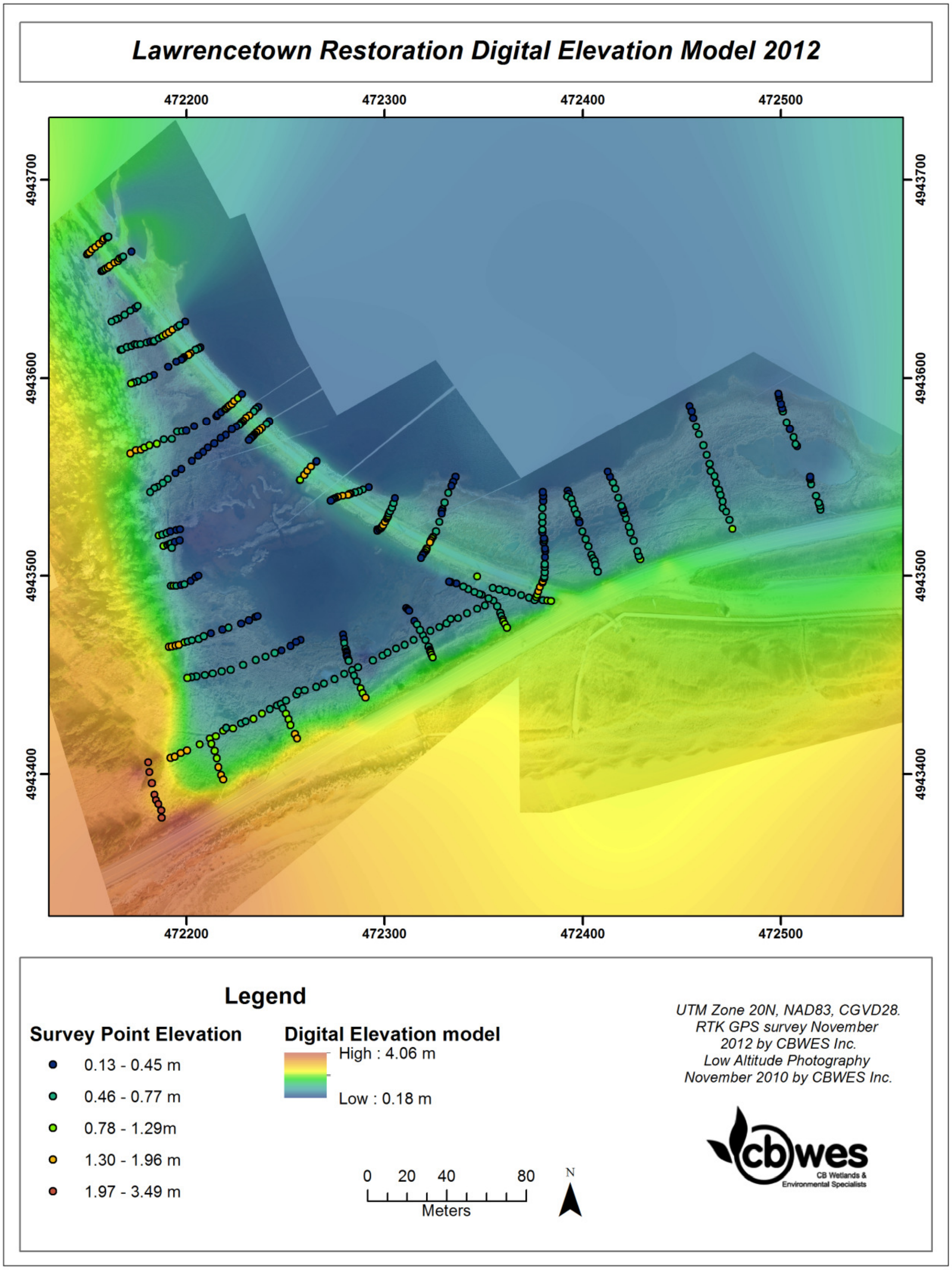


Figure 21 DEM showing elevation above mean sea level for LT and LT-R for 2012. Blue colors indicate low elevation and red colors indicate high elevations.

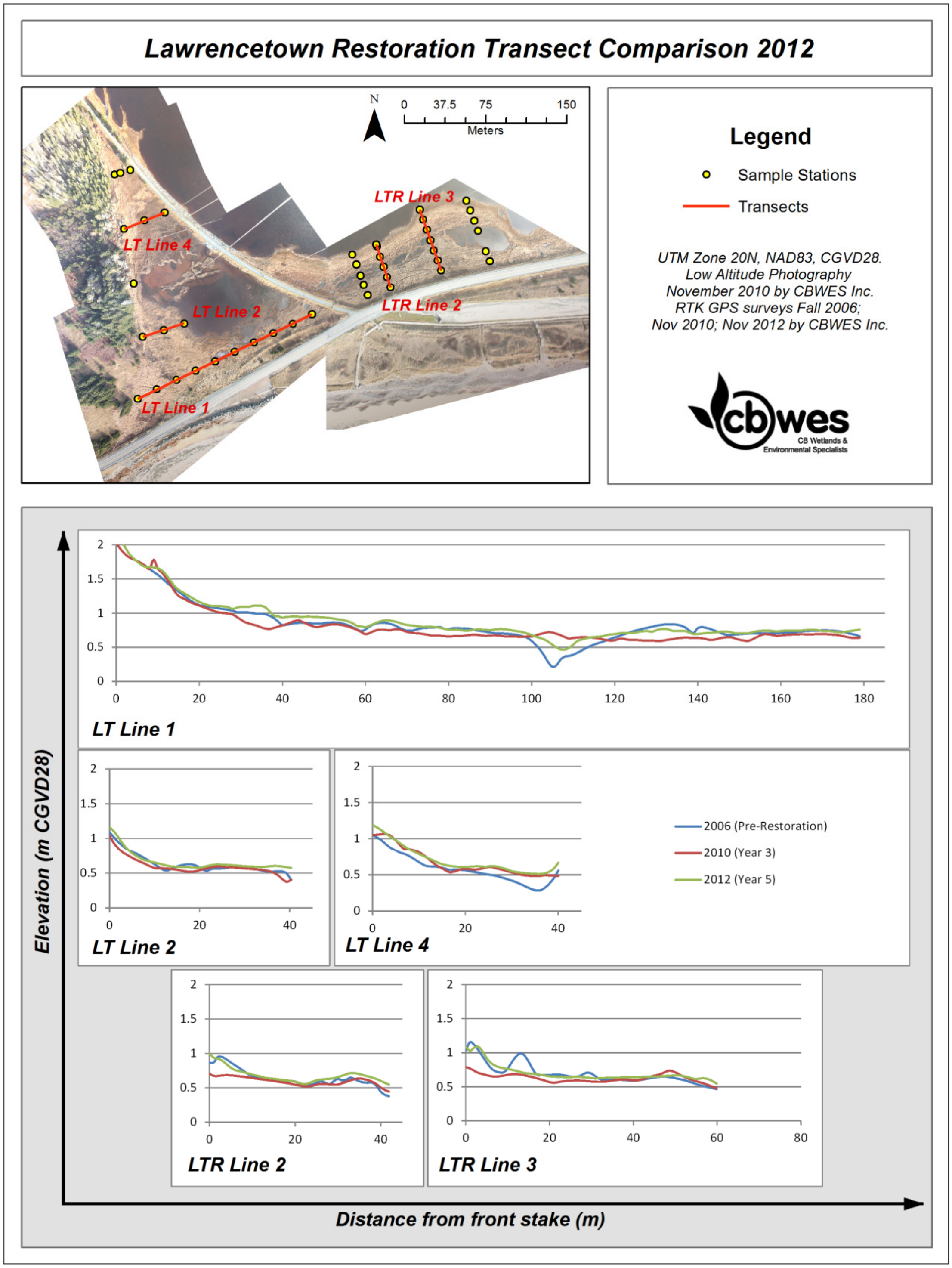


Figure 22 Changes in elevation along select surveyed transects for LT and LT-R.

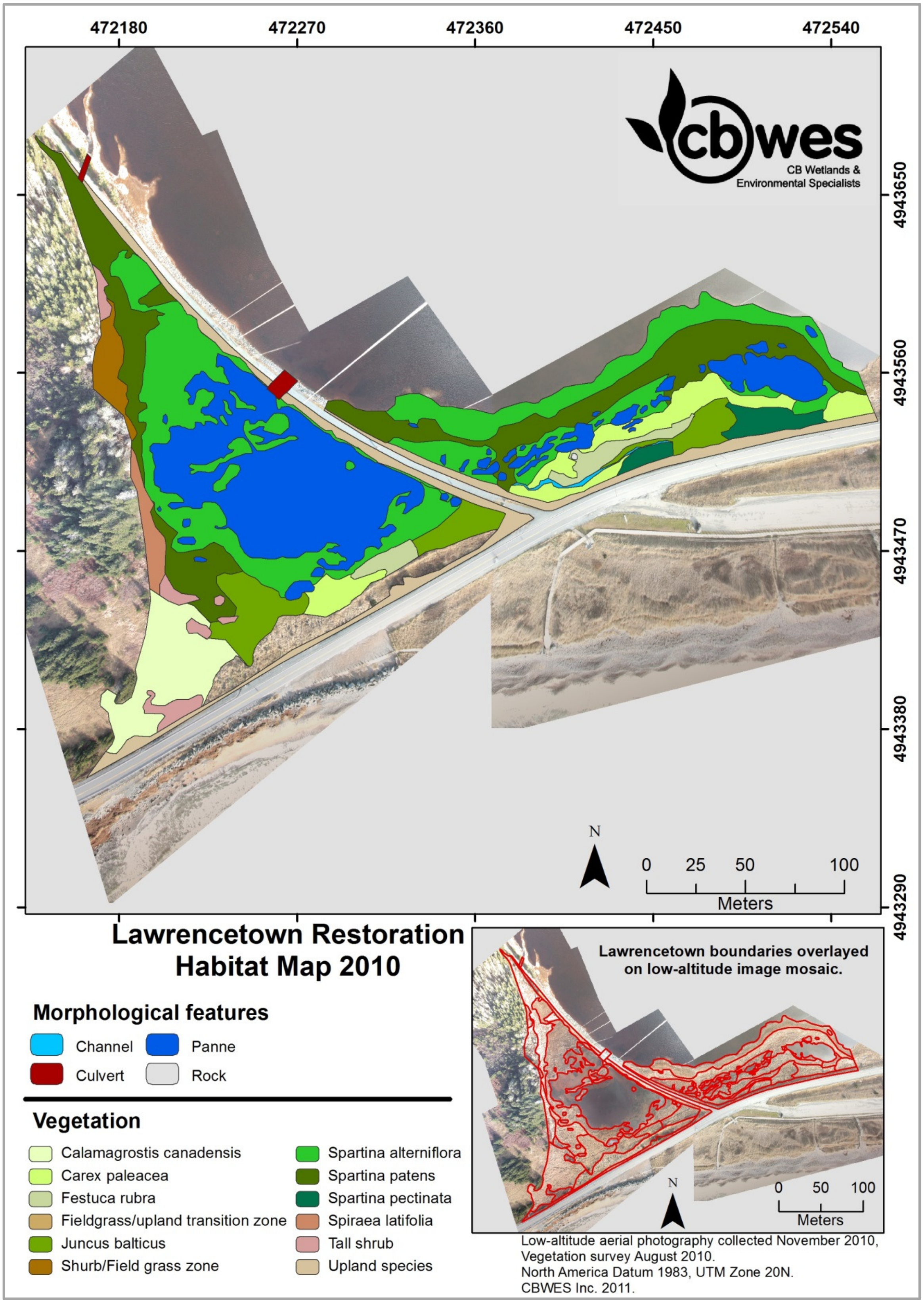


Figure 23 Habitat map for LT and LT-R showing vegetation type and morphological features using 2010 data.

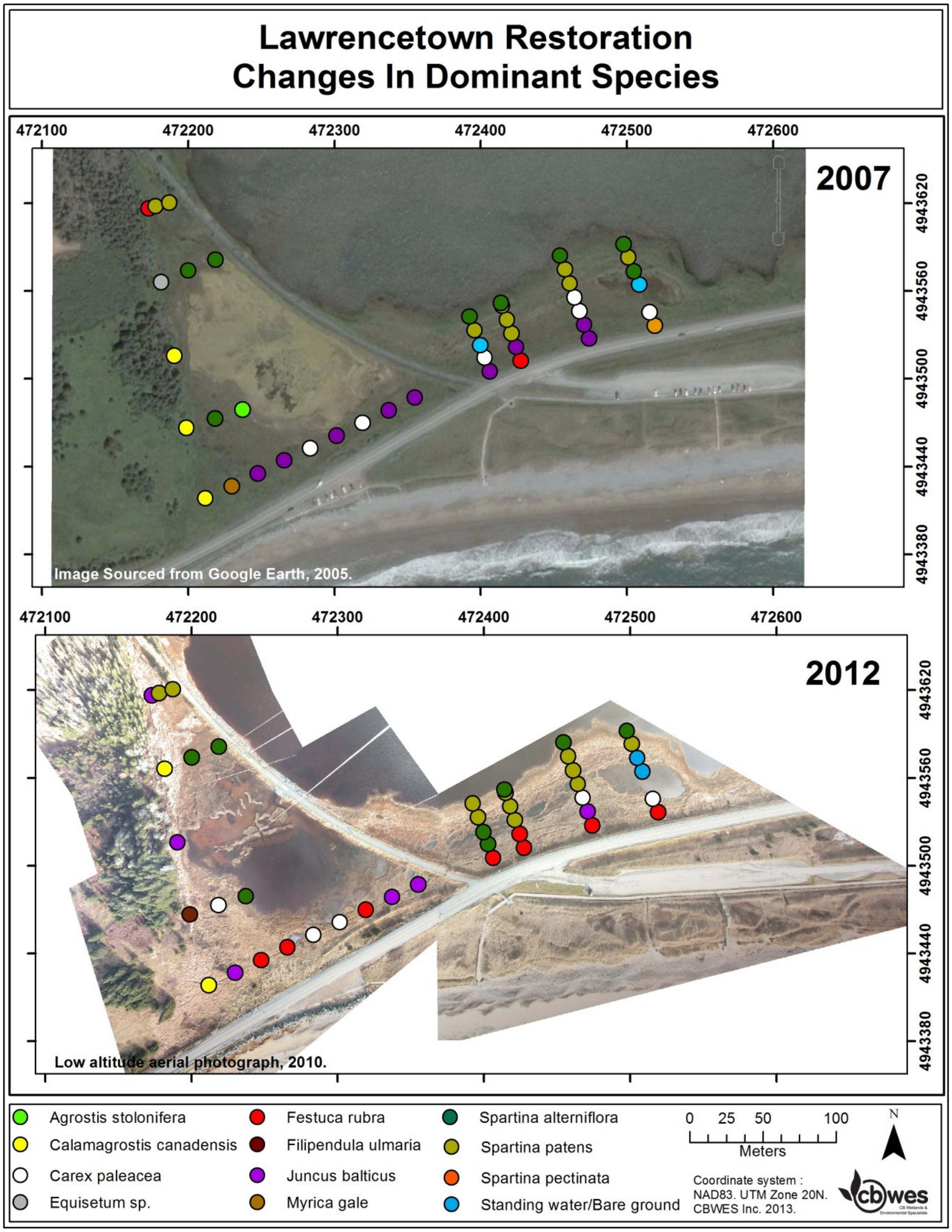


Figure 24 Change in dominant vegetation species at LT from 2007 (pre-restoration) to 2012 (5 years post-restoration).

4.2 Hydrology

Hydroperiod and Tidal Signal

The tide level recorder statistics can be found in Table 3. The maximum water level at LT during the 2012 data collection was 0.9 m (CGVD28) with a maximum of 1.0 m (CGVD28) at LT-R (Table 3). Frequently the peak tide (maximum elevation) occurred in the lake before peak tide within LT. This occurred 60% of the time during data collection (Table 4). 24% of the time the peak tide occurred within LT first. This would be expected since there were times when tidal waters did not drain completely out of the site before the tide started to rise again; therefore, the peak within the site would occur sooner. This temporal delay could be as high as 1:40:00 on a maximum tide (peak tide in lake first) to 0:30:00 (peak tide in LT first: Table 4). Although this temporal delay was large, the tide height differences were small (1 – 3 cm) and the water level remained high throughout much of the sampling period in the both the lake and the LT central panne (Table 4 and Figure 26).

The hypsometric curve, a graphical version of the flood map (Figure 27) for LT and LT-R (based on tide signal and DEM) is presented in Figure 25 and illustrates the amount of area covered at different water heights. Changes in the hypsometric curves were reflective of changes in the DEM of each site and since there were no significant changes in the 2012 DEM for either site, the graph presents data from 2007 (pre-restoration) and 2010 (three years post-restoration). Note that the pre-restoration curve presented for LT was the representation of how the site would flood with no restriction. The changes between LT pre- and post-restoration curves were attributed to dewatering and accretion of the marsh surface, as well as inaccuracies associated with the 2010 DEM model in the central panne, which could not be surveyed due to water depth.

As shown in Figure 27, the majority of LT (1.32 ha) would be covered on a mean tide (0.6 m: CGVD28) (Table 5). The area covered at LT for the maximum tide recorded in 2012 (0.9 m: CGVD28) was 1.79 ha (Figure 27: Table 5).

Table 3 Tide level recorder statistics for 2012 for LT and LT-R (m CGVD28).

	2006	2008	2010	2012
Recording Period Start	29-Sep	21-Oct	02-Dec	24-May
Recording Period Finish	11-Oct	14-Nov	22-Dec	14-Jun
Recording Period Duration (Days)	12	24	20	20
Min Study Water Level (m)	--	0.42	0.3	0.4
Max Study Water Level (m)	**--**	**1.03**	**1.36**	**0.9**
Min Reference Water Level (m)	0.2	0.31	0.25	0.2
Max Reference Water Level (m)	0.7	1.04	1.37	1.0
Study Area covered at max tide (ha)	**1.41**	**1.82**	**2.58**	**1.79**

Table 4 Difference in time and water height for the mean, maximum and minimum tide heights between LT and Lawrencetown Lake.

	Time (h:mm:ss)		
	Peak Tide in Lake First (60%)	**Peak Tide in LT First (24%)**	**Height (cm)**
Mean	0:21:15	0:05:53	-0.01
Maximum	1:40:00	0:30:00	0.03
Minimum	0:00:00	0:00:00	-0.03

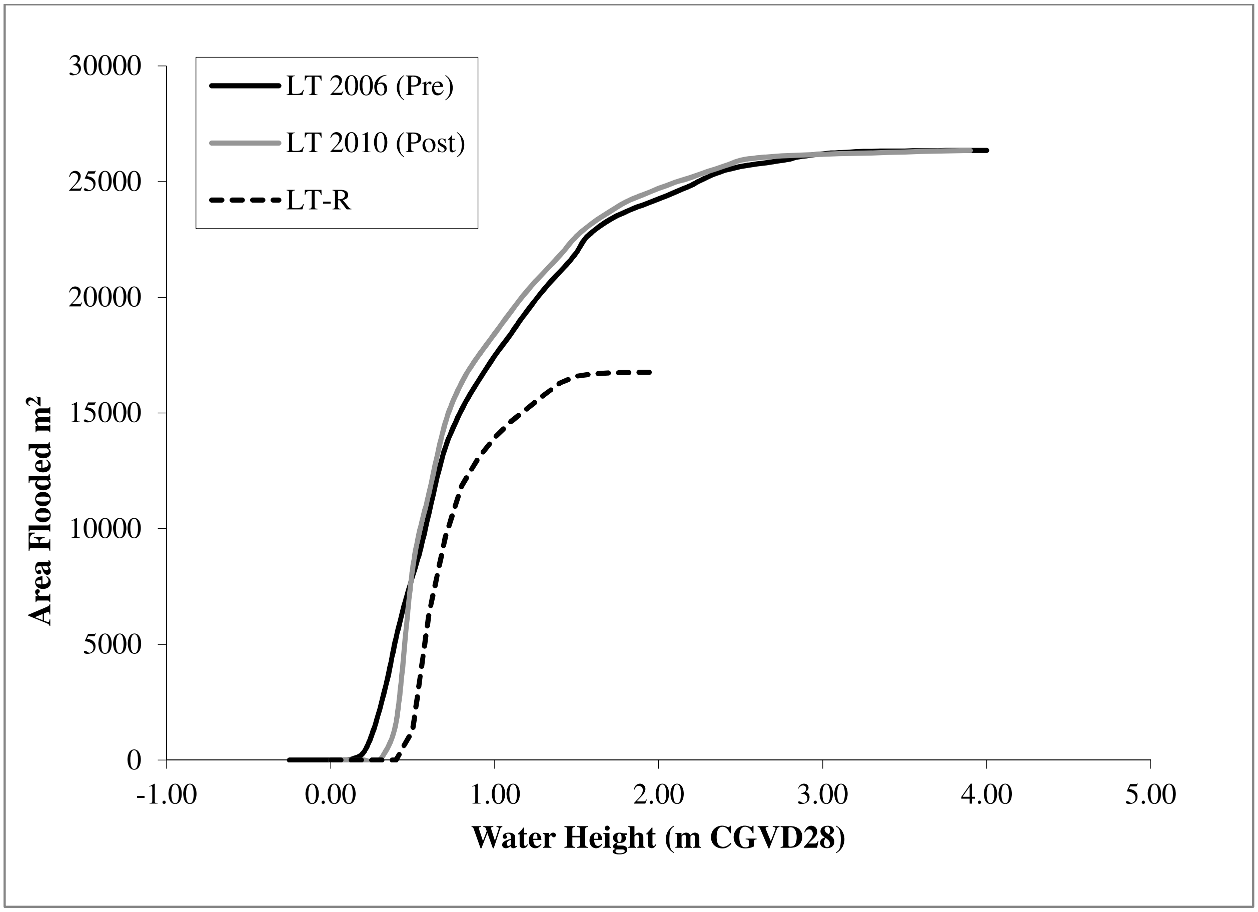


Figure 25 Hypsometric curve showing amount of area covered by elevation at LT pre-restoration (2006) and post-restoration (2010).

Table 5 Tide height and area covered for LT and LT-R.

	Tide Height (m)		**Area (ha)**	
	LT	LT-R	LT	LT-R
Highest Tide	0.9	1.0	1.79	1.23
Mean High Tide	0.6	0.6	1.32	0.93
Min High Tide	0.4	0.4	0.35	0.15
Mean Water Level	0.5	0.5		
Min Water Level	0.4	0.2		

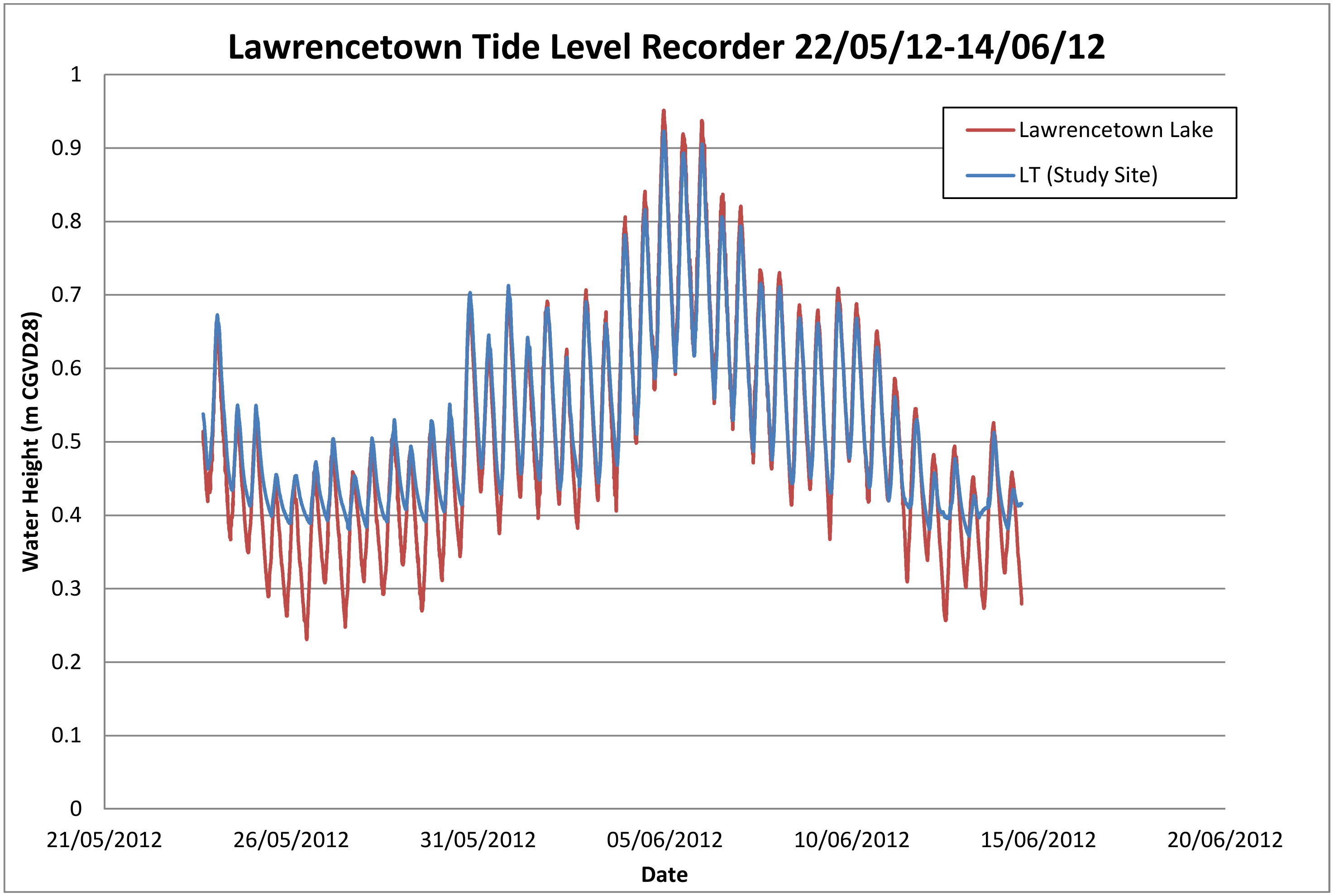


Figure 26 Graph of tide level data (tide signal) gathered with the Solinst Levelogger (Model 3001) from 22 May 2012 to 14 June 2012 at LT (inside study site) and Lawrencetown Lake.

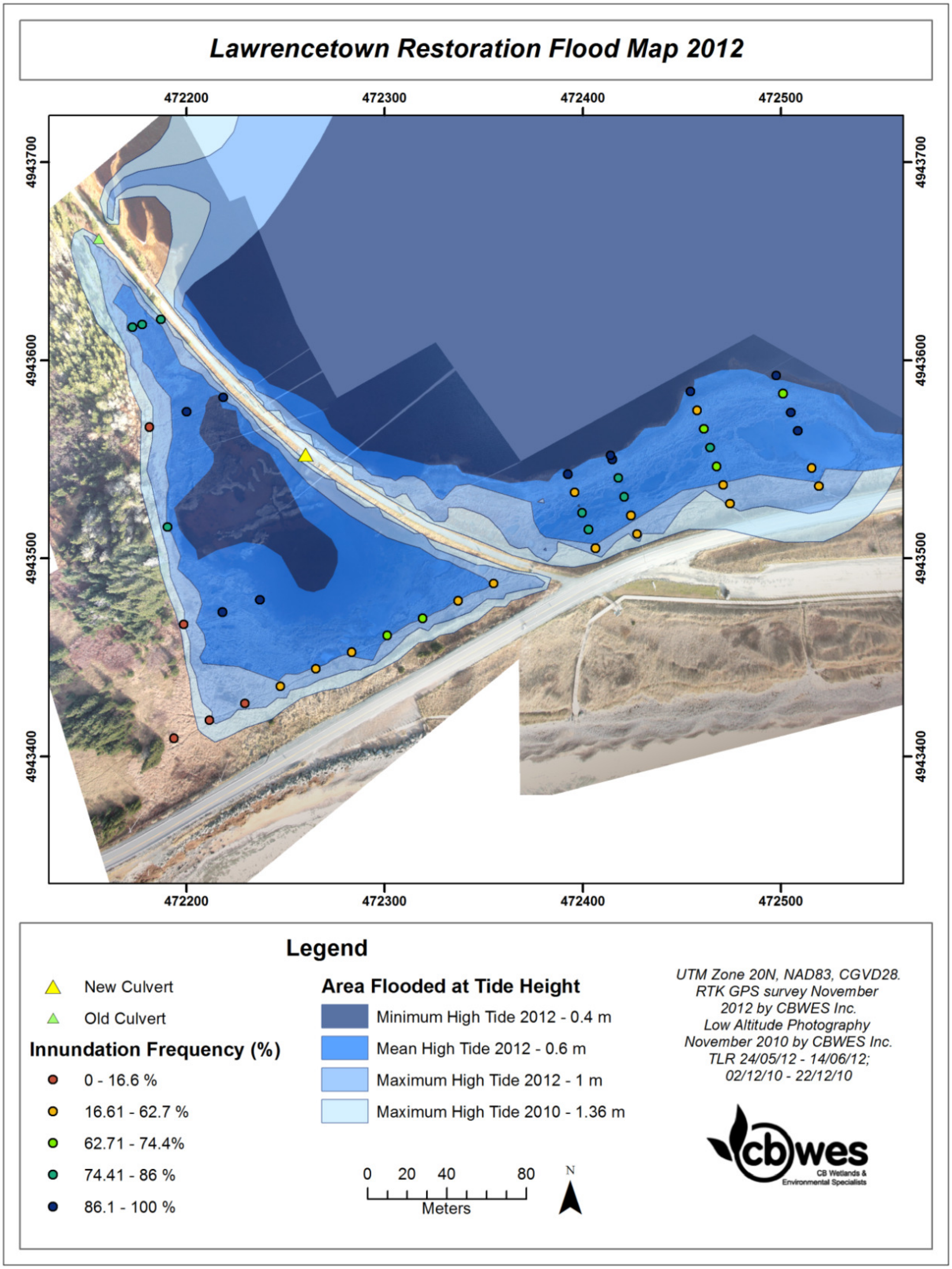


Figure 27 Flood map of LT and LT-R showing inundation frequency for each sampling station.

Water Quality

As discussed in Bowron et al. (2009), the comparison of the 2007 (pre) and 2008 (post) data showed that there was little difference between the abiotic factors at LT and LT-R (lake), indicative of the elimination of the tidal restriction. This has been shown for each year post-restoration (2008 – 2012: Table 6). Pre-restoration the average salinity reported at LT-R was 15.7 ppt and at LT 8.6 ppt. The average salinity for all years post-restoration at LT-R was 25.5 ppt and at LT 25.7 ppt with the highest salinities found in 2010 (Table 6). Higher salinities were again recorded in 2012 for the June readings. The trend of decreasing water temperature into the fall was apparent, particularly during sampling in years 2009 to 2011, with a subsequent increase in DO levels (Table 6). This trend was not as apparent in the Year 5 data. The pH levels ranged from 7.0 to 8.2, all years post-restoration included, with the normal range of pH for seawater being 7.5 to 8.5. Figure 28 illustrates the comparison between LT and LT-R of mean baseline readings for all water quality parameters compared to the mean readings five years post-restoration. Of particular note is the change in salinity after restoration.

Table 6 Water quality parameters for LT and LT-R.

Date	Sampling Site	Sample Location	Salinity (ppt)	Temperature (^oC)	Dissolved Oxygen (mg/l)	pH
27-Nov-06	LT-R	Lake	7.8	22.6	11.6	8.8
	LT-R	Panne	11.6	11.8	7.4	8.9
	LT	Panne	11.6	8.9	11.8	7.4
14-Jun-07	LT-R	Lake	8.6	12.1	12.9	5.9
01-Oct-07	LT-R	Lake	27.9	15.3	9.1	7.7
30-Oct-07	LT-R	Lake	17.5	7.2	11.2	7.7
14-Nov-07	LT-R	Panne	9.7	16.4	9.1	4.4
	LT	Panne	5.6	14.5	10.9	8.9
23-Jul-08	LT-R	Lake	13.0	20.0	-	-
21-Oct-08	LT	Panne	26.7	11.9	10.5	7.8
	LT-R	Lake	28.2	11.3	9.4	7.6
	LT-R	L4 Panne	17.3	11.9	10.5	7.8
	LT-R	L2 Panne	21.3	16.3	13.2	7.0
27-Jul-09	LT-R	Lake	28.1	18.6	8.9	7.9
	LT	Panne	26.1	20.1	8.8	7.8
24-Sep-09	LT-R	Lake	27.7	17.5	8.5	7.6
21-Oct-09	LT-R	L2	11.9	10.3	14.3	6.9
13-Sep-10	LT	Panne	30.1	16.5	8.5	7.8
	LT-R	Lake	29.6	16.1	8.9	7.7
12-Oct-10	LT-R	Lake	30.3	10.3	10.3	8.2
06-Jul-11	LT-R	Lake	28.6	18.8	4.3	8.1
	LT	Panne	28.1	22.1	5.0	8.2
07-Oct-11	LT-R	Lake	19.9	6.1	15.5	7.9
	LT	Panne	19.8	6.6	12.6	8.2
22-Jun-12	LTR	Lake	30.4	15.9	11.9	7.9
	LT	Panne	29.0	19.1	12.5	8.1
21-Sep-12	LTR	Lake	22.7	16.4	9.0	7.8
	LT	Panne	15.2	17.6	10.9	7.7

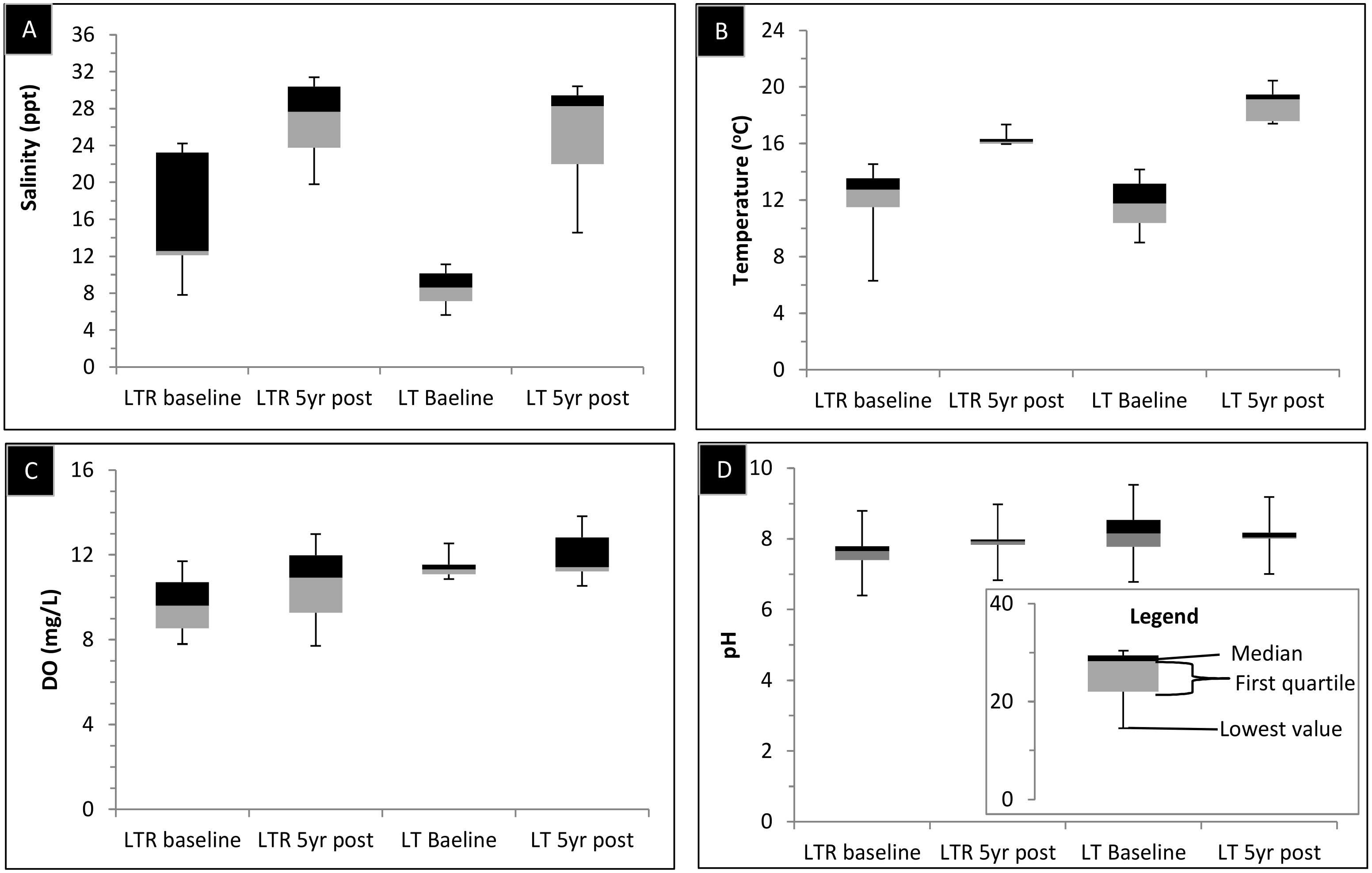


Figure 28 Boxplots for A) salinity; B) temperature; C) DO; and D) pH for LT and LT-R pre- and five years post-restoration (Baseline).

4.3 Soils and Sediments

Pore Water Salinity

The 2012 descriptive statistics for pore water salinity at each sampling station for LT and LT-R, as well as for each site overall, are found in Table 7. The 2012 mean salinity value for LT-R was 8.74 ppt with a range of 0.26 to 15.15 ppt and a standard deviation of 4.26 ppt (Table 7b). The 2012 mean salinity value for LT was 6.92 ppt with a range of 0.18 to 17.28 ppt and a standard deviation of 4.95 ppt (Table 7b). The lowest mean salinity readings for LT were found at the sample stations along Line 1, with the highest mean salinities found at Line 4 and 5 (Table 7a). Line 2 site LT_L2S3, situated on the edge of the central panne in *S. alterniflora*, also showed a higher mean salinity than those stations on Line 1 (Table 7a). As shown on the LT flood map (Figure 27), the majority of stations on Line 1 were inundated by 0 – 62.7 % of the high tides, whereas the majority of Line 4 and 5 stations were inundated by 74 – 100% of the high tides. Station LT_L2S3 was inundated on 86 - 100 % of the high tides (Figure 27). At five years post-restoration, the salinity gradient of LT was found to go from lowest at Line 1 to highest at Lines 4 and 5, similar to previous years (Table 7).

T-tests completed for LT-R between years 2011 and 2012 showed a significant difference, therefore, reference samples were not grouped. Histograms for shallow and deep readings show some shift in pre-restoration (2007) and post-restoration (2012) conditions. In 2012, both LT-R and LT have seen a decrease in the frequency of lower salinity values (0-3.00 ppt range) compared to pre-restoration levels for shallow readings (Figure 29). There was also an increase in the frequency of the higher salinity values (12.10–16.00 ppt range) in 2012 for the shallow readings at both sites (Figure 29). Five years post-restoration the salinity readings at LT followed the distribution of LT-R readings more than pre-restoration readings. For 2012 deep readings at LT the opposite trend was found, with an increase in frequency of the lower salinity readings (0-3.00 ppt), as well as an increase in frequency of the higher salinity values (16.10-18.00 ppt), which were not found at LT-R (Figure 30). For deep readings, the pre-restoration conditions at LT and LT-R were more similar than conditions five years post-restoration (Figure 30).

T-tests (95% CI) completed for LT-R between years 2011 and 2012 showed a significant difference ($t = 6.07$; $p = 4.24E-08$). No significant difference was found between years at LT ($t = 1.23$; $p = 0.22$). T-tests (95% CI) completed between shallow and deep readings showed a significant difference for both LT-R ($t = 1.15$; $p =0.26$) and LT ($t = 0.33$; $p = 0.76$). Finally, t-tests (95% CI) performed between LT-R and LT in 2012 showed no significant differences when shallow ($t = 0.99$; $p = 0.33$) and deep ($t = 1.06$; $p = 0.29$) readings were tested separately, nor when all readings ($t = 1.45$; $p = 0.15$) were tested together.

Although 2012 mean salinities for LT (6.92 ppt) and LT-R (8.74 ppt) were lower than those recorded in 2011, this decrease in salinity values was not statistically significant as described above. Lower mean salinity at LT could be contributed to freshwater input from the adjacent drumlin and its watershed, as well as differences in inundation frequency and duration. LT has 10 stations out of 20 that are inundated by 62.71-100 % of the high tides, whereas LT-R has 15 stations out of 24 with the same inundation frequency (Figure 27). LT also has 5 stations that are only inundated by 0-16.60 % of the high tides, whereas LT-R has no stations in this category (Figure 27). LT did, however, have a larger salinity value range than LT-R in 2012, most likely due to the higher salinity values found in the deep readings (Figure 30).

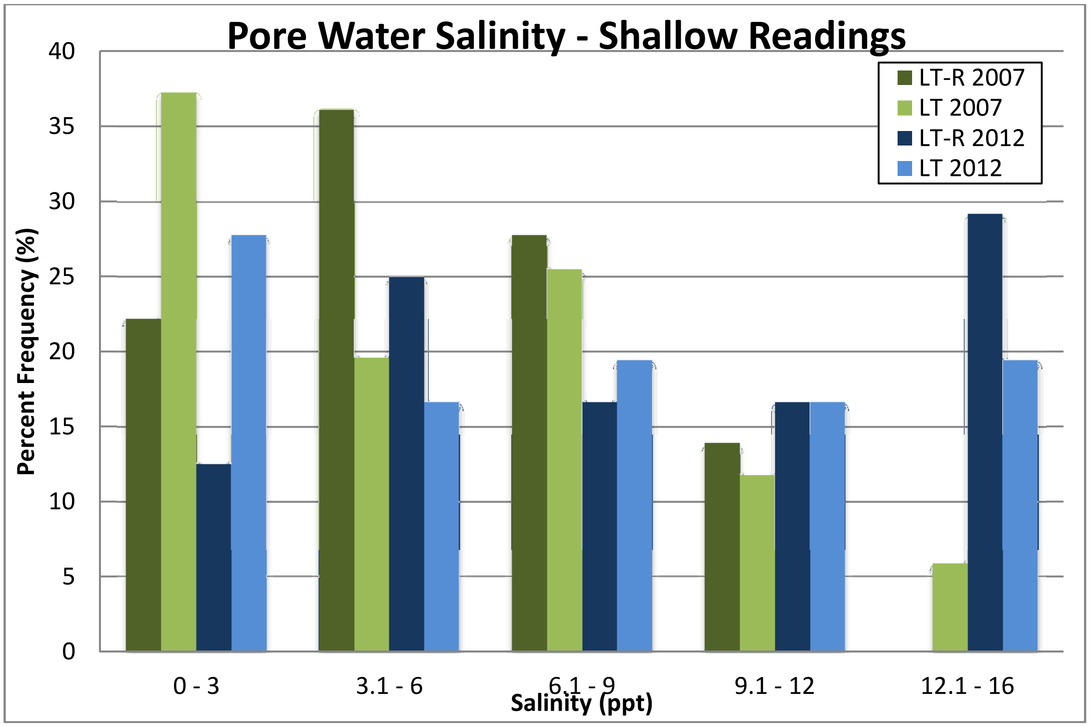


Figure 29 Frequency of pore water salinity values for shallow sample readings at LT and LT-R for 2007 (pre-restoration) and 2012 (five years post-restoration).

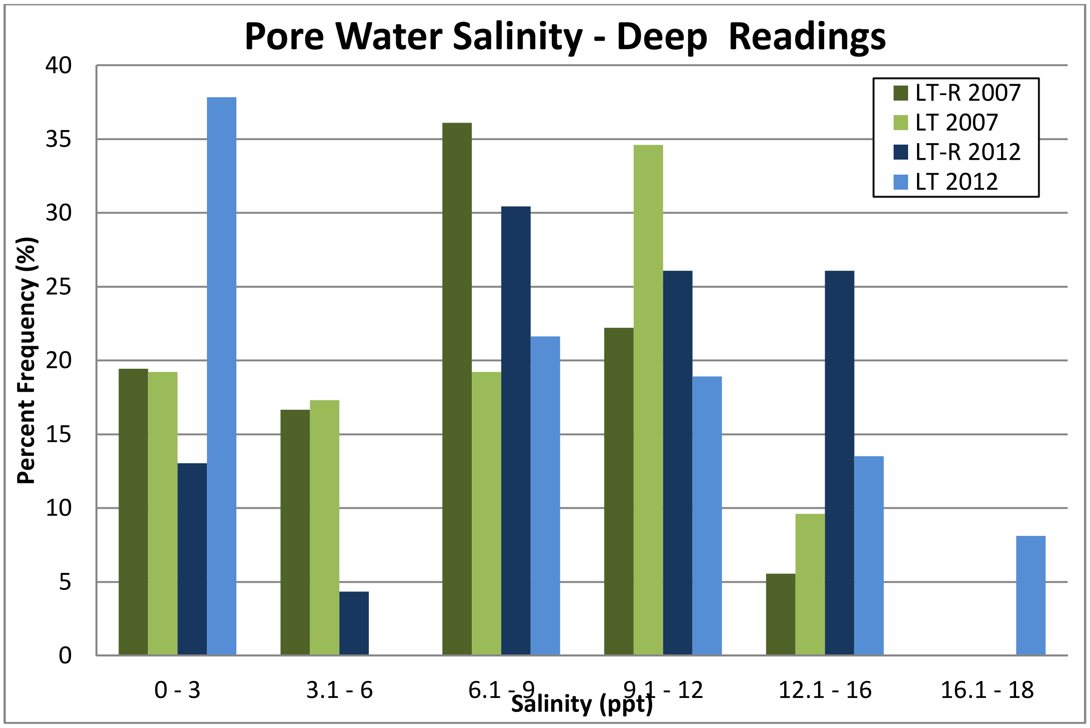


Figure 30 Frequency of pore water salinity values for deep sample readings at LT and LT-R for 2007 (pre-restoration) and 2012 (five years post-restoration).

Table 7 2012 descriptive statistics for pore water salinity for LT-R and LT at: A) individual sampling stations and B) each site overall.

A)	**Shallow Readings**					**Deep Readings**					**All Readings**				
Station	Sample Size (n)	Min	Max	Mean	St. Dev.	Sample Size (n)	Min	Max	Mean	St. Dev.	Sample Size (n)	Min	Max	Mean	St. Dev.
LTR L1S2	5	3.19	12.09	7.69	4.36	5	3.83	10.45	7.74	2.79	10	3.19	12.09	7.72	3.45
LTR L1S4	6	2.13	12.80	8.80	4.47	4	7.07	12.80	9.94	2.37	10	2.13	12.80	9.26	3.65
LTR L1S5	4	7.01	13.41	9.96	2.64	5	7.47	11.96	9.55	1.84	9	7.01	13.41	9.73	2.09
LTR L3S2	5	1.12	4.82	3.41	1.84	5	0.26	7.47	1.72	3.22	10	0.26	7.47	2.56	2.63
LTR L3S4	6	7.32	15.15	11.54	2.79	5	12.40	14.92	13.41	1.20	11	7.32	15.15	12.39	2.33
LTR L3S7	5	4.11	14.10	11.38	4.17	4	7.20	12.03	9.92	2.00	9	4.11	14.10	10.73	3.29
LT L1S2	6	0.18	0.90	0.38	0.29	5	0.36	0.97	0.51	0.26	11	0.18	0.97	0.44	0.27
LT L1S5	5	2.06	5.60	3.95	1.77	5	1.25	12.00	7.15	5.36	10	1.25	12.00	5.55	4.12
LT L1S9	5	2.00	9.29	5.19	3.76	5	1.34	2.25	1.88	0.39	10	1.34	9.29	3.53	3.07
LT L2S3	5	9.76	14.06	12.50	1.89	5	7.42	11.66	8.60	1.76	10	7.42	14.06	10.55	2.68
LT L3HM	5	0.66	3.60	2.66	1.18	5	1.12	1.86	1.52	0.37	10	0.66	3.60	2.09	1.02
LT L4S2	4	7.01	10.26	8.18	1.47	4	9.73	12.35	11.55	1.23	8	7.01	12.35	9.87	2.19
LT L4S3	4	8.33	14.82	12.81	3.04	5	13.19	17.28	15.72	1.69	9	8.33	17.28	14.43	2.69
LT L5S2	5	4.61	9.90	7.07	1.89	6	6.50	10.34	7.46	1.48	11	4.61	10.34	7.28	1.60
LT L5S3	5	7.79	13.29	10.89	2.11	4	10.34	12.20	10.88	0.88	9	7.79	13.29	10.88	1.59

B)	**Shallow Readings**					**Deep Readings**					**All Readings**				
Site	Sample Size (n)	Min	Max	Mean	St. Dev.	Sample Size (n)	Min	Max	Mean	St. Dev.	Sample Size (n)	Min	Max	Mean	St. Dev.
LT-R	28	0.26	14.92	8.63	4.28	31	1.12	15.15	8.85	4.30	59	0.26	15.15	8.74	4.26
LT	44	0.36	17.28	7.07	5.25	44	0.18	14.82	6.76	4.68	88	0.18	17.28	6.92	4.95

Sediment Accretion and Elevation

Overall net sediment accretion tends to display both spatial and temporal variability which is likely associated with the availability of sedimentary material. This was best illustrated by the high accretion values of 2009, which may be attributed to storm surge associated with Hurricane Bill (August 2009; Table 8). This was most likely the case for stations furthest on-shore such as LTR-MH4_L3HM, which would have experienced the surge from the lake or LT-MH3_L1S2 from over wash from the road, dune and beach. In 2009 and 2012, storm deposits, as evidenced by discrete sediment layers overtopping vegetation, were observed along the back of LT (Figure 32); however, this area also continued to experience deposition of fine sediments from the eroding drumlin (Figure 33a and b). As well, similar to 2008 and 2011, an occurrence of heavy rain events in 2012 brought approximately 200 mm more rain in August, October and September respectively compared to the 1971-2000 climate normals (Figure 31). This would likely explain the high rates of accretion for 2008 to 2009 and 2010 to 2012 at LT in the high and mid marsh, closest to the eroding drumlin (Table 8 and Figure 33).

Table 8 Sediment accretion measured by marker horizon cores at LT.

Lawrencetown Restoration marker horizon measurements 2011-					Net annual accretion (cm/yr)					Annual average
Transect I	**Habitat Zone**	**mean**	**# cores**	**Quality**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**cm/yr**
LT MH-1 L1S8	high marsh	1.68	2	ok	0.05	0.98	-0.4	1.01	0.05	0.34
LT MH-2 L1S4	high marsh	3.40	1	ok	0.05	0.73	1.15	1.13	0.35	0.68
LT MH-3 L1S2	high marsh	10.53	1	poor	0.15	3.19	-1.44	4.03	4.60	2.11
Transect 3										
LT MH-4 L3FS	high marsh	no feldspar visible			NA	1.61*	NA	NA	NA	NA
Transect 4										
LT MH-5 L4S2	mid marsh	10.15	2	ok	0.60	8.20	-0.08	2.71	-1.28	2.03
LT MH-6 L4S3	mid marsh	6.13	1	good	0.25	4.60	-0.43	1.06	0.65	1.23
Transect 5										
LT MH-7 L5S2	mid marsh	2.85	1	great	0.10	1.34	0.01	0.75	0.65	0.57

Table 9 Sediment accretion measured by marker horizon cores at LTR. *indicates that the average value was derived from the 2007 to 2011 time interval.

Lawrencetown Reference- Marker Horizons measurement 2011-					Net accretion (cm/yr)					Annual average
Transect 1	**Habitat Zone**	**mean**	**# cores**	**Quality**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**cm/yr**
LTR MH-1 L1LM	low marsh	NA	N/A	0	NA	NA	NA	NA	0	NA
LTR MH-2 L1MM	mid marsh	NA	missing	0	0.03	1.96	2.06	0.73	NA	1.20*
LTR MH-3 L1HM	high marsh	2.08	1	good	0.04	0.89	0.54	1.07	-0.46	0.42
Transect 3										
LTR MH-4 L3HM	high marsh	2.40	1	ok	0.54	0.09	1.31	0.79	-0.33	0.48
LTR MH-5 L3MM	mid marsh	2.13	2	good	0.05	1.81	0.84	0.13	-0.71	0.43
LTR MH-6 L3LM	low marsh	NA			NA	NA	NA	NA	NA	NA

Rates of sediment accretion in 2011 were lower than the previous year at LT-R with the exception of LTR-MH3_L1HM (1.07 $cm \cdot yr^{-1}$), which recorded the greatest amount of sediment accretion compared with all years (Table 8). The lowest rate was recorded on Line 3 mid marsh (0.13 $cm \cdot yr^{-1}$). However, rates of sediment accretion were higher at LT compared with the previous year (Table 9). In addition, the significant rainfall event of October 2011 (Figure 31) likely contributed to the high accretion rates at LT: LT-MH1_L1S2 (4.03 cm·yr^{-1}), LT-MH5_L4S2 (2.71 cm·yr^{-1}) and LT-MH6_L4S3 (1.06 cm·yr^{-1}) (Table 9 and Figure 35c,d,e). These stations also had the highest values in 2008-09. Two significant storms also struck the Lawrencetown area with surges greater than 0.5 m relative to the higher high water line (actual surge values not known) on 6 December 2010 and 30 October 2011 (ISDM, 2012). It is not known if these events overtopped the road as had occurred in previous events (Figure 36 and Figure 37). Although large storms were experienced in 2012, none of these exceeded 0.5 m above HHWLT chart datum. The main impact of 2012 storms was heavy rainfall, particularly in September when approximately 200 mm of rain fell within a short period (Figure 31). It was also not surprising that stations in close proximity to the lake (e.g. LTR_L1S2, LT_L3FS) have eroded or been flooded (Table 8 and Table 9). Sediment accretion in 2012 was lower than in 2011, particularly at LT. Station LT_L4S2 continued to have the highest rate of accretion (4.60 cm·yr^{-1}, Figure 33d), likely from erosion of the adjacent drumlin during the heavy rainfall events. This station also had the lowest organic matter content and largest mean grain size.

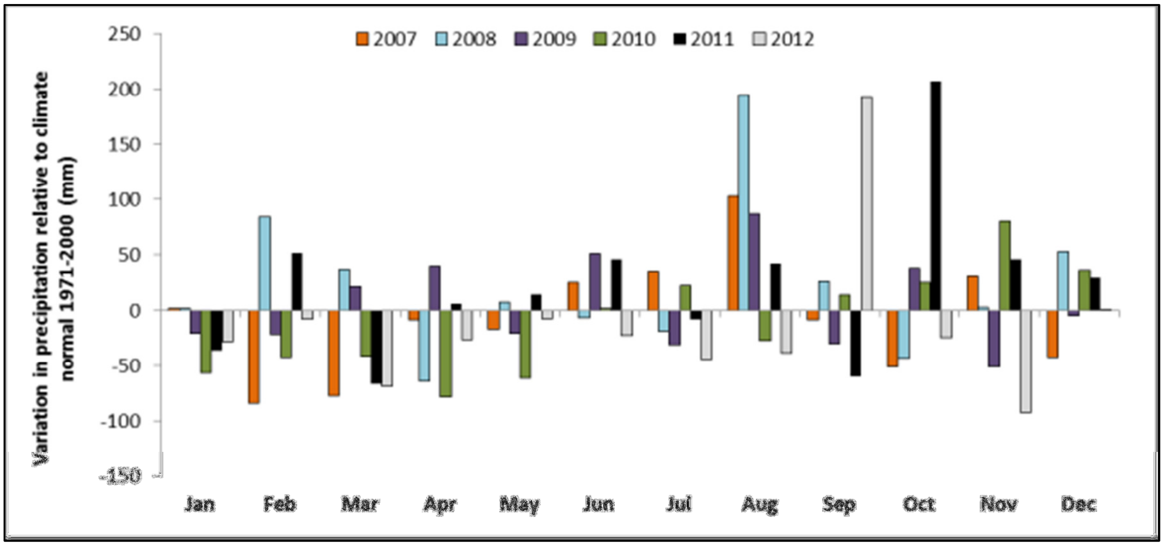


Figure 31 Deviation in total monthly precipitation values (2007-2012) from 1971-2000 climate normals determined by Environment Canada at the Halifax International airport.

Figure 32 View towards Lawrencetown Beach along the upland edge at LT in 2009. Note significant deposition on vegetation. Photograph by T. Bowron 23 October 2009.

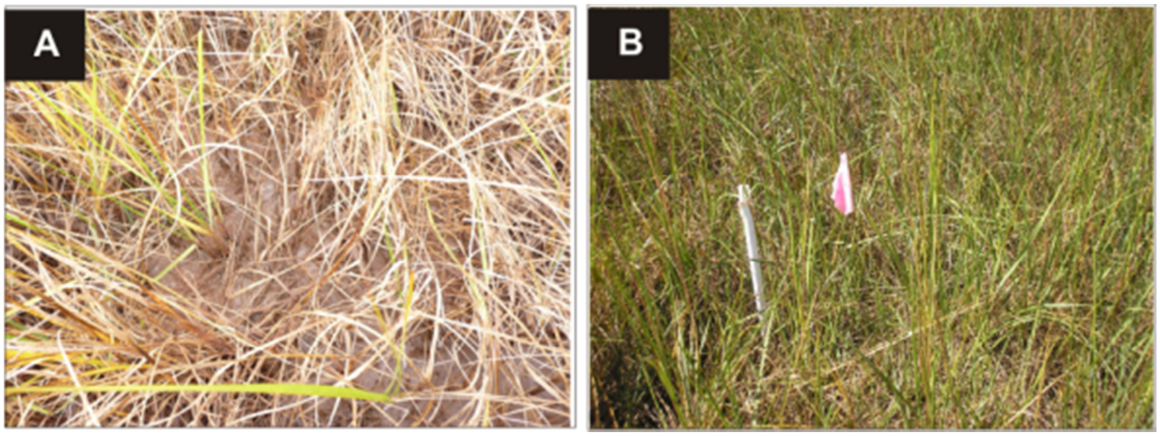


Figure 33 a) Sediment deposit from eroding drumlin near Line on 23 October 2009 and b) MH LT_L4S2 on 11 September 2012.

Figure 34 Marker horizons at LT-R for a) LTR-MH3_L1 high marsh; b) LTR-MH5_L3 mid marsh and c) LTR-MH4_L3 high marsh sampled on 29 August 2012.

Figure 35 Marker horizons at LT for a) LT-MH1_L1S8; b) LT-MH2_L1S4; c) LT-MH3_L1S2; d) LT-MH5_L4S2; e) LT-MH6_L4S3 and f) LT-MH7_L5S2 on 29 August 2012.

Figure 36 Wash-over deposits from post-tropical storm Noel on 6 November 2007 near Line 1 at LT. Photograph by B. Pett, 2007.

Figure 37 Wash-over deposits near Line 1 at LT after post-tropical storm Noel contributing coarse sediment and debris. Wash-over fan did not reach sampling plots. Photograph by B. Pett, 2007.

Figure 38 Wrack deposit in low marsh along Line 1 at LT-R on 11 September 2012**.** Photograph by N. Neatt.

Figure 39 Open water in mid marsh along Line 3 at LT-R on 11 September 2012. Photograph by N. Neatt.

Sediment accretion at this site tends to be controlled predominantly by storm deposits with material either being eroded from the drumlin or re-suspended in the nearshore and brought into the system on the rising tide. Although the average annual rates of accretion suggest that both LT-R and LT are keeping up with sea level rise, as calculated for Halifax (0.32 cm per year from

1920-2009; Forbes et al. 2009), with no RSETs (surface elevation change) it is unknown how subsurface processes are behaving and how the surface as a whole is trending over time. This may be a concern with greater relative rates of sea level rise in the future (Forbes et al. 2009).

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 water source 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).

Results for the organic matter content, water content and bulk density analysis are summarized in Table 10. All cores revealed significant amounts of live and decaying root matter (Figure 40 and Figure 41).

Water content was consistently higher at LT-R than at LT both pre- and post-restoration. Water content increased one year post-restoration at LT at five stations, all along Line 1 and at L2S2 and L5S1, which was to be expected. The lowest value remained at LT_L4S2 in all years. However, these changes were likely within the range of natural variability. By 2010, almost all stations recorded lower percent water content within the cores than previous years. In 2012, many sites recorded higher water content than previous years.

Organic matter increased with distance from the lake at LT-R. The highest organic matter content was recorded at L1S1 (65.17%) and L3S1 (62.78%) at the upland boundary while the lowest was recorded at L1S4 (19.75%) and L3S6 (20.70%) near the lake (Table 11a). A similar relationship was observed in 2007-08; however, values were higher. By 2010, a similar trend occurred as in 2008 with the highest value (61.4%) recorded at LTR_L3S1 near the road and the lowest (35.7%) recorded at LTR_L3S6 near the lake. Not surprisingly given field observations, station LTR_L1S4 recorded the highest organic matter content in 2012 (62.3%), likely associated with the noticeable wrack deposit (Figure 38). LTR_L3S6 once again recorded the lowest value (32%) (Table 11a).

An almost inverse relationship was observed at LT both pre- and post-restoration. At LT, very low organic matter values were recorded at L4S1 (3.65%) in 2006, L1S4 (7.37%) in 2006-07 and L4S2 (3.1%) in 2007-08 (Table 11b). Organic matter values decreased at almost all stations post-restoration (2008 and 2010) with the lowest value (1.7 and 4.5%) once again at LT_L4S2 in 2010 and 2012 respectively and highest (40.7%) at LT_L1S8 and were generally lower than those recorded at LT-R. The organic matter values for all sampling stations along Line 4 and Line 5 were low, as expected due to the proximity of these Lines to the tidal influence from the existing culvert just north of Line 5 and the deposition of sediment originating from the drumlin above this portion of the marsh. In 2012, values at almost all stations were greater than 2010 values as well as pre-restoration with the highest value at LT_L5S1 (49.1%) likely associated with decaying wrack material.

Bulk density is a measure of the amount of pore space within a soil matrix and is dependent on the mineral make-up of soil and the degree of compaction. A low bulk density value implies a larger amount of pore space within the soil. In general, bulk density increased towards the lake and was inversely proportional to the trend in organic matter content at LT-R in 2006. The following years, however, this relationship was not as apparent. All stations recorded bulk density values between 0.08 and 0.11 $g \cdot cm^{-3}$ in 2008 (Year 1) and 2010 (Year 3) with the exception of LTR_L3S6 (> 0.20 $g \cdot cm^{-3}$ in all years). Values were slightly higher in 2012 (Year 5) with lowest values at LTR_L1S4 (0.08 $g \cdot cm^{-3}$) and greatest values at LTR_L3S6 (0.25 $g \cdot cm^{-3}$). Bulk density values of less than 1 are indicative of highly organic soils which are supported by the relatively high organic matter content found in the cores. This trend of highest organic matter values found at the upland edge and the highest bulk density values found within the low marsh is similar to trends found on salt marshes in Louisiana, Alaska, New England and the Bay of Fundy (DeLaune et al. 1979; Vince and Snow 1984; Ward et al. 1998; Bowron and Chiasson 2006a/b).

At LT, the highest dry bulk density pre-restoration was found at L4S1 (1.15 $g \cdot cm^{-3}$) which had the lowest organic matter content. Post-restoration, the highest value was recorded at L4S2 (1.01 $g \cdot cm^{-3}$ in 2008; 1.15 $g \cdot cm^{-3}$ in 2010; and 1.08 $g \cdot cm^{-3}$ in 2012) which also had the lowest organic matter content. This may be associated with the 8.2 cm of accretion recorded by the marker horizon near L4S2 in 2008 and generally high measures of inorganic sediment accretion from the eroding drumlin. The lowest bulk density values were consistently recorded at L2S2 (0.16 $g \cdot cm^{-3}$ 2006; 0.08 $g \cdot cm^{-3}$ 2010; and 0.07 $g \cdot cm^{-3}$ 2012). This station was adjacent to the pond at LT, so it was not surprising to find decaying organic matter. Generally, the bulk density values one year post-restoration were lower than pre-restoration values at LT. Values decreased at a few stations again in 2010; however, in 2012 there were a few stations that increased slightly over 2010 values.

Table 10 Sediment characteristics from core samples at the pre- (2006), one year (2008), three years (2010) and five years (2012) post-restoration a) LT-R and b) LT.

A)

Location	Water Content (%)				Organic Matter (%)				Dry Bulk Density (g·cm^{-3})			
	2006	2008	2010	2012	2006	2008	2010	2012	2006	2008	2010	2012
LTR-L1S1	85.2	86.5	76.1	81.4	65.2	58.5	36.2	49.7	0.10	0.11	0.11	0.23
LTR-L1S3	80.9	60.2	86.6	91.1	51.5	92.4	58.6	35.9	0.15	0.08	0.10	0.10
LTR-L1S4	65.9	74.9	74.5	82.4	19.8	64.9	40.5	62.3	0.39	0.08	0.11	0.08
LTR-L3S1	83.0	73.2	87.3	83.1	62.8	83.1	61.4	54.4	0.16	0.10	0.10	0.11
LTR-L3S3	86.7	77.5	85.8	90.0	59.1	78.3	56.9	43.8	0.13	0.08	0.10	0.11
LTR-L3S6	70.2	59.1	70.0	72.6	20.7	42.2	35.7	32.0	0.28	0.24	0.20	0.25

B)

Location	Water Content (%)				Organic Matter (%)				Dry Bulk Density (g·cm^{-3})			
	2006	2008	2010	2012	2006	2008	2010	2012	2006	2008	2010	2012
LT-L1S1	71.7	77.3	61.4	71.5	29.0	32.3	25.5	37.4	0.27	0.44	0.26	0.29
LT-L1S4	47.4	80.0	66.8	64.8	7.4	26.9	24.1	14.4	0.64	0.34	0.21	0.25
LT-L1S8	81.5	83.3	79.3	81.2	41.5	45.7	40.7	46.7	0.19	0.13	0.16	0.13
LT-L2S2	80.6	81.1	82.4	83.9	33.4	31.6	39.1	39.1	0.16	0.14	0.08	0.07
LT-L3S1	79.8	74.6	71.2	68.5	43.7	27.3	29.1	24.2	0.19	0.20	0.16	0.18
LT-L4S1	32.4	NA	NA	NA	3.7	NA	NA	NA	1.15	NA	NA	NA
LT-L4S2	65.8	23.0	17.8	29.5	16.0	3.1	1.7	4.5	0.71	1.01	1.15	1.08
LT-L5S1	54.2	56.6	52.5	83.3	10.5	10.3	13.1	49.1	0.65	0.39	0.45	0.23
LT-L5S2	57.6	43.1	55.2	70.7	14.6	25.6	12.5	20.6	0.53	0.33	0.27	0.37

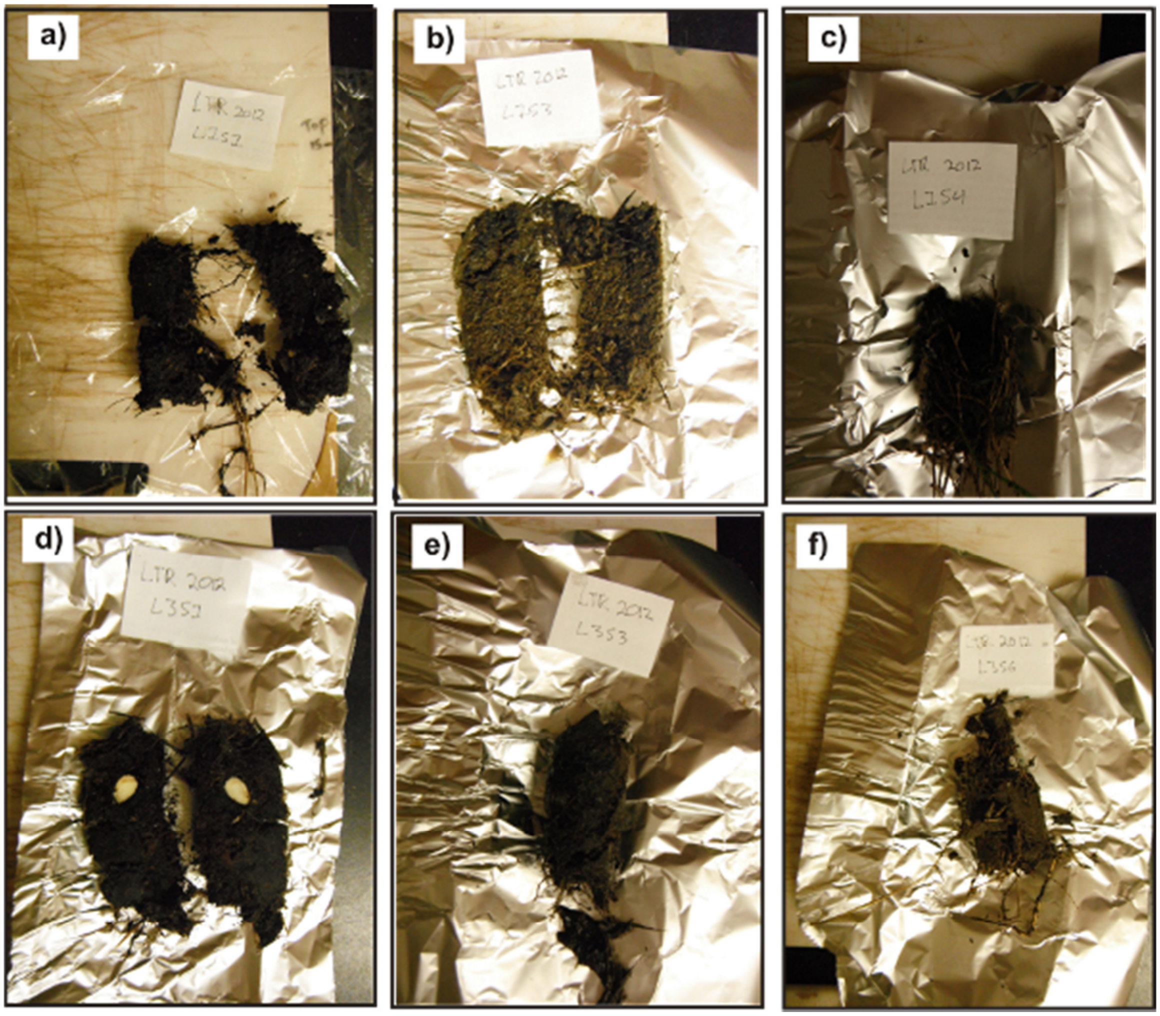


Figure 40 Split cores collected in fall 2012 at the LT-R A) LTR_L1S1; b) LTR_L1S3; c) LTR_L1S4; d) LTR_L3S1; e) LTR_L3S3 and f) LTR_L3S6.

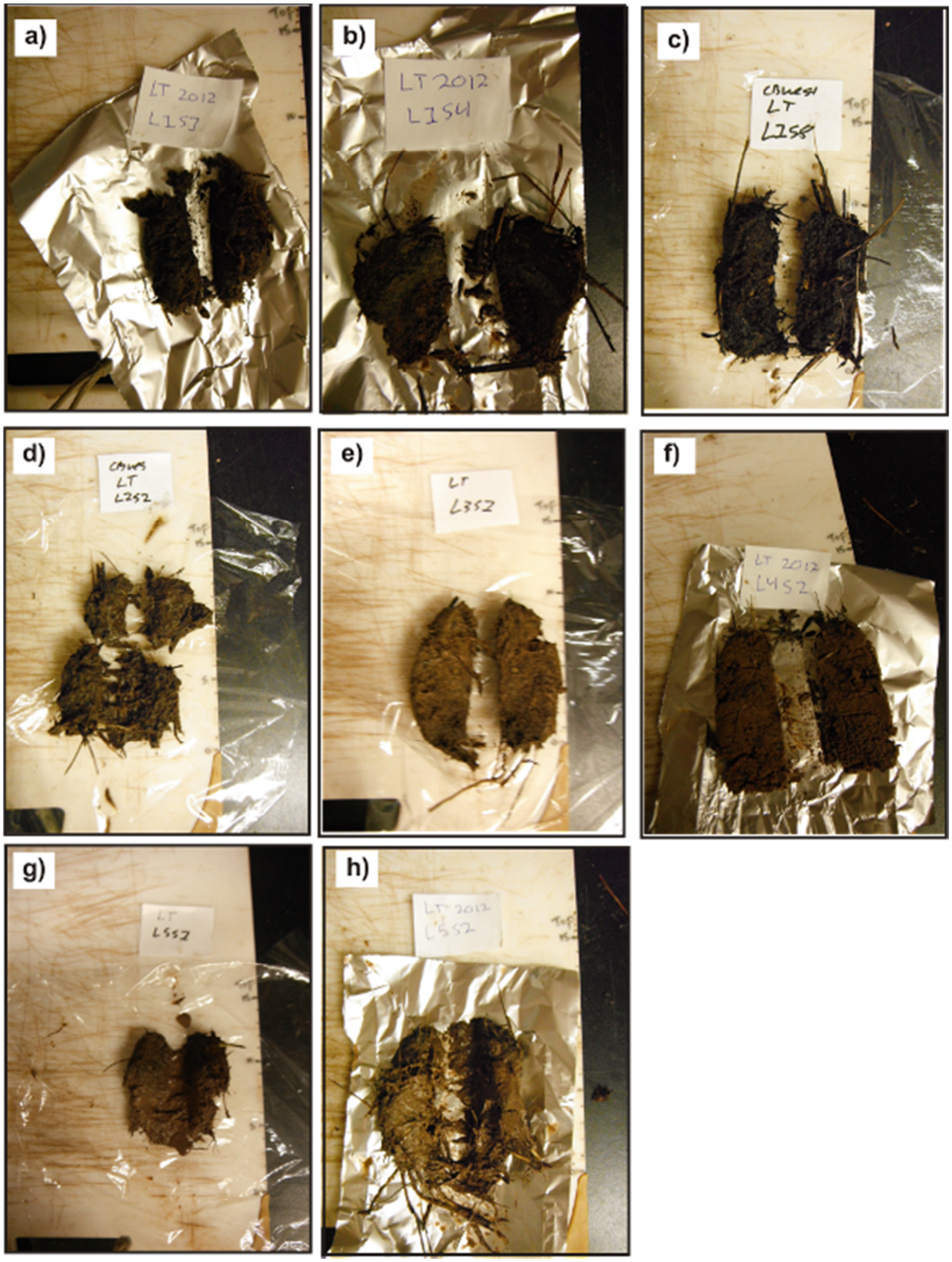


Figure 41 Split cores collected in fall 2012 at LT A) LT_L1S1; b) LT_L1S4; c) LT_L1S8; d) LT_L2S2; e) LT_L3S1; f) LT-L4S1; g) LT-L5S1 and h) LT_L5S2.

Table 11 Grain size characteristics of homogenized cores collected in 2006, 2008, 2010 and 2012 at a) LTR and b) LT. Sediment characterization determined using Folk and Ward method in GRADISTAT (Blott and Pye 2001).

a) LTR Location	Mean grain size (µm)				Size classification			
	2006	2008	2010	2012	2006	2008	2010	2012
LTR-L1S1	22.00	22.78	9.41	8.00	Coarse silt	Coarse silt	Med silt	Med silt
LTR-L1S3	26.36	26.51	8.59	6.45	Coarse silt	Coarse silt	Med silt	Fine silt
LTR-L1S4	107.6	26.91	10.39	10.56	V.fine sand	Coarse silt	Med silt	Med silt
LTR-L3S1	37.80	27.56	9.53	7.15	V. coarse silt	Coarse silt	Med silt	Fine silt
LTR-L3S3	29.54	18.65	8.33	7.84	Coarse silt	Coarse silt	Med silt	Fine silt
LTR-L3S6	67.65	38.80	11.53	9.40	V. fine sand	V. coarse silt	Med silt	Med silt

b) LT Location	Mean grain size (µm)				Size classification			
	2006	2008	2010	2012	2006	2008	2010	2012
LT-L1S1	68.66	30.97	8.82	8.92	V. fine sand	Coarse silt	Med silt	Med silt
LT-L1S4	290	66.74	9.65	11.35	Med sand	V. fine sand	Med silt	Med silt
LT-L1S8	70.5	44.22	8.21	7.63	V. fine sand	V. coarse silt	Med silt	Fine silt
LT-L2S2	25.11	24.92	6.88	6.43	Coarse silt	Coarse silt	Fine silt	Fine silt
LT-L3S1	35.21	18.32	6.09	4.94	V. Coarse silt	Coarse silt	Fine silt	Fine silt
LT-L4S1	14.81	NA	NA	NA	Med silt	NA	NA	NA
LT-L4S2	159	16.85	10.70	12.83	Fine sand	Coarse silt	Med silt	Med silt
LT-L5S1	12.71	9.55	6.70	4.98	Med silt	Med silt	Fine silt	Fine silt
LT-L5S2	13.01	8.30	6.75	5.28	Med silt	Med silt	Fine silt	Fine silt

Although all cores were processed at the In_CoaST research unit for bulk density, water and organic matter content, grain size analyses were performed at Mount Allison University in 2006 and 2008 Coulter Laser instrument and within In_CoaST using a Coulter Multiziser 3^{tm} in 2010 and 2012. The latter instrument is more accurate in the analysis of fines and results from the Coulter laser will need to be compared with caution since it tends to overestimate grain size (McCave et al. 2006) and miss the tail of fines. McCave et al. 2006 suggests that coarse clay and fine silt recorded using a Coulter Multisizer would show up as medium to coarse silt on the Coulter laser due to differences in the type of measurement. Fine sediments are typically platy in nature with a large surface area which is overrepresented using the laser method. Grain size statistics were derived using Gradistat (Blott and Pye 2001) within In_CoaST.

Soil texture of samples from both LT and LT-R consisted mostly of silt and sand (Figure 42 and Figure 36; Table 11). Although direct comparison of samples between 2010 or 2012 and other years was not possible due to differences in instrumentation, one can compare between sites. Minimal changes in sediment classification were observed at LT-R, most falling within the coarse silt range with the exception of LTR_L1S4, which changed from very fine sand to coarse silt according to the modified Udden-Wentworth grain size classification (Figure 37; Table 11). This was likely associated with the placement of the core location rather than a complete change in grain size. By 2010, all stations at LT-R recorded the same grain size class of medium silt (Table 11a); however, stations L1S1, L3S1, L3S3 decreased in grain size class. There was a chance that the readings from 2008 reflected remnants of a strong post-tropical storm that passed through the area in November 2007 and sand deposits from the Lawrencetown Beach dune system across the road. Post-tropical storm Noel occurred during the culvert installation phase and Figure 36 and Figure 37 provide evidence of the extent of over-wash deposits that may occur during a major storm event, influencing the sediment composition along Line 1 (LT) and along the road at LT-R. No other evidence of storm deposits was found in subsequent years despite significant storms in the region, although evidence of surface erosion from the drumlin at the back of the site would contribute sedimentary material. Similar studies on both restricted and unrestricted salt marshes in the Bay of Fundy showed a general trend of increasing mean grain size with distance from the watercourse (van Proosdij et al. 1999; Bowron and Chiasson 2006a/b). This was mostly attributed to the mechanism of marsh formation in these locations rather than the mechanics of particle settling during flooding. A larger range of grain sizes were observed at LT. Pre-restoration, the smallest grain sizes were found on Line 5 (12.71-13.01 µm medium silt) near the old culvert and the largest (290 µm medium sand) at L1S4. Given its proximity to the road and adjacent dune complex, this may also represent a storm deposit. Post-restoration in 2008, Line 5 still had the smallest grain sizes despite increasing the size of the culvert and the largest grain size (66.74 µm very fine sand) was still recorded at L1S4. In 2010 and 2012, there was an even distribution of fine to medium silt with the smallest grain size (6.09 and 4.94 µm) recorded at LT_L3S1 and the largest (10.70 and 12.83 µm) at LT_L4S2 similar to previous years. These small grain sizes and similarity to LT-R suggest deposition from suspended sediment rather than storm or ice deposits.

A significant advantage of the Coulter Multisizer is the ability to perform disaggregated grain size analysis and plot grain size versus normalized volumetric concentration (Figure 43). The shape of the curve is an indication of both source material and transport mechanism (Krank and Milligan 1985), specifically transport as single grains or as flocs. Flocculation is the development of an aggregate of fine particles, which assembles to fabricate a porous bunch of sediment larger than equivalent individual single grains. Sedimentation is greatly dependent on the flocculation of particles in both a matter of how much deposits and also where on the marsh it deposits. A floc contains particles of all grain sizes which would have a smaller settling rate if it were in single form. The settling rate of small particles which are included in flocs can be several orders of magnitude greater than it would be individually (Milligan et al. 2007). After flocs deposit, they are an amalgamation of both the flocculated flux and the single grain flux when consolidated on the bed. They cannot be distinguished from the single grains as both forms are now together on the bed. Analyzing the disaggregated inorganic grain size distributions of the sediment with the use of a parametric model, the inverse floc model, is a way to comprehend the depositional process that the particles carried through, therefore determining if the particle settled in floc form or single grain form (Curran et al. 2004). This analysis, however, was only available for samples collected in 2010 and 2012.

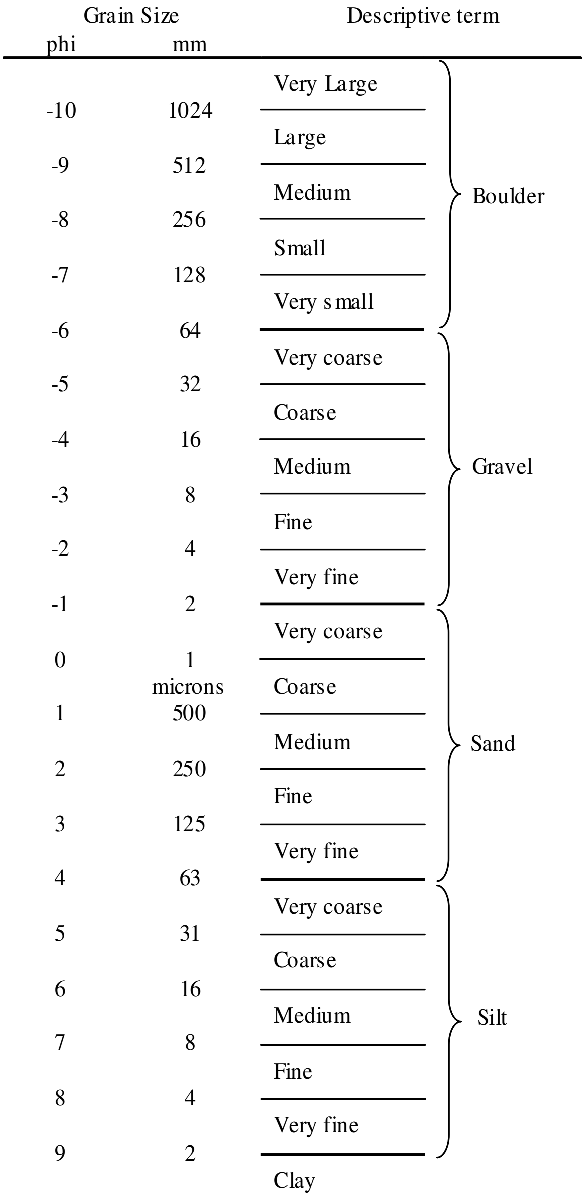


Figure 42 Size scale adopted in the GRADISTAT program, modified from Udden (1914) and Wentworth (1922) (Blot and Pye 2001).

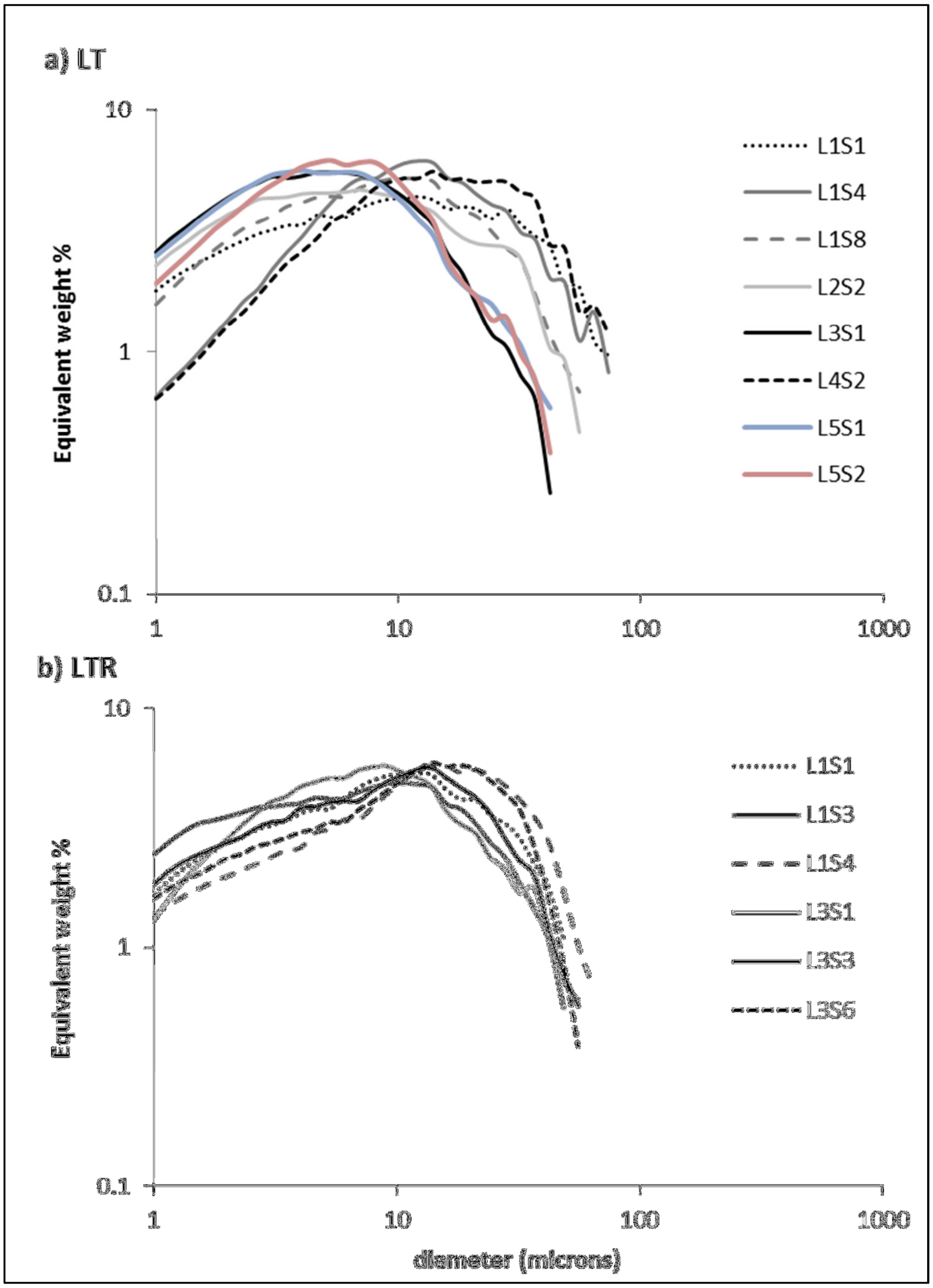


Figure 43 Comparison of Grain size spectra of top 5 cm of sediment determined by the Coulter Multisizer at Lawrencetown in fall 2012 at a) LT and b) LTR.

All stations at LT-R displayed similar curves with limited single grain settling (Figure 43b). The grain size spectra at LT were more varied. Similarities were observed between LT_L1S1, L2S2 and L1S8 (Figure 43a) and they resembled LT-R. LT_L4S2 and LT_L1S4 reveal a sharp coarser tail, which could indicate a different transport mechanism. Overall, LT appeared to be trending towards conditions observed at LT-R; however, both sites were significantly influenced by extrinsic variables and sediment supply.

Because flocs take particles from the water column, which are unsorted and therefore in the same proportion that is found in the suspended material, they are unbiased samplers of the parent material in suspension (Milligan et al. 2007). The second Matlab script used was *Drawers*, which used the inverse floc model developed by Curran et al. 2004. Its output consisted of floc fraction (K_f) which is the portion of the deposited sediment which was deposited in flocculated form and the floc limit (d_f) which is the size which has the same amount of grains in flocculated form as in single grain form. It also displayed the source slope (*m*) which represents the source material and the dhat (^*d*) that is the roll-off diameter and represents the size of the largest grain in suspension (Curran et al. 2004).

Table 12 Inverse floc model statistics at Lawrencetown in 2012 at a) LT-R and b) LT.

a) LTR Location	**Rolloff Diameter (*dhat*)**	**Floc Fraction (K_f)**	**Floc Limit (d_f)**	**Source Slope (m)**
LTR-L1S1	13	0.62	12	0.47
LTR-L1S3	13	0.68	12	0.26
LTR-L1S4	19	0.53	12	0.41
LTR-L3S1	11	0.75	16	0.80
LTR-L3S3	16	0.67	14	0.40
LTR-L3S6	18	0.57	12	0.35

b) LT Location	**Rolloff Diameter (*dhat*)**	**Floc Fraction (K_f)**	**Floc Limit (d_f)**	**Source Slope (m)**
LT-L1S1	16	0.66	16	0.40
LT-L1S4	9	0.37	7	1.02
LT-L1S8	13	0.72	16	0.59
LT-L2S2	10	0.69	12	0.42
LT-L3S1	9	0.77	12	0.50
LT-L4S1	NA			
LT-L4S2	10	0.37	8	0.95
LT-L5S1	9	0.77	12	0.56
LT-L5S2	8	0.75	12	0.80

Over 53% of the deposited material at LT-R fell as flocs rather than single grains. While LT reported similar floc fractions, some differences were observed. At LT, the lowest floc fraction (37%) was recorded at L1S4, which also recorded the second highest grain size (Table 11). Most of the stations shared a similar source slope or parent material (Table 12); however, there were a number that stood out. LT_L1S4, L4S2 and L5S2 shared very similar source slope values greater than 80 (Table 12) suggesting similar source material or transport mechanism. These values were also consistent with LTR_L3S1 located adjacent to the road.

Overall, the re-introduction of tidal flow to LT has resulted in a healthy salt marsh ecosystem. Sediment analysis indicates the substrate composition of LT is starting to trend towards LT-R; however, there are uncertainties that will remain.

4.4 Vegetation

Similarities between LT-R and LT include: both sites have roughly equivalent amounts of species such as *Carex paleacea*, *Calystegia sepia*, *Festuca rubra, Hierochloe odorata, Potentilla anserina, Solidago sempervirens, S. pectinata*, and these have fluctuated little over latter part (Years x to y) of the monitoring program (Table 13). These species are somewhat salt tolerant and likely represent a brackish meadow community. Many of these species were characteristic of plots in the middle-right of Figure 46. *Atriplex glabrisculata* was also roughly equal in abundance at both sites, but tended to occur in more saline parts of the sites. *S. alterniflora* increased at LT to the point where overall average abundance was similar between the sites (Table 13); however, most of this change was due to a single plot at LT.

Differences between LT-R and LT include: within the same general type of habitat, e.g. brackish, there were consistent differences among sites for *Juncus balticus* (more at LT). There were also upland species, freshwater wetland, or wet meadow species at the LT that were not present or were uncommon at LT-R (*Mentha arvensis, Myrica gale, Lysimachia terrestris*). Plots on the right side of Figure 46 tended to be LT plots and contained a number of these species. Plots on the left of Figure 46 were dominated by salt marsh grasses (*S. alterniflora*, left middle; *S. patens*, center lower left) and were much more common at LT-R compared to LT.

Many of the LT plots remained similar in plant species composition over the seven year monitoring program. For example, LT_L1S1 had roughly equal abundance of *Calamagrostis canadensis* in all seven years. LT_L4S2 had high cover of *S. alterniflora* throughout the monitoring period and LT_L1S10 had fairly consistent abundance of *Carex paleacea*. This consistency of plant community composition was common to most of the plots at LT.

In a few plots, there did appear to be a signature of increased salinity post-restoration. LT_L3HM appeared to shift between a *Myrica gale* dominated-community, to one dominated by *Juncus balticus* (which may have a greater salt-tolerance) by 2012. A minority of plots (e.g. LT_L5S3, and LT_L5S2: Figure 51) showed increases in *Artriplex glabrisculata* in 2008 (immediately post-restoration of tidal flow), consistent with the idea that increased salinity due to restoration activities will cause die-off of some non-halophytic plants, and these areas will be colonized by halophytic pioneer species (annuals such as *Atriplex*, *Suaeda* and *Salicornia*),

Overall trends in other indicators showed a decline in average plot species richness followed by an increase in the last three years at LT (Table 14, Figure 47). This suggests that some species were lost following restoration of tidal influence but other, more salt tolerant species may have colonized in recent years (e.g. *Spergularia canadensis*, Table 13). Halophytic species richness increased over time in both sites, and was equivalent in LT and LT-R (Table 15, Figure 48). These trends were fairly subtle and may simply represent increased detection ability of the plant identification team. Conversely, LT-R had significantly more halophytic species on average in 2006 and in the last few years, LT has become more similar. Average halophyte abundances were initially lower in LT, but have caught up in recent years (Table 16, Figure 49). Species that increased include *S. alterniflora*, but overall changes were subtle and only detectable at the scale of the entire site; individual plots mainly had consistent community structure across the study period. The amount of unvegetated area on both marshes was highly variable across years, likely due to the formation and disappearance of pannes (Table 17, Figure 50).

In summary, the vegetation community at LT has shown minimal changes over the monitoring program, with the greatest impact of restoration activities confined to a few plots (such as Figure 52). There were distinct differences in the overall species composition between the two sites. LT still contained more plots with upland or freshwater species, which were likely too high in elevation to be influenced by the increased tidal flow post-restoration.

Table 13 Mean plot abundances for major species at LT and LT-R 2006-07 and 2011-12 only.

	LT06	LT-R06	LT07	LT-R07	LT11	LT-R11	LT12	LT-R12
Agrostis stolonifera	5.8		6.6	2.2	3.8	1.9	5.5	1.7
Atriplex glabrisculata			1.0	0.1	0.2	0.1	0.3	0.2
Calamagrostis canadensis	0.9		4.4	0.0	3.6		3.3	
Calystegia sepia			0.6	0.2	0.1	0.2	0.3	0.1
Carex brunnescens							0.3	
Carex hormathodes			0.2		0.1		0.5	0.7
Carex paleacea	4.6	5.9	6.0	6.2	6.7	5.3	8.6	6.0
Chelone glabra			0.1		0.3			
Dryopteris cristata			0.2				0.3	
Eleocharis parvula							0.6	
Elymus repens	0.2							
Equisetum arvensis	0.4		1.9		0.3		0.6	
Festuca rubra	0.4	0.0	10.6	7.5	8.0	6.5	9.2	7.1
Filipendula ulmaria							1.3	
Gallium mollugo							0.8	
Gallium palustre			0.8	0.3	0.6	0.4		0.1
Hierochloe odorata	0.8		4.1	3.2	1.8	3.0	3.1	2.2
Impatiens capensis	0.0				0.5			
Iris versicolor			0.1				0.2	
Juncus arcticus							0.1	
Juncus balticus	0.2		9.6	4.4	8.1	4.6	11.3	4.8
Juncus effusus		1.2						
Lathyrus maritima							0.3	1.0
Lycopus americana		0.2					0.2	
Lycopus uniflora	0.1		0.5		0.5			
Lysimachia terrestris	0.1		1.1		0.1		0.4	
Maianthemum stellata			0.1					
Mentha arvensis				0.1	0.1		0.5	0.2
Myrica gale	0.9		2.8	0.5	0.2			
Onoclea sensibilis	0.2		0.1				0.5	
Poa palustris			1.3		0.3	1.2		0.9
Polygonum sagitatum			0.3		0.6		0.1	
Potentilla anserina	0.1	0.2	0.2	0.6	0.3		0.2	0.2
Potentilla palustris			0.2	1.2	0.4	1.2	0.8	0.9
Rosa virginiana			0.4		0.5			
Rubus pubescens					0.2		0.9	
Salicornia europea			0.1		0.2		0.2	0.1
Scirpus americana			0.2		0.7		1.0	
Scutellaria galericulata			1.5	0.7	0.1	0.1	0.4	
Solidago sempervirens	0.1	0.1	0.2	0.3		0.1	0.2	0.4

	LT06	LT-R06	LT07	LT-R07	LT11	LT-R11	LT12	LT-R12
Spartina alterniflora	3.7	6.7	4.4	5.7	4.0	6.2	5.0	4.3
Spartina patens	2.9	10.0	2.9	7.9	2.6	8.2	3.0	10.3
Spartina pectinata	1.3		1.9	1.0	2.9	1.8	1.8	1.2
Spergularia canadensis							0.6	
Spirea latifolia	0.4		0.3		0.7			
Symphotrichum lanceolata	0.4						1.0	0.5
Symphotricum novi-belgii	0.9	0.1	2.6	0.9	0.2	0.6		0.3
Thalictrum pubescens			0.4		0.1			
Thelypteris palustris							0.2	
Triglochin maritima				0.2			0.2	0.1
Typha latifolia								0.1
Vaccinium macrocarpon						0.1		0.4
Vicia sp.			2.9	1.6	0.5	0.6	0.1	0.1

Table 14 Mean plot species richness comparing LT-R and LT over time.

Between plots	**Df**	**Sum Sq**	**Mean Sq**	**F**	**P**
Site	1	413.3	413.3	5.584	0.0233
Year	3	866.3	288.8	3.901	0.0159
Site x Factor	1	346.5	346.5	4.681	0.0368
Residuals	38	2812.6	74.0		
Within plots					
Year	6	218.5	36.42	12.297	<0.0001
Site x Year	6	87.9	14.66	4.949	<0.0001
Residuals	244	722.7	2.96		

Table 15 Mean plot halophytic species richness comparing LT-R and LT over time.

Between plots	**Df**	**Sum Sq**	**Mean Sq**	**F**	**P**
Site	1	4.20	4.204	0.984	0.327
Year	3	11.31	3.770	0.882	0.459
Site x Year	1	0.63	0.626	0.146	0.704
Residuals	38	162.36	4.273		
Within plots					
Year	6	24.99	4.164	7.666	<0.0001
Site x Year	6	7.90	1.317	2.424	0.0271
Residuals	244	132.54	0.543		

Table 16 Mean plot halophytic species abundance comparing LT-R and LT over time.

Between plots	**Df**	**Sum Sq**	**Mean Sq**	**F**	**P**
Site	1	3236	3536	5.992	0.0191
Year	3	1983	661	1.120	0.3530
Site x Year	1	17	17	0.029	0.8658
Residuals	38	22429	590		
Within plots					
Year	6	384	64.06	1.41	0.211
Site x Year	6	431	71.77	1.58	0.153
Residuals	244	11083	45.42		

Table 17 Mean plot unvegetated area comparing LT-R and LT over time.

Between plots	**Df**	**Sum Sq**	**Mean Sq**	**F**	**P**
Site	1	82.6	82.65	2.149	0.151
Year	3	48.3	16.12	0.419	0.740
Site x Year	1	11.7	11.70	0.304	0.584
Residuals	38	1461.1	38.45		
Within plots					
Year	6	106.3	17.72	1.543	0.165
Site x Year	6	115.9	19.31	1.682	0.126
Residuals	244	2801.8	11.48		

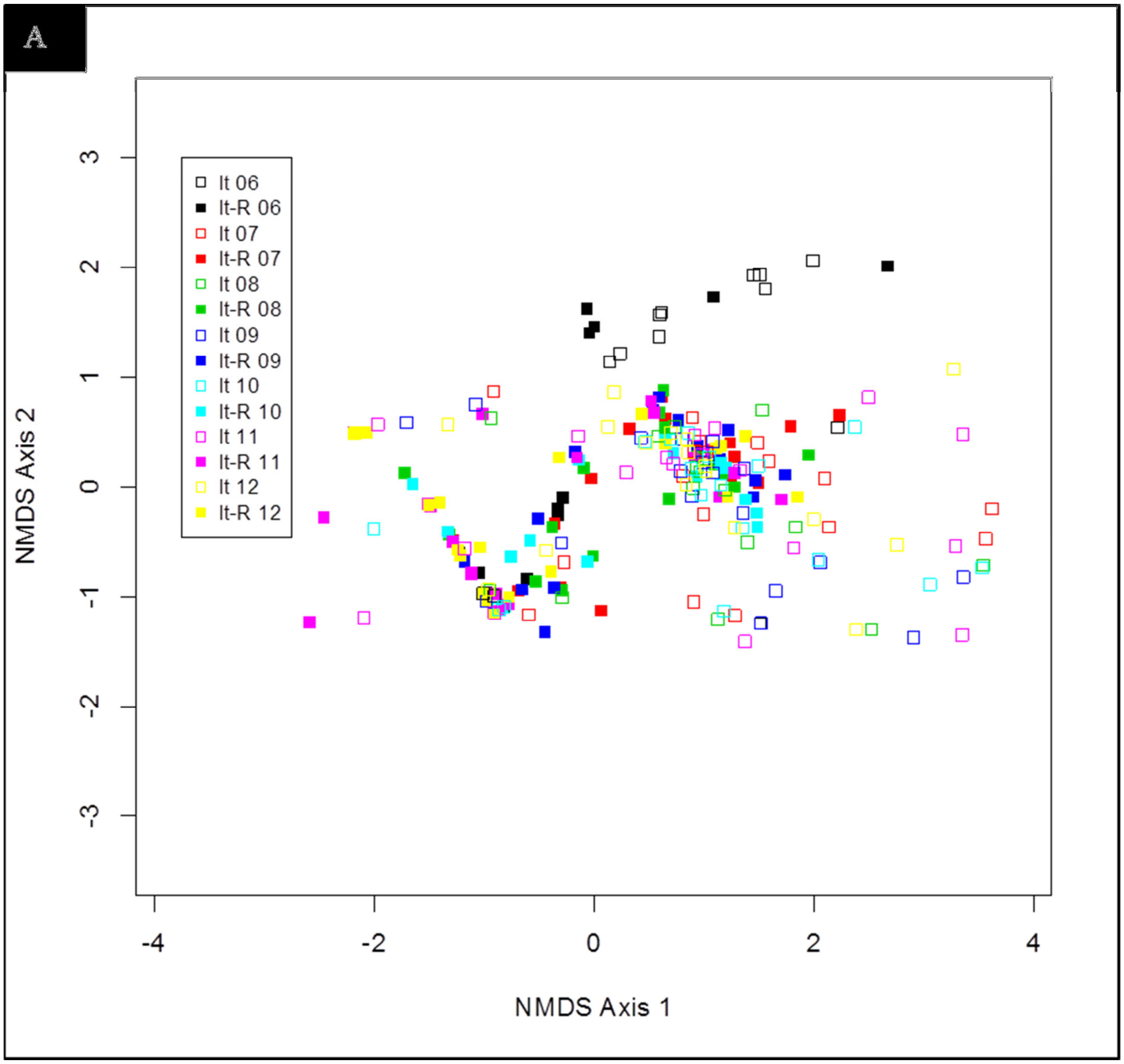


Figure 44 Non-metric multidimensional scaling ordination of plant species composition/abundance at LT and LT-R: A) plots (vegetation plots closer together have more similar species composition and abundances); B) species plotted in same ordination space as plots; and C) 2006, 2007, 2012 only.

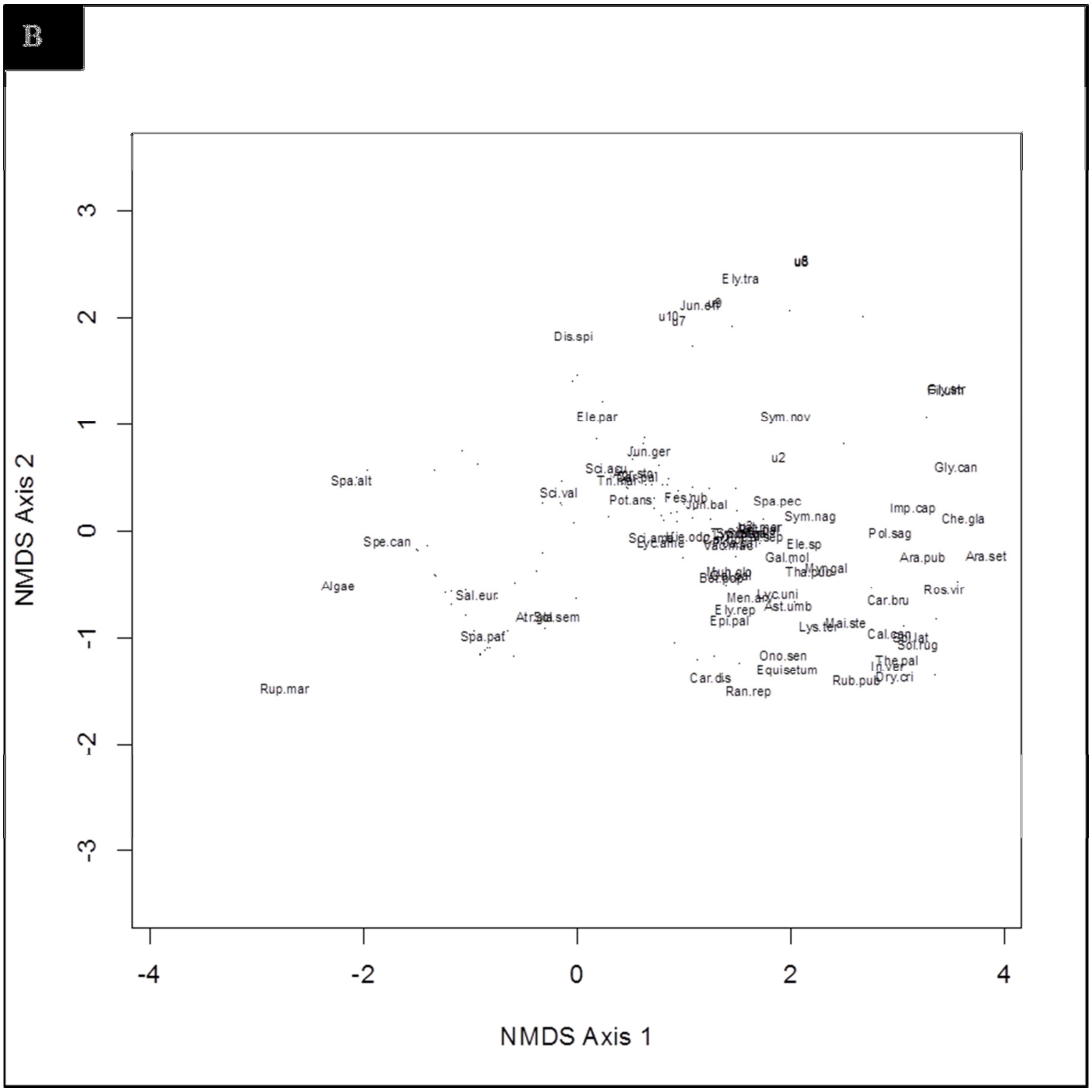


Figure 45 Non-metric multidimensional scaling ordination of plant species composition/abundance at LT and LT-R: A) plots (vegetation plots closer together have more similar species composition and abundances); B) species plotted in same ordination space as plots; and C) 2006, 2007, 2012 only.

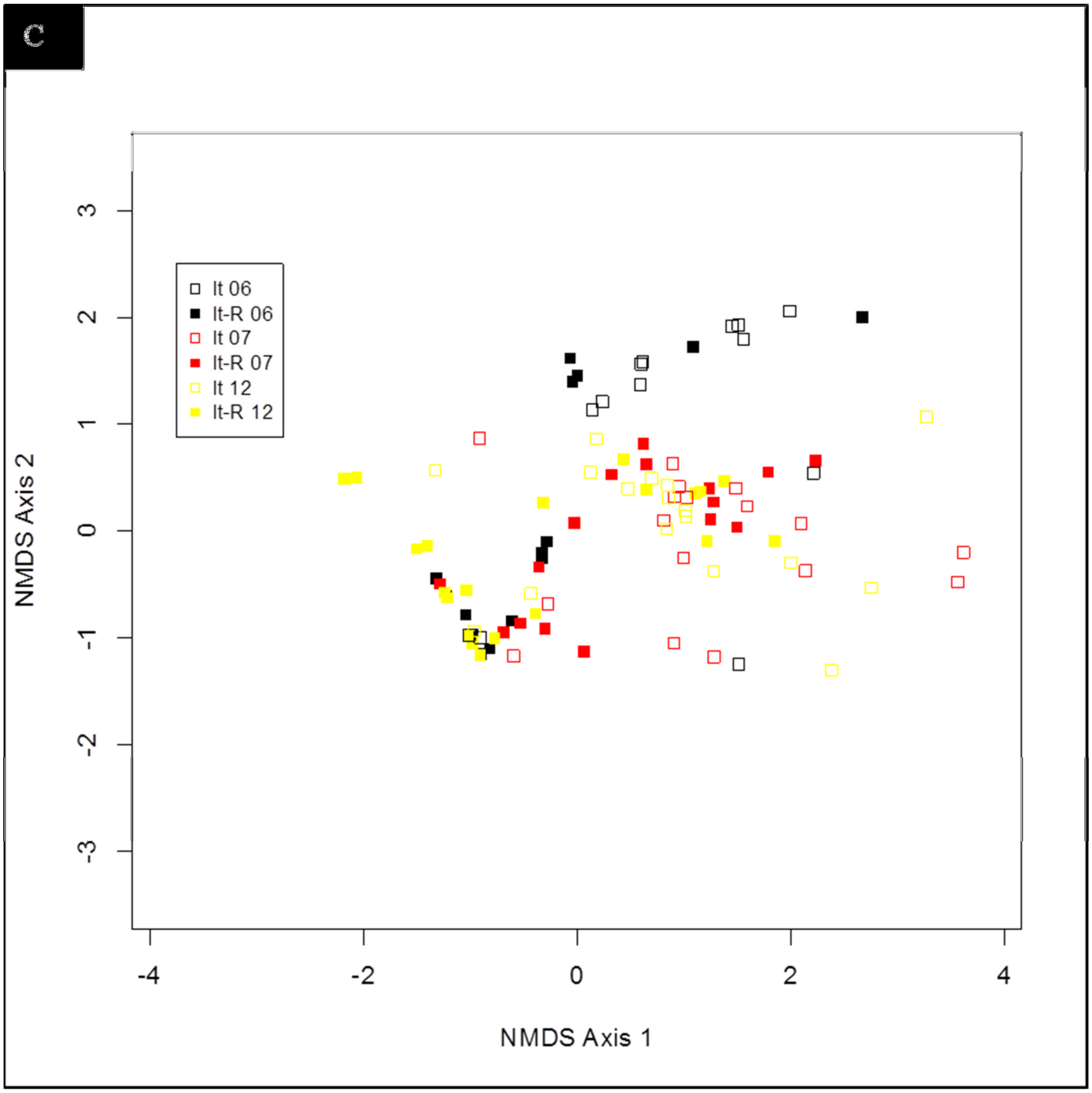


Figure 46 Non-metric multidimensional scaling ordination of plant species composition/abundance at LT and LT-R: A) plots (vegetation plots closer together have more similar species composition and abundances); B) species plotted in same ordination space as plots; and C) 2006, 2007, 2012 only.

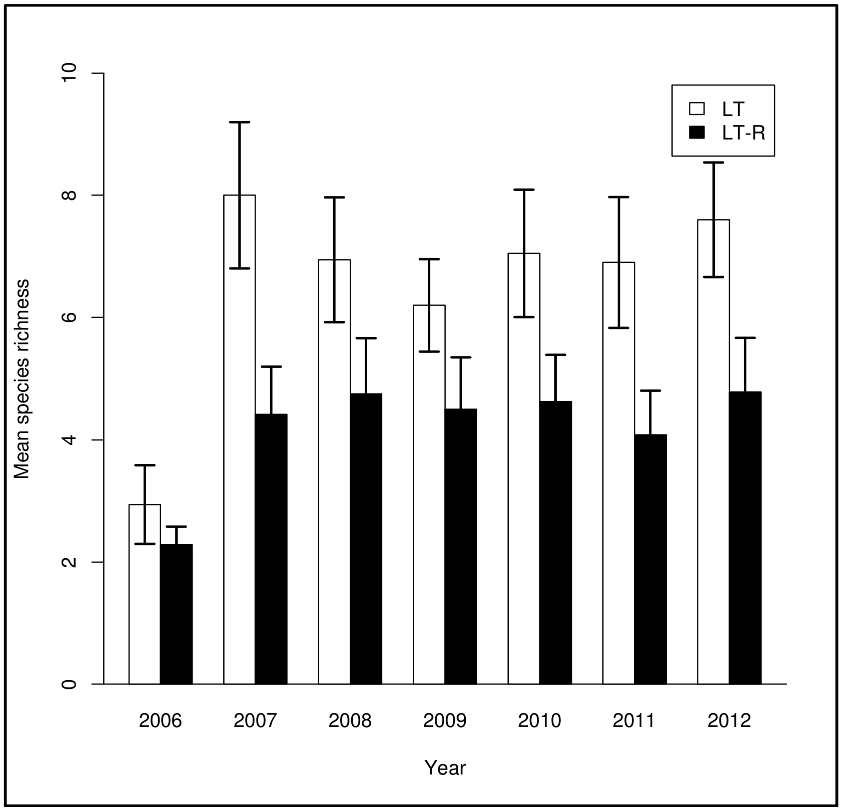


Figure 47 Mean species richness at LT and LT-R.

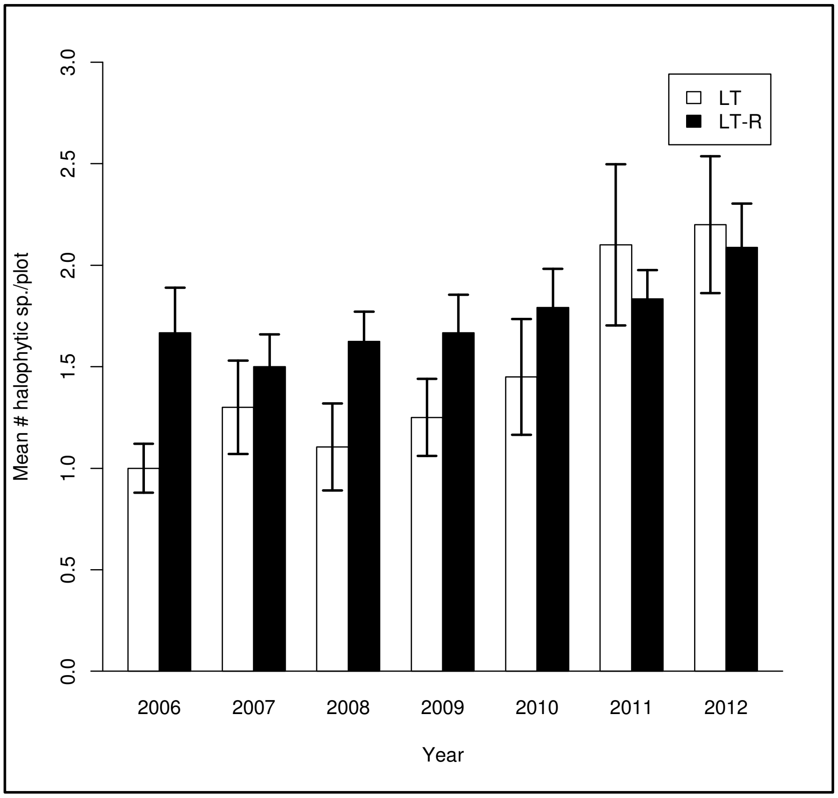


Figure 48 Mean halophytic species richness at LT and LT-R.

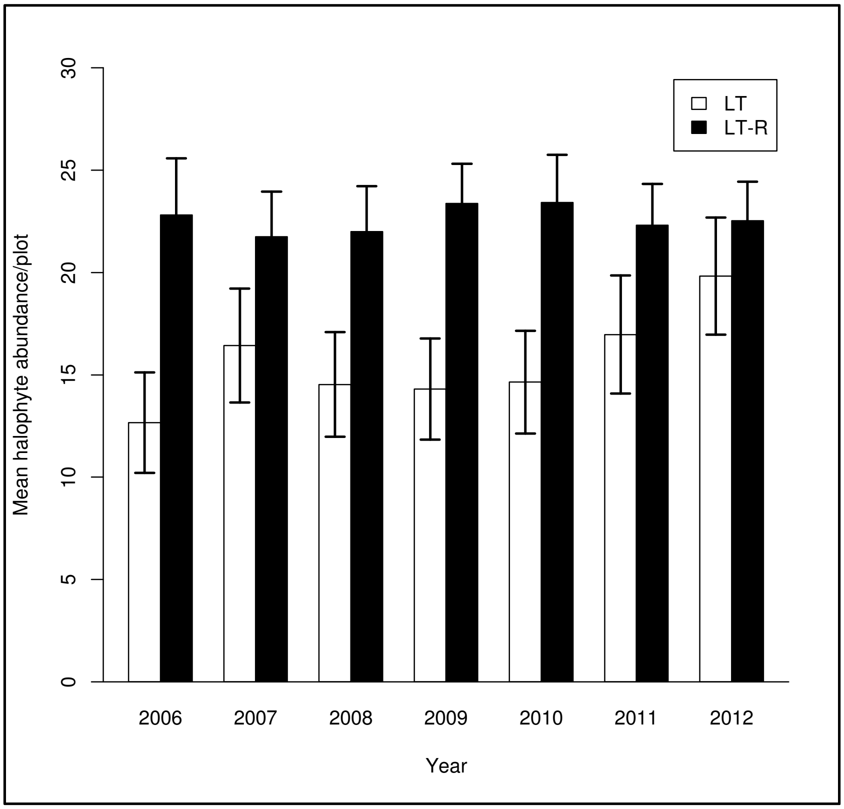


Figure 49 Mean halophytic species abundance at LT and LT-R.

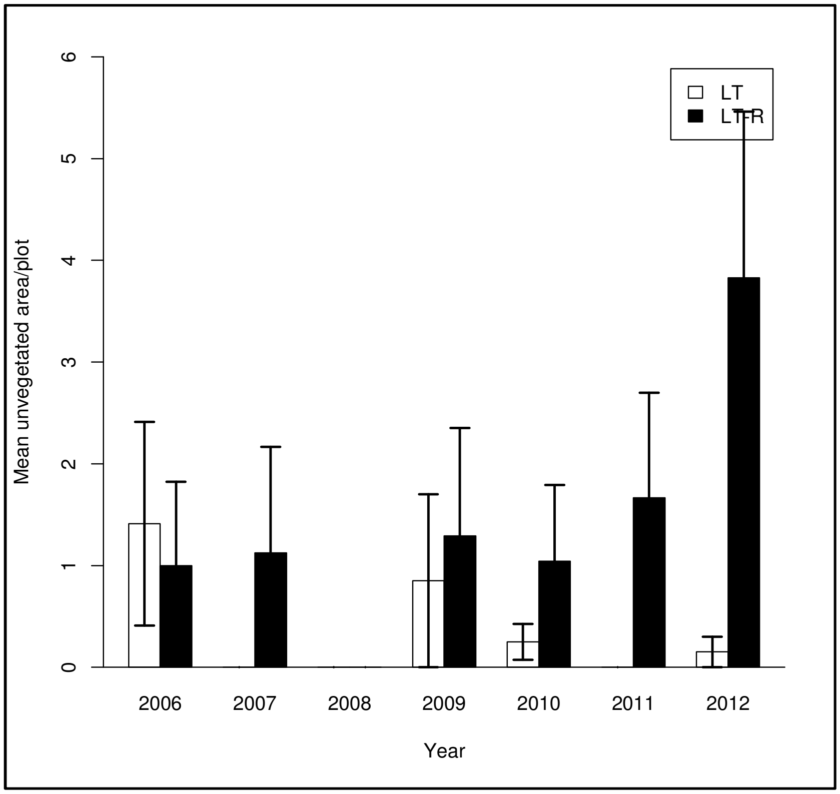


Figure 50 Mean unvegetated area at LT and LT-R.

Figure 51 Landscape photographs of LT during the vegetation surveys of August 2007 (A, B: pre-restoration) and August 2012 (C, D: five years post-restoration).

Figure 52 Change at Line 3 over the five years of the post-monitoring program A) 2007; B) 2010; and C) 2012. Photographs were taken during the vegetation surveys in August for 2007 and 2010 and in July for 2012.

4.5 Nekton

For the pre-restoration surveys at LT, only minnow traps were used as the other methods were either unavailable or conditions did not allow their use. Individuals from eleven nekton species were encountered during the survey work at LT and LT-R during the 2012 season (Table 19). Twenty different nekton species were encountered during the monitoring program. LT-R has had a greater species diversity (9-12 species) compared to LT (6-8 species) every year during the seven years of monitoring (pre- and post-restoration; Table 19). LT-R has also had a greater total catch than LT for all years except 2009 (Year 2) and 2012 (Year 5) (Table 19). 2012 had the largest catch at LT for all years pre- or post-restoration, almost three times the catch at LT-R (Table 19). In 2011 the total catch for each site was similar (Table 19). However, the total catch average for the post-restoration monitoring program at LT-R was 766 and at LT 687.

Over the five years of post-restoration monitoring, the dominant species caught at LT has been a combination of Mummichogs (*Fundulus heteroclitus*), Atlantic silversides (*Menidia menidia*), and Three-spine sticklebacks (*Gasterosteus aculeatus*) (Table 19). This was similar to LT-R, although crabs were also dominant at this site in 2009 and 2011 (Table 19).

For the seven years of pre- and post-restoration monitoring, the relative abundance average for the minnow traps was similar at LT (23.41) and LT-R (24.76), with a similar sample size (Table 18). The minnow trap relative abundance fluctuated year to year with no clear trend, especially for LT, found between pre- and post-restoration surveys (Table 18). Although the fyke net and beach seine cannot be compared, it should be noted that the relative abundance average, including all years the method was used, was similar for each survey method, but with significantly less sample numbers of the fyke net (Table 18). This illustrates the fish habitat restoration value of LT, especially considering its small size compared to other restoration sites being monitored in the region (Cheverie Creek, Walton River, St. Croix, and Cogmagun River).

The standard length average and range were calculated for the most common species caught at LT and LT-R for each year pre- and post-restoration. Although the methods used for LT-R and LT differed, juveniles and adults were still represented at both sites. The Mummichog had a similar standard length average for LT-R (53) and LT (56), with a range of 30 to 80 at LT-R and 30 to 90 at LT (Table 20). The Atlantic silverside had a higher standard length average at LT-R (85) than LT (58), with a range of 10 to 140 and 30 to 90 at LT-R and LT respectively. The Three-spine stickleback had similar standard length averages, but the ranges differed with LT-R having higher length values and LT lower (Table 20).

The species caught at LT were expected as they are found in salt marsh habitat. Mummichogs are a resident species of salt marshes and are more likely to be found in brackish pools (pannes) where they can burrow into the much at low tide (Gibson 2003). Atlantic silversides, as well as Three-spine sticklebacks, are known to swim into salt marshes at high tide to forage (Gibson 2003). Therefore, the presence of a large number of these species in the fyke net and minnow traps at LT is indicative that this site is used as fish habitat.

There are many factors that can affect the number of individuals caught during a nekton survey. These include survey type, net placement and species behaviour. For example, installing the fyke net in different places will sometimes yield differing catches. If it is placed across a channel, which captures most of the outflow of the site, the net will likely yield a high catch: sometimes too high. Then species such as the Atlantic silverside, which often swim in a large school, can change the total catch number by the hundreds. There are also surveys where the unexpected can occur. The high total catch at LT in 2012 was attributed to a large number of Mummichogs captured in the fyke net, which was placed in an area that previously did not yield such a high catch.

Table 18 Relative abundance for each sampling method at LT and LT-R, for pre- and five years post-restoration. Sample size is the total number of samples over the five years of sampling.

Year	LT Minnow Trap	LT-R Minnow Trap	LT Fyke	LT-R Seine
2006	23.00	14.00		887.00
2007	31.17	31.83		207.57
2008	6.00	15.25	434.00	380.25
2009	2.00	15.17	622.00	50.83
2010	45.17	60.83	107.67	106.00
2011	23.75	21.00	119.50	57.40
2012	32.75	15.25	659.50	74.83
Total	**163.84**	**173.33**	**1942.67**	**1763.88**
Average	**23.41**	**24.76**	**388.53**	**251.98**
	n=30	n=32	n=9	n=36

Table 19 Percent composition of total catch of fish species at LT and LT-R, all methods, all years.

		2006		**2007**		**2008**		**2009**		**2010**		**2011**		**2012**	
Common Name	**Species Name**	**LTR**	**LT**	**LTR**	**LT**	**LTR**	**LT**	**LTR**	**LT**	**LTR**	**LT**	**LTR**	**LT**	**LTR**	**LT**
Alewife (Gaspereaux)	*Alosa pseudoharengus*					1.1		5.4	3.8			7.7		0.7	
Atlantic Silverside	*Menidia menidia*	19.6		31.2		2.8	19	24.4	31.8	40.6	0.5	5.6	15.5	44.6	11.2
Mummichog	*Fundulus heteroclitus*	4.5	93.5	13.1	99.5	5.9	70.1	9.2	16	38.6	82.2	17.8	29.8	16.1	78.6
Three-spine stickleback	*Gasterosteus aculeatus*	62.2		28.8		31.7	2.2	35.4	47.6	4.3	15.6	45.5	49.9	29.4	4.7
Nine-spine stickleback	*Pungitius pungitius*	12.2	6.5	24.5	0.5	1.1	5.2	1.2	0.2	0.9	0.2	3.5	0.3	0.2	0.5
Four-spine stickleback	*Apeltes quadracus*					0.3	1.1	0.3		6.8	0.8	0.3	0.3	0.2	0.3
Banded Killifish	*Fundulus heteroclitus*						0.2								
Flounder sp		0.2		0.2		0.3		1.8		0.4		1.3		0.4	
Tommy Cod	*Microgadus tomcod*							0.9		0.2		0.5			
Rainbow Smelt	*Osmerus mordax*									0.1		0.5			
Sculpin sp	*Cottoidea sp*	0.3				0.1		1.2		0.3		0.3		0.2	
Pipefish sp	*Syngnathinae sp.*			0.1											
Jellyfish	*Medusozoa sp.*											0.5			
American Eel	*Anquilla rostrata*					1									
Glass Eel	*Anquilla rostrata*	0.1		0.1											
Atlantic Rock Crab	*Cancer irroratus*	0.1								0.3				0.2	0.9
Green Crab	*Carcinus maenas*	0.2		1.9		13.5		20.2	0.6	7.4	0.7	16.5	4.2	7.3	3.7
Sand shrimp	*Crangon septemspinosa*	0.6				43.1	2.2								
Unknown Species 1	-													0.7	0.1
LT Unknown A 07	-			0.1						0.1					
	TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	TOTAL CATCH	**1802**	**46**	**1644**	**199**	**1582**	**458**	**336**	**630**	**1001**	**594**	**376**	**335**	**534**	**1426**

Table 20 Standard length (SL) average and range in mm for the most common fish species caught at LT and LT-R.

		SL Average (mm)		SL Range (mm)	
Date	Species	LT-R	LT	LT-R	LT
Pre	Mummichug	43	47	20 to 80	30 to 85
	Atlantic Silverside	78	0	40 to 130	0
	Nine-spine stickleback	42	50	30 to 60	40 to 50
	Three-spine stickleback	35	0	25 to 60	0
	Flounder sp.	100	0	70 to 170	0
2008	Mummichug	56	47	35 to 100	30 to 85
	Atlantic Silverside	81	65	30 to 110	55 to 80
	Nine-spine stickleback	51	51	35 to 100	40 to 85
	Three-spine stickleback	45	50	25 to 85	40 to 75
	Four-spine stickleback	38	40	30 to 45	30 to 50
	Flounder sp.	96	0	90 to 100	0
2009	Mummichug	41	45	30 to 60	20 to 70
	Atlantic Silverside	86	35	40 to 120	10 to 90
	Nine-spine stickleback	38	40	30 to 40	40
	Three-spine stickleback	44	47	30 to 60	20 to 70
	Four-spine stickleback	50	0	50	0
	Flounder sp.	82	0	70 to 110	0
2010	Mummichug	45	46	30 to 70	25 to 90
	Atlantic Silverside	86	45	55 to 130	40 to 50
	Nine-spine stickleback	42	35	25 to 65	35
	Three-spine stickleback	43	32	30 to 85	20 to 25
	Four-spine stickleback	42	40	35 to 50	35 to 55
	Flounder sp.	85	0	40 to 150	0
2011	Mummichug	47	53	30 to 60	35 to 80
	Atlantic Silverside	73	70	10 to 100	50 to 80
	Nine-spine stickleback	46	50	40 to 60	50
	Three-spine stickleback	42	38	30 to 60	30 to 70
	Four-spine stickleback	40	40	40	40
	Flounder sp.	119	0	85 to 140	0
2012	Mummichug	53	56	30 to 80	30 to 90
	Atlantic Silverside	85	58	10 to 140	30 to 80
	Nine-spine stickleback	0	46	0	40 to 50
	Three-spine stickleback	39	38	40 to 70	25 to 55
	Four-spine stickleback	45	43	45	35 to 50
	Flounder sp.	80	0	70 to 90	0

4.6 Benthic and Other Aquatic Invertebrates

Benthic Invertebrates

In 2012, the benthic samples at LT had 14 species, compared to 16 species at LT-R, typically marine/estuarine species. Mean species richness for the samples from LT was higher in all years post-restoration compared to the baseline (Figure 55). There was no clear trend for species richness when LT and LT-R (panne and lake samples separated) were compared over time. In 2012, LT had the highest abundance for all years pre- and post-restoration (Figure 56). It appeared that abundance was increasing each year post-restoration at LT, but 2011 (Year 4) saw a very low abundance of species. Abundance in the samples at LT and LT-R appear to be higher than the baseline condition. When looking at LT samples for panne and lake together, LT had a higher abundance than baseline values for all years post-restoration, except for Year 3.

In 2012, the dominant species at LT included oligochaetes, ostracods, the gastropod *Hydrobia totteni,* the amphipods *Corophium insidiosum, Corophium* sp. and *Gammarus mucronatus*; and insects (Diptera-Ceratopogonidae, Chironomidae, Dolichopodidae and Ephydridae larvae; Figure 53). In addition to these species, polychaete worms *Heteromastus filiformis* and *Nereis diversicolor* and an unidentified Hydrozoan were present, as well as diptera organisms (Ephydridae larvae and Psychodidae pupae). The dominant species at LT-R included the amphipod, *Corophium insidiosum*, Tanaids, insects (Diptera-Chironmidae larvae), and the polychaete worm *Nereis diversicolor*. In addition, several taxa were present in low numbers, such as the gastropod, *Hydrobia totteni* and softshell clam, *Mya arenaria*; the bubble shell snail, *Retusa* sp; aquatic beetles (Corixidae-water boatman) and diptera pupae; and oligochaetes (Figure 54).

The baseline condition at LT was mostly Diptera species and *Hydrobia totteni*. Through all years post-restoration *Hydrobia totteni* continued to be present, but other species as well including *Corophium insidiosum*, *Garmmarus*, Ostracoda, other Diptera species and Oligochaeta. The last three species listed had very high numbers in 2012 (Year 5). LT-R was mostly Diptera and *Hydrobia totteni* species as well. Ostracoda and *Gammarus* species were present in very large numbers in year two. Over most years post-restoration species present at LT-R included *Corophium insidiosum*, Diptera species, *Nereis diversicolor* (LT low numbers), *Hydrobia totteni*, and Tanaidacea species (not found at LT). *Nereis diversicolor*, *Corophium insidiosum* and Tanaidacea species were mostly found in the lake samples. The species found in the LT Ekman samples over the five years of post-monitoring more closely resembled that of the LT-R panne samples.

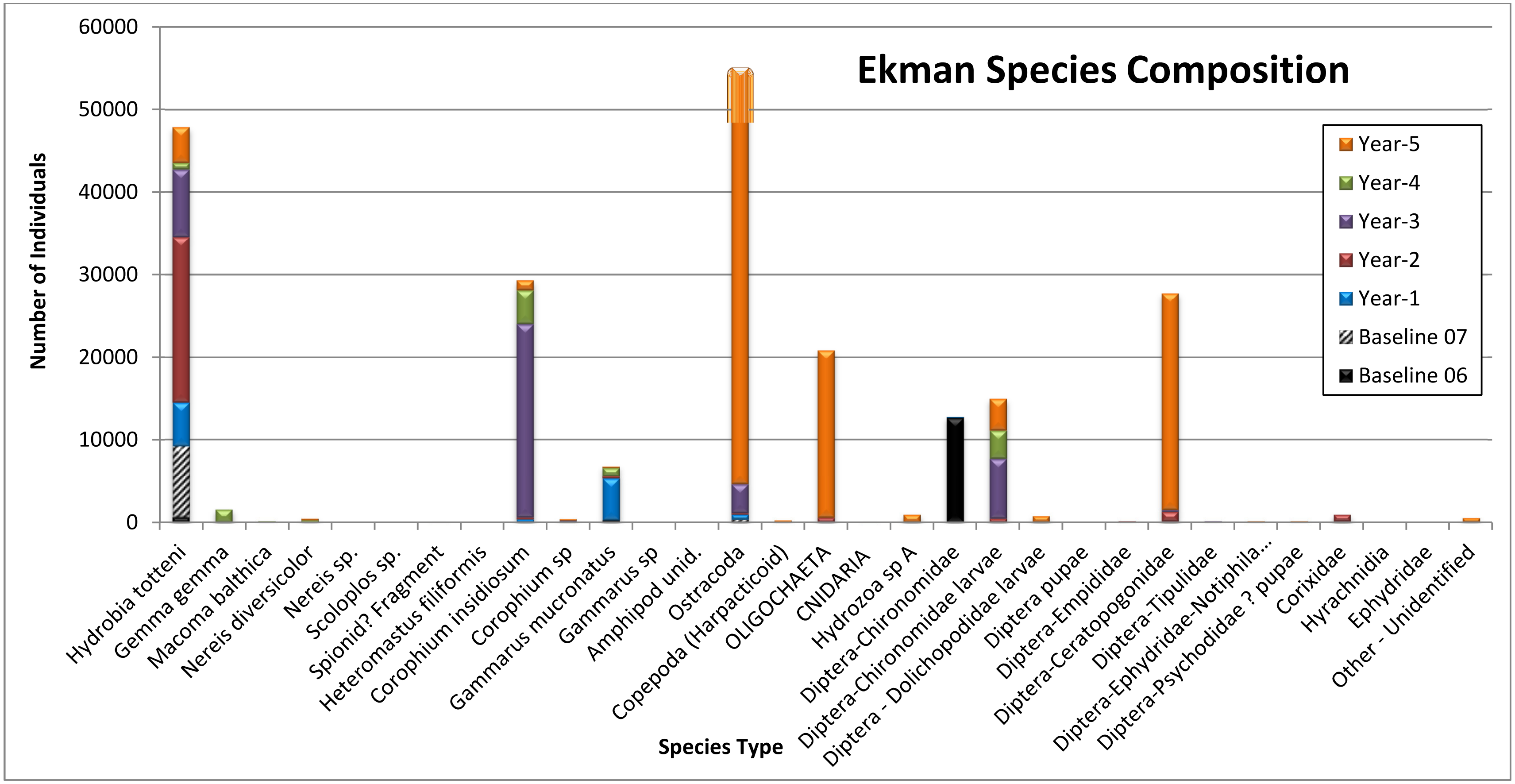


Figure 53 Species composition for Ekman samples taken from LT for all years.

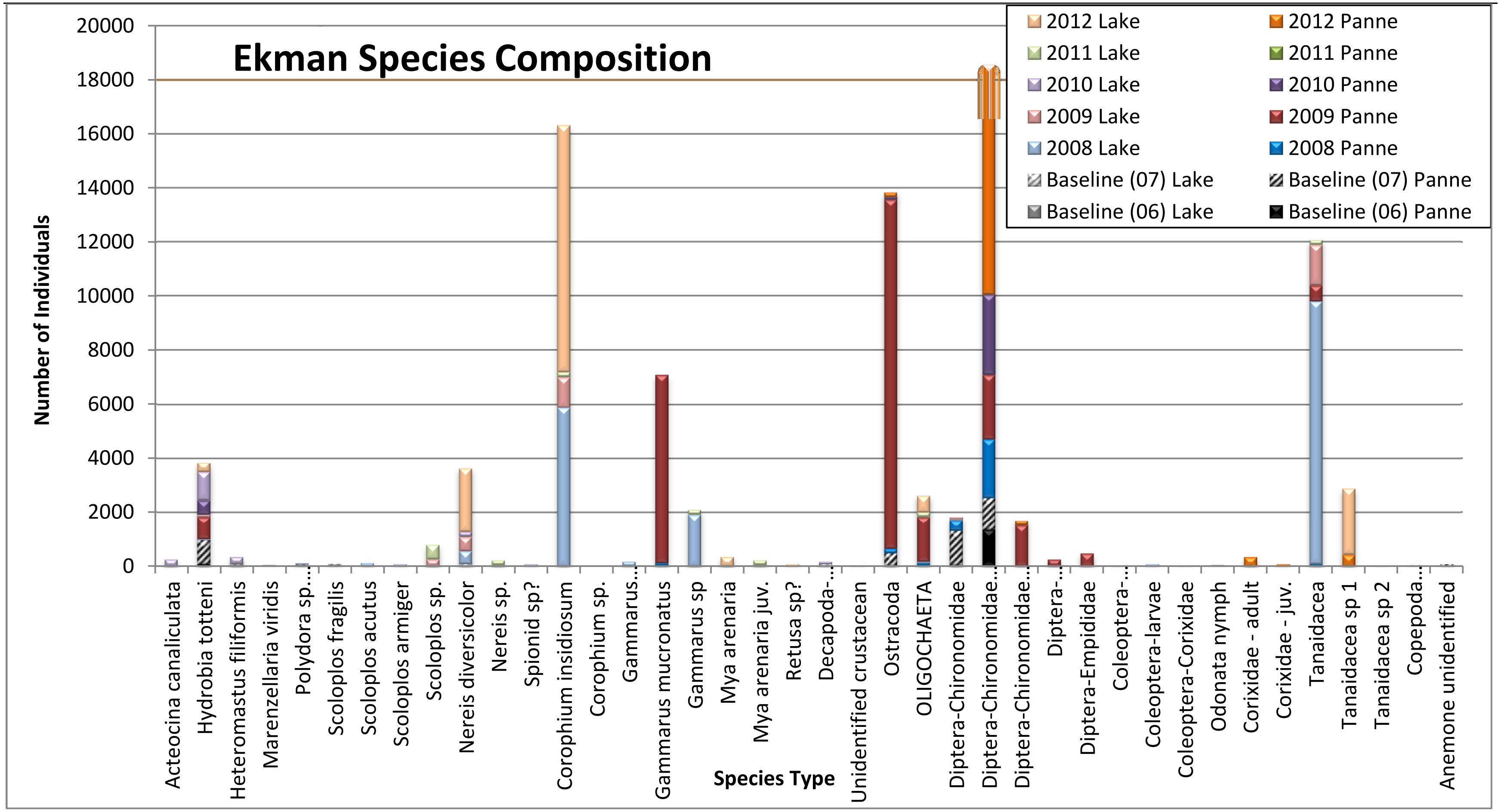


Figure 54 Species composition for the Ekman samples taken at LT-R for all years.

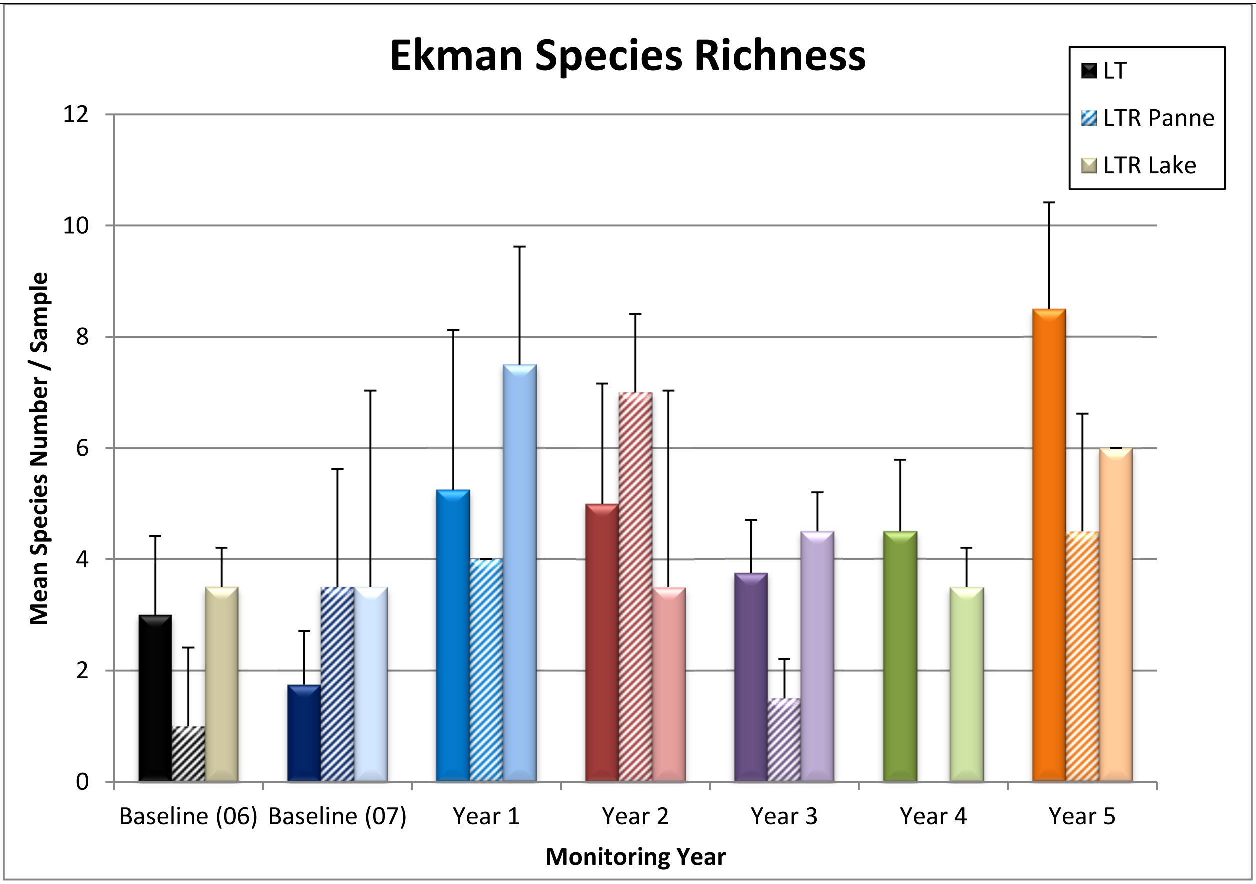


Figure 55 Species richness for the Ekman samples taken from LT and LT-R for all years.

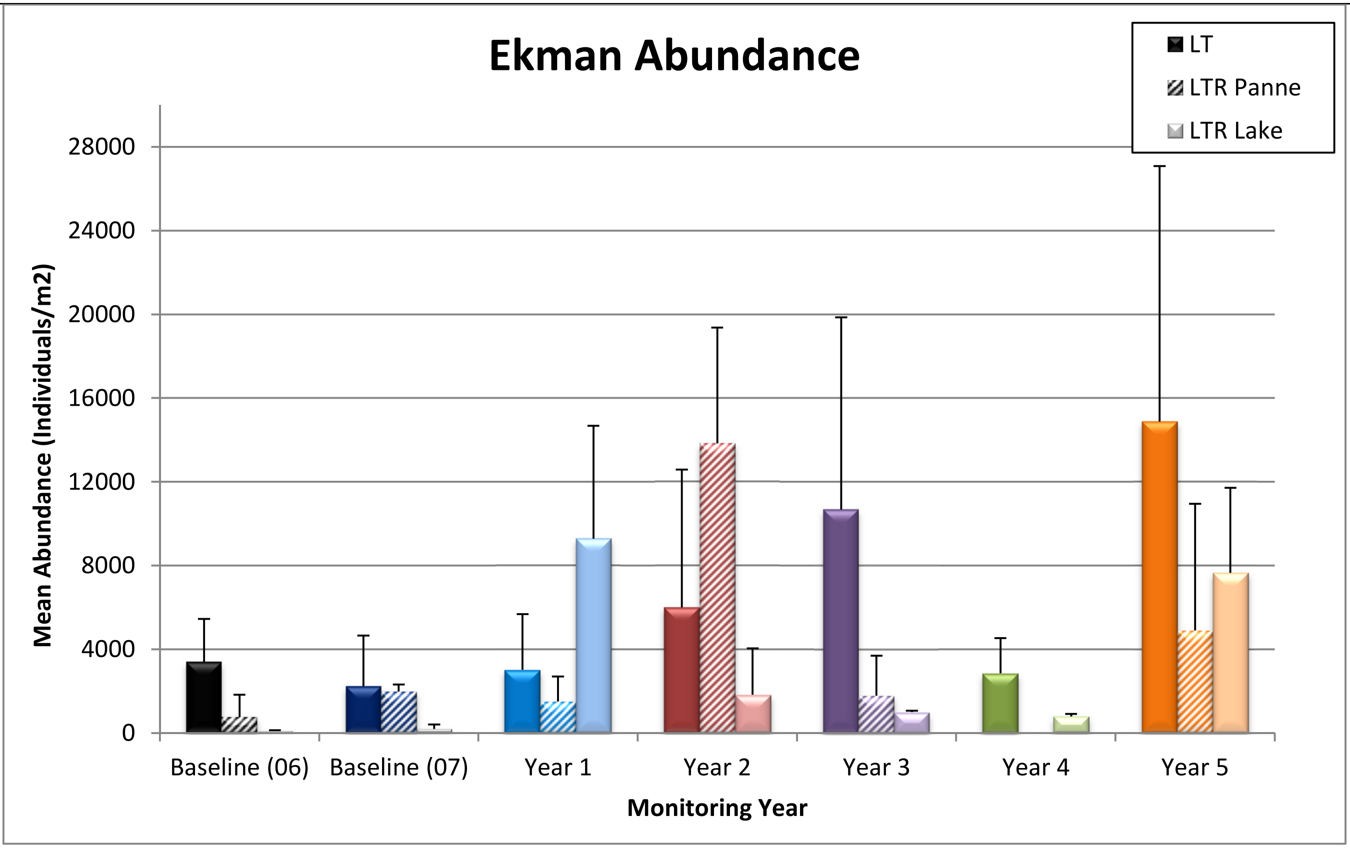


Figure 56 Abundance for the Ekman samples taken from LT and LT-R for all years.

Aquatic Invertebrates

In 2012, the IAT samples at LT contained 12 species, typically a mix of estuarine and freshwater-associated, compared to 12 species at LT-R. For all years post-restoration, LT had a higher species richness compared to the baseline condition (Figure 59). Three years post-restoration LT and LT-R both had a low abundance (August: Figure 60). In 2012, the mean species richness was higher at LT-R than LT; however, there does not appear to be any clear trends in this data over the five years following restoration. Mean abundance saw baseline and Year 1 post-restoration values highest at LT compared to other years post-restoration. These years the abundance means were higher than samples from LT-R. Generally Years 2 to 5 post-restoration, LT-R had higher mean abundances of species, especially at Year 5.

For 2012, the amphipod *Gammarus mucronatus* occurred at all sample sites with a higher abundance at LT-R. Corixidae (Water Boatmen) adults also occurred in higher numbers at LT-R. Copepods (predominantly cyclopoids) occurred in five of the six samples in low to moderate abundance at both sites. At LT-R, over the past six years (includes baseline), samples mainly contained Corixidae and *Gammarus mucronatus*. Over the last three years post-restoration there have been more Corixidae juveniles, *Hydrobia totteni*, Copepoda and increases in Diptera species, particularly in year three (Figure 58). At LT-R, there were no major shifts in species over the time of the monitoring program. At LT, baseline and Year 1 saw greater numbers of Corixidae and *Gammarus* species, although *Gammarus* species were still present most years post-restoration, but in lower numbers. After Year 1 post-restoration, other species emerged such as ostracoda and copepod (larger numbers) and *Hydrobia totteni*, as well as Corixidae larvae (Figure 57).

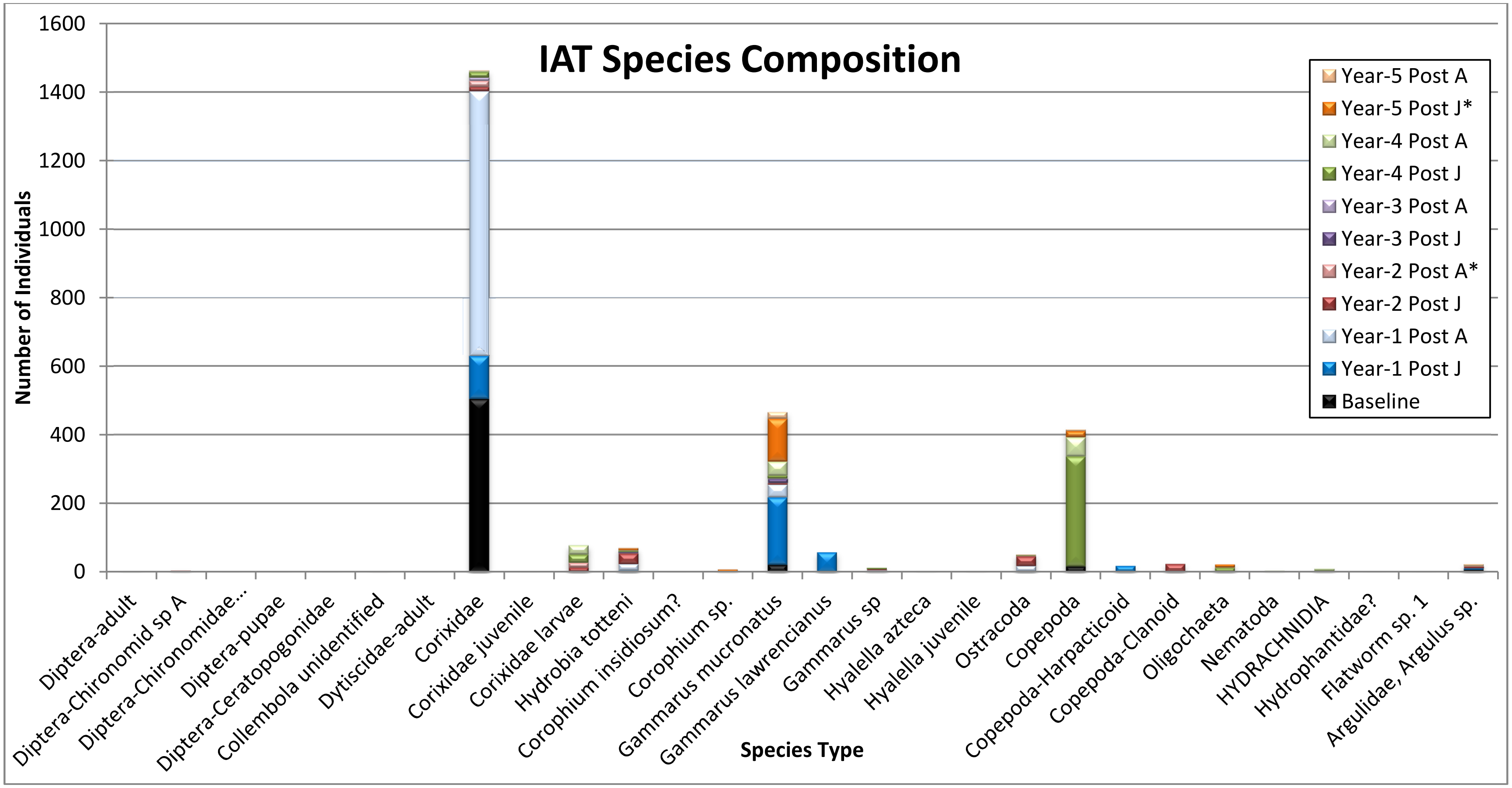


Figure 57 Species composition of IATs at LT for all years. *Only have one sample.

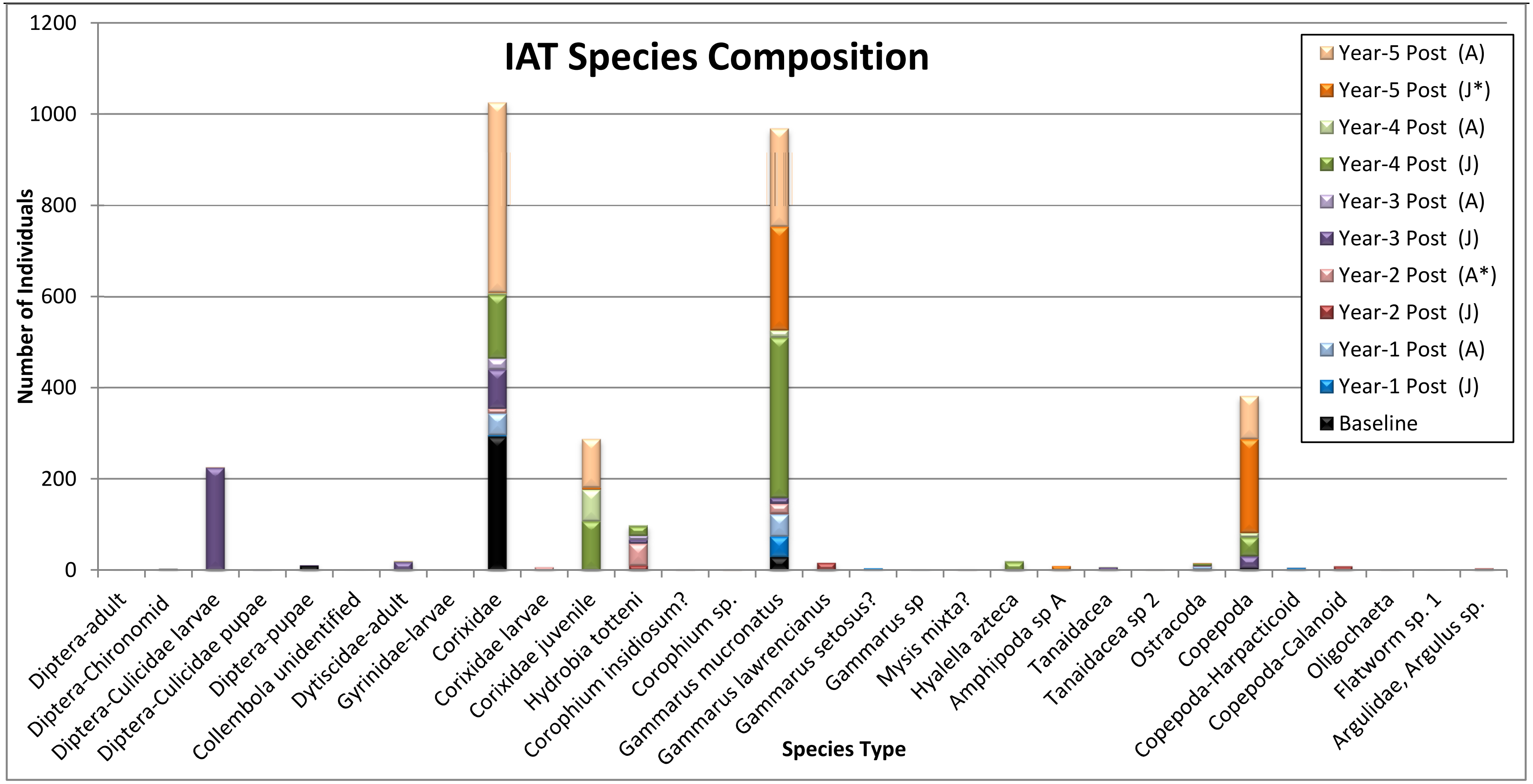


Figure 58 Species composition of IAT samples at LT-R for all years. *Only have one sample.

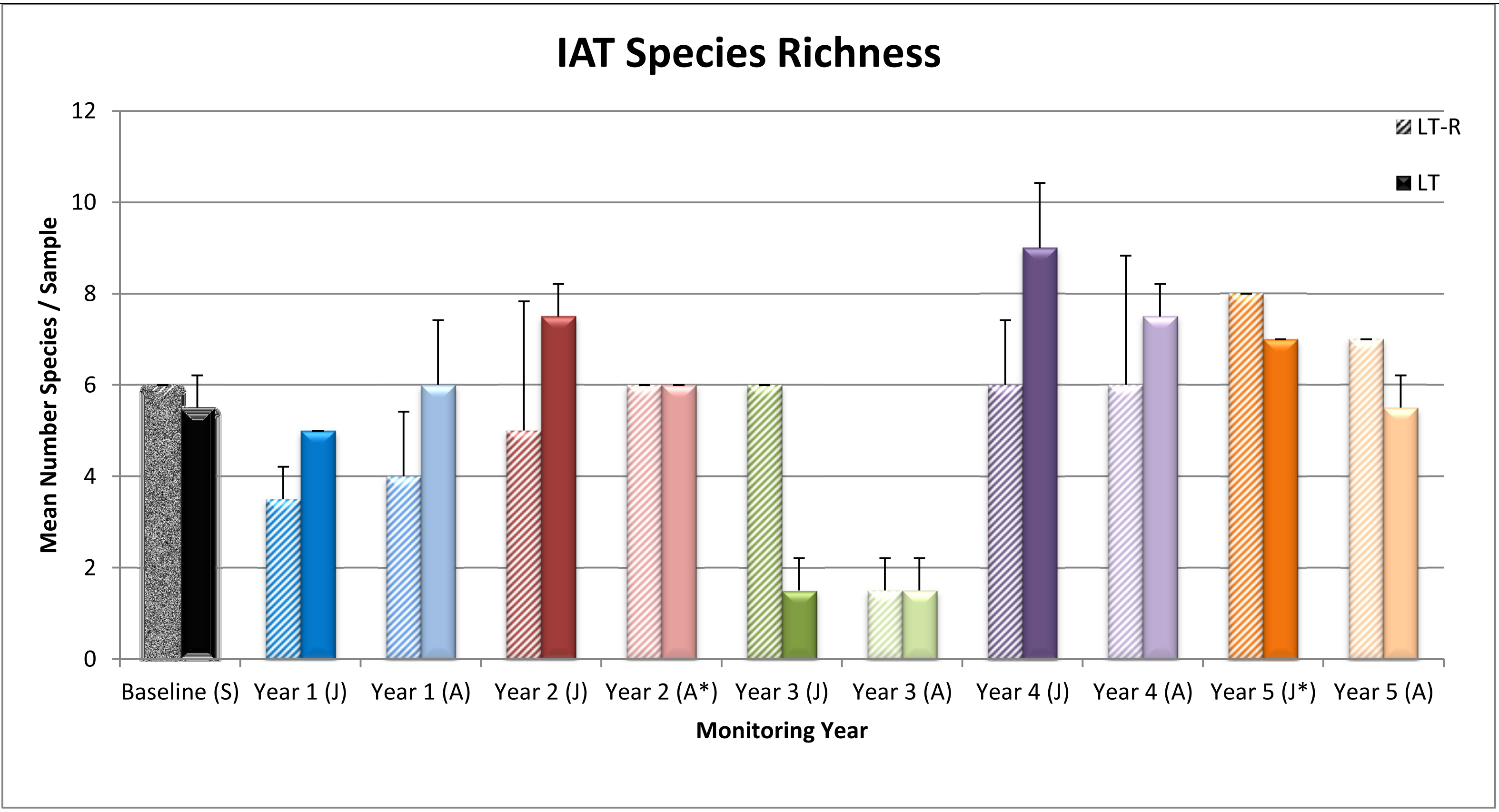


Figure 59 Species richness for the IAT samples taken from LT and LT-R for all years. *Only have one sample.

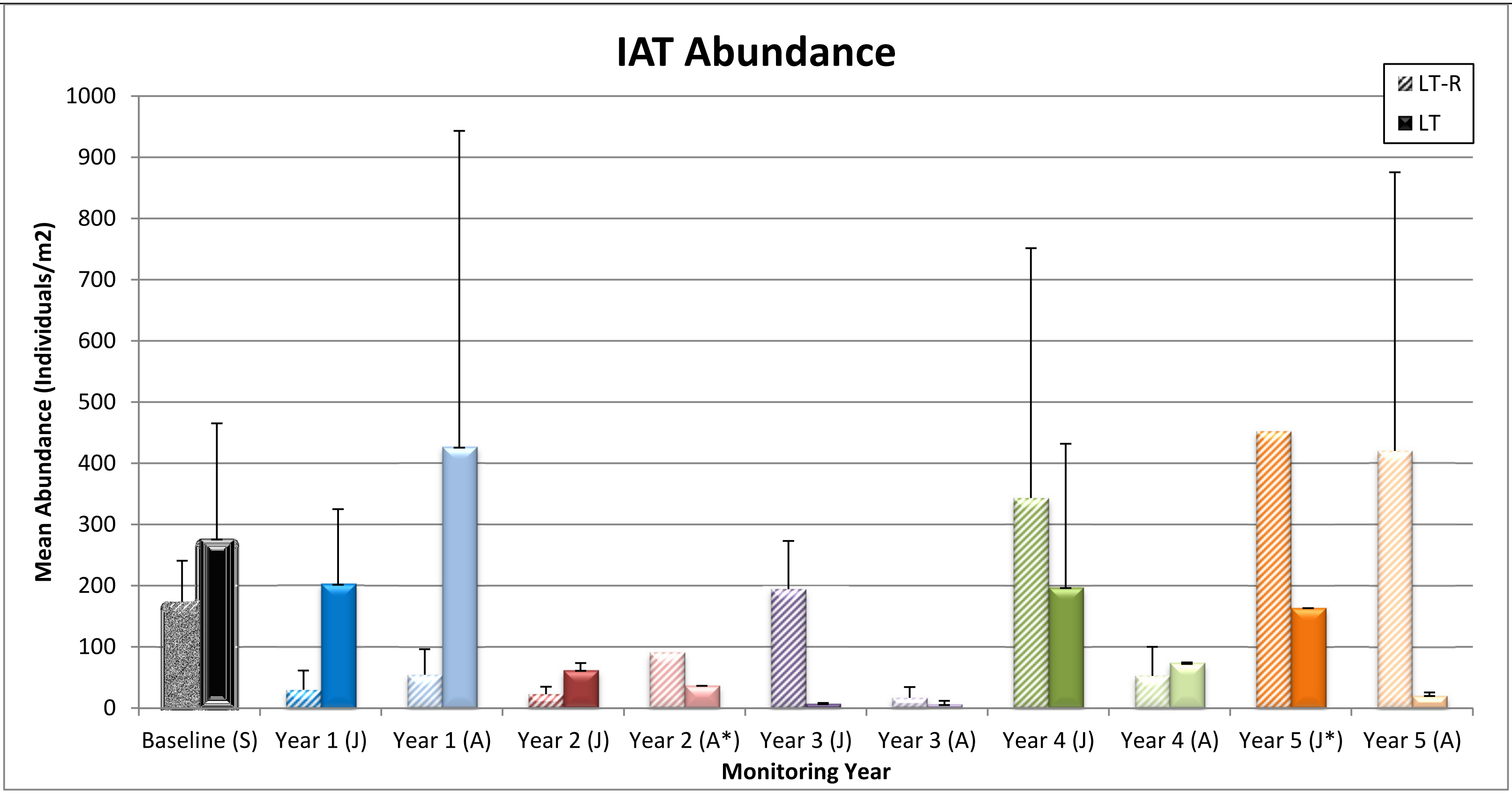


Figure 60 Abundance for the IAT samples taken from LT and LT-R for all years. *Only have one sample.

4.7 Structured Winter Site Walk

Ice and snow conditions on the marshes were moderate during January 2013 as the province received a fair amount of both snow and rain. There was more snow and ice formation on LT/LT-R during the February site walk than the previous two years; however, little change in habitat was evident at either site (Figure 61 to Figure 64). A selection of photographs from the winter site walk is provided in Appendix B.

Figure 61 LT landscape from trail. Photograph by N. Neatt, 6 February 2013.

Figure 62 LT Line 2. Photograph by N. Neatt, 6 February 2013.

Figure 63 LT-R from trail. Photograph by N. Neatt, 6 February 2013.

Figure 64 LT-R Line 4. Photograph by N. Neatt, 6 February 2013.

5.0 Lawrencetown Lake Year-Five Project Summary

The 2012/13 field season was the fifth and final year of post-restoration monitoring required for the Lawrencetown Lake Salt Marsh Restoration Project. The results of the fifth year of monitoring are presented in this report. It has been found that the installation of a more appropriately sized and placed culvert in 2007 has resulted in a more natural hydrological regime in the LT system. The observed changes over the five years of post-restoration monitoring included improved water quality and pore water regime, expansion of halophytic vegetation and improved fish passage and usage. These changes were positive responses to the intervention at LT and were not observed at LT-R.

Over the seven year monitoring program many of the vegetation plots remained similar at LT. A few plots were observed by 2012 to have shifted from *Myrica gale* and *Calamagrostis canadensis* to *Juncus balticus* or had changes immediately post-restoration with increases in *Atriplex glabrisculata*, a colonizer in salt environments. *Spartina alterniflora* increased at LT to a point where the overall average abundance was similar between LT and LT-R; although most of this change was due to a single plot at LT. However, changes observed in the field, that were not captured by the plot-based vegetation survey, have included halophyte species expansion in areas that have become more exposed due to changes in the central panne (improved drainage, sediment deposition and consolidation). Key areas where this was observed were adjacent to Lines 2 and 3 and around the immediate parameter of the central panne. In the first year of post-restoration, there was a decline in average plot species richness followed by an increase in the last three years of the program at LT. This suggests that there was a loss of terrestrial species due to restoration (increase in tidal influence), followed by colonization of salt tolerant species. LT-R had significantly more halophyte species, on average, pre-restoration compared to LT, with LT becoming more similar to LT-R by year five. The average halophyte abundances were also initially lower at LT, but approaching parity with LT-R by Year 5.

A dominant controlling factor on the halophyte growth at LT has been the increase in salinity levels at the site. Pre-restoration, the average salinity of the floodwaters at LT and LT-R were 8.6 ppt and 15.7 ppt respectively. The average salinity of the floodwaters for all years post-restoration combined at LT was 25.7 ppt and 25.5 ppt at LT-R. The tide level recording data showed that the maximum water level at LT was 0.9 m (CGVD28) and 1.0 m (CGVD28) at LT-R. These findings support the change in tidal flooding at LT and that increasing similarity in tide levels between the two sites has occurred. For pore water salinity there were no significant differences found between LT and LT-R when shallow and deep readings were tested separately, nor when all readings were test together. LT did have a greater range (0.18 ppt to 17.28 ppt) than LT-R (0.26 ppt to 15.15 ppt). The lowest readings for LT were found along Line 1 with the highest salinity readings found along Lines 4 and 5. This salinity gradient was similar to previous years, including pre-restoration.

The sediment accretion at LT and LT-R was lower in 2012 than in previous years, particularly at LT. In 2009 there was high accretion values due to Hurricane Bill, however, in 2012 there were also storm deposits found along the back of LT (Line 3 to Line 5). This area also experienced fine sediment deposits from the adjacent drumlin and gravel pit. The impact of the large storms in 2012 was mainly heavy rain. Line 4 continued to have the highest rate of accretion, mainly due to erosion of the adjacent drumlin. The transect profiles (Figure 22) illustrate this accretion at Line 4, as well as at the edge of Line 2, which has been building up and into the central panne, with a subsequent change in vegetation from *Agrostis stolonifera* to *Spartina alterniflora* (Figure 24).

The soil characteristics are influenced by source material, elevation in tidal frame, distance from water source and flow velocity. The bulk density, water content and organic matter are influenced primarily by sediment characteristics of the underlying substrate and presence/absence of vegetation. Soil texture at LT and LT-R initially consisted of mostly silt and sand, but by 2012 both sites had shifted to medium to fine silts. At LT the smallest grain size was recorded at L3S1 (upland), mostly likely derived from erosion of the adjacent drumlin. The largest grain size was found at LT_L1S4 (upland), which was most likely associated with storm over-wash from the adjacent highway, dune and beach system. The small grain sizes which dominated at LT, combined with the similarity to LT-R, suggest that deposition was by suspended sediment from the water column rather than by storm (terrestrial runoff) or ice deposits.

Water content values of the sediment samples taken at LT were lower than LT-R for all years. A station on Line 4 had the lowest value all years. At LT water content increased in year one and then decreased in year three, with an increase at a few stations in year five. There have been field observations of the increased de-watering and consolidation at LT. The transect profiles illustrated this at Line 2 and 4 (Figure 22). Organic matter content decreased at almost all stations at LT post-restoration, and were generally lower than LT-R. Organic matter values for all stations along Line 4 and 5 were low as expected due to their proximity to the old culvert north of Line 5 (Figure 12) and the deposition of sediment originating at the gravel quarry on the hill above this portion of the marsh. The highest organic matter values were found at Line 1. Values at almost all stations were greater than 2010 and pre-restoration values. The bulk density (low bulk density = larger amount of pore space) at LT decreased in year one, with a further decrease in year three. In 2012 there was an increase at a few stations. Line 4 had the highest bulk density value found and Line 2 the lowest, as it was nearest the central pond. Although some patterns were difficult to discern, the substrate composition of LT is trending towards LT-R.

Since culvert installation, the dominant fish species caught at LT has been a combination of Mummichogs (*Fundulus heteroclitus*), Atlantic silversides (*Menidia menidia*), and Three-spine sticklebacks (*Gasterosteus aculeatus*). This was similar to LT-R, although crabs were also dominant at this site in 2009 and 2011. These species are expected to be present in a salt marsh environment either regularly or during the high tide conditions. LT-R had a greater total catch than LT for all years except 2009 (Year 2) and 2012 (Year 5). However, the total catch average for the post-restoration monitoring program at LT-R was 766 and at LT 687. Although the methods used for LT-R and LT differed, the standard length average showed that juveniles and adults were represented at both sites. This data indicates that LT is providing fish habitat with the restored tidal flow and is productive given its small size, especially compared to other restoration sites being monitored in the region (Cheverie Creek, Walton River, St. Croix, and Cogmagun

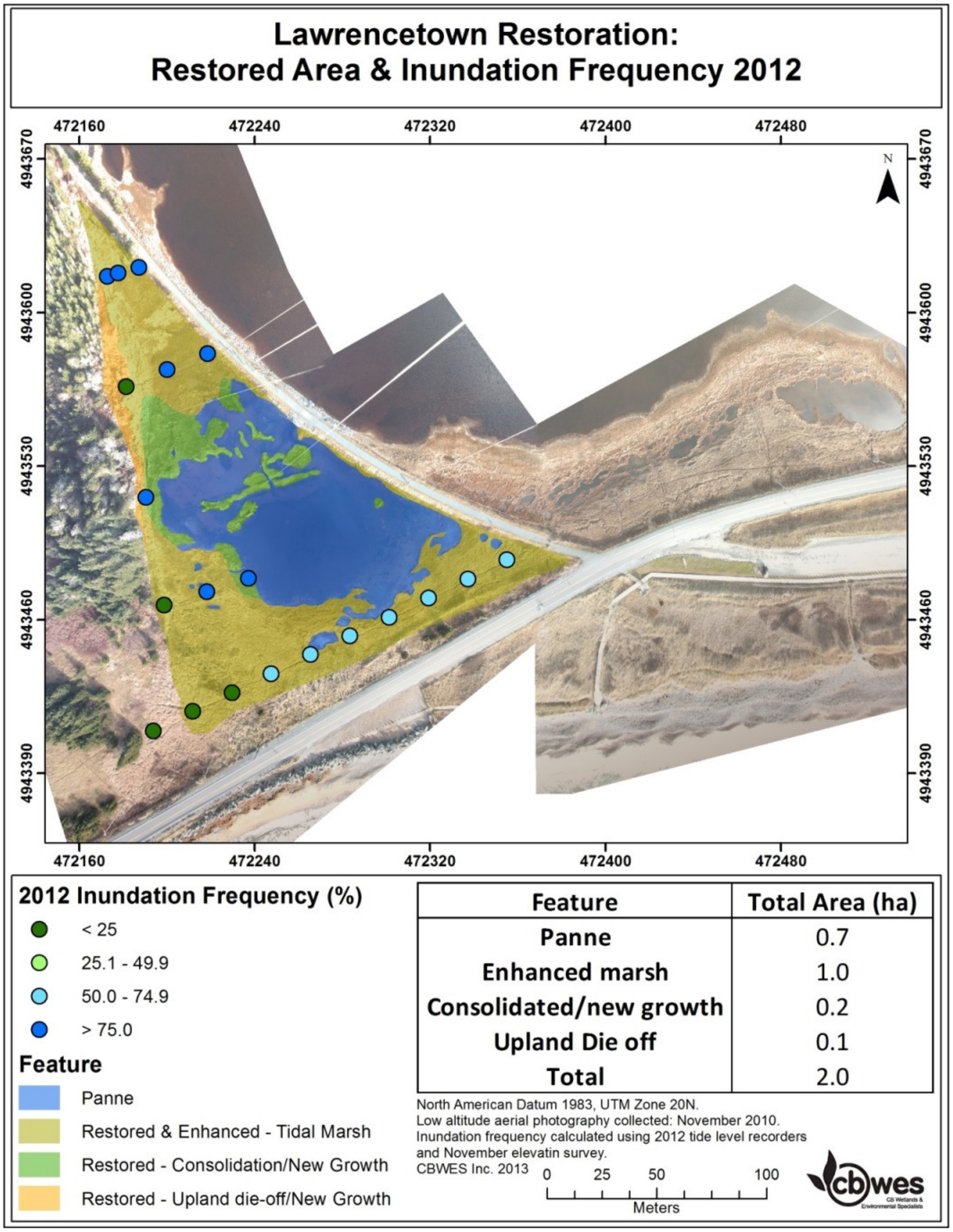
River). This site highlights the importance of restoring smaller sites in the landscape as well as larger ones.

Changes at LT have not been as dramatic as the changes observed at the other restoration sites (i.e., Walton River Salt Marsh) and the rate of change has been gradual over the five year post-restoration monitoring program. However, the changes that have been occurring at LT, as illustrated above, have been moving the site towards that of the reference condition. The installation of the new culvert has enabled the site to re-establish tidal wetland habitat conditions and biological community structures similar to those of adjacent intact marshes. Although it is difficult to predict the long term condition of the site, a self-sustaining and resilient tidal wetland system has been developing at LT as a direct result of the restoration activities.

5.1 Restored Area at Lawrencetown

As reported in Bowron et al. (2012b), the 2010 low-altitude aerial imagery, including vegetation and habitat date, and the 2010 tide level data were combined to produce a restored area map. Based on the 2010 data, the restored tidal wetland area (including vegetation die-off, new growth and enhancement) at LT was determined to be 1.97 ha. Five years post-restoration (2012), additional elevation and hydrology data (Figure 27) was collected and used to produce an updated restored area map (Figure 65). The new restored area was determined to be 2.00 ha. Through observation in the field, wetland conditions in the proximity of Lines 4 and 5 have been enhanced by the increased tidal flow and the area has been de-watering and accreting. Habitat conditions in the remainder of the site (Lines 1 to 3) have experienced a shift from freshwater and terrestrial conditions to tidal wetland (restored), as tidal waters were unable to reach this part of marsh prior to the installation of the new culvert.

While it is difficult to predict how successful this restoration will be in the long term, it is clear that the major objectives (significantly reduce the tidal restriction caused by the Trans Canada Trail (former railway bed); re-establishment of a more natural hydrological regime to the site; improve fish passage; increase the extent, distribution and abundance of halophytic vegetation) were achieved. Although there are still differences in the habitat zonation pattern between LT and LT-R, the restoration activities undertaken at LT in 2007 have resulted in the restoration of a self-sustaining and resilient salt marsh and tidal wetland system.



Feature	Total Area (ha)
Panne	0.7
Enhanced marsh	1.0
Consolidated/new growth	0.2
Upland Die off	0.1
Total	2.0

North American Datum 1983, UTM Zone 20N.
Low altitude aerial photography collected: November 2010.
Inundation frequency calculated using 2012 tide level recorders and November elevatin survey.
CBWES Inc. 2013

Figure 65 Restored area map of LT showing upland die-off, new growth, consolidation and restored/enhanced areas.

6.0 Recommendations for Future Post-Restoration Monitoring Activities

The monitoring program developed for the Lawrencetown Lake Salt Marsh Restoration Project was a modified version of the GPAC Regional Monitoring Protocol. It utilized a similar suite of ecological indicators of salt marsh form and function, and a set of sampling methods suitable for the Atlantic Coast tidal conditions. The intention of the monitoring program was to enable the determination of not only the effectiveness of the original restoration activity, but also to provide valuable information on how both the overall system and the individual physical and biological components responded to the restoration treatment. The program for this site included baseline data collection in 2006 and 2007 and then five consecutive years of post-restoration monitoring (2008 – 2012).

Annual monitoring during the first three years following restoration is critical because it is during these initial years that the greatest and most rapid changes occur. Monitoring beyond the first three years following restoration allow a greater period of time for change to occur and for the documentation of the longer term, often more gradual, changes in response to restoration (Able et al. 2008; Burden et al. 2013; Garbutt and Wolters 2008; Mitsch et al. 2012; Neatt et al. 2013).

The results of the five years of post-restoration monitoring, as discussed in this report, indicate that the system has responded in a positive and acceptable manner to the original intervention. That the objectives for the project have been met and that the LT site has been restored to a self-sustaining and resilient salt marsh and tidal wetland system.

Additionally:
Tidal Wetland Restoration Monitoring Recommendations:

- The long term monitoring programs associated the longer and more comprehensive ones in NS, such as the Cheverie Creek Salt Marsh Restoration Project, have provided data sets that provide new insights into the form and function of tidal wetland systems in NS and their response to restoration efforts. One of the important lessons learned from these projects relates to the importance of conducting monitoring activities both over the immediate post-restoration periods (1-3 years) and the longer term (>5 years). Many of the trends in habitat condition recovery (e.g. depth to water table; parity in salinity levels; and replacement of non-halophytic vegetation by halophytes) were only evident in the data at and beyond the five-year post-restoration point in the monitoring program. When the experiences with this restoration site are combined with those of other sites in NS (Walton, Cogmagun, St. Croix), it is confirmed that monitoring as part of any restoration project is crucial; that documentation of baseline habitat conditions must be conducted before restoration activities are undertaken; and that monitoring changes in habitat conditions post-restoration requires a period of at least five years.

- The incorporation of low-altitude photogrammetry into the monitoring program greatly improved our ability to detect and document landscape level morphological conditions and marsh functions, and assisted in large scale wetland delineation. It is recommended that this be included in the monitoring programs for all tidal wetland restoration projects.

- It is recommended that measuring redox potential be considered for inclusion in the monitoring programs for all new projects, particularly those that were completely restricted prior to restoration. Measuring redox potential is important because it affects biogeochemical cycles of nitrogen, sulfur and other redox-sensitive elements and is basically a measure of how the soil is affecting other biological systems within the marsh framework (Callaway et al. 2001).

- We (CBWES – SMU) have been using the monitoring data from six of the tidal wetland restoration reference sites to quantify the elevation ranges and other environmental characteristics of the tidal marsh vegetation communities. The hope is that this will enable us to progress from the traditional paired restoration-reference site approach to a multiple-reference site approach where vegetation plots from any of a regional set of reference sites can be matched with plots at restoration sites that have similar environmental conditions (Reynoldson et al. 1997; Reynoldson 2005; Westhead 2005). This reference condition approach using knowledge of environment-vegetation relationships at reference sites will hopefully enable us to reduce the intensity of monitoring activities on individual reference sites in favour of applying some of those resources to monitoring restoration sites, while reducing the overall cost of monitoring. However, the importance of key environmental variables (salinity, inundation, elevation, soil characteristics) in differentiating plant communities strongly supports the recommendation that the current level of monitoring of restoration projects needs to be maintained, and that for parameters such as soil salinity be increased. Some of the information needed to fully develop the reference condition approach could also be gained by conducting additional analyses of existing data (e.g., soil characteristics) to examine the spatial variability within each site in relation to vegetative communities and hydrologic patterns.

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Appendix A – Summary of CBWES Supported Student Research

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

Current Projects:

Peer-review Publication

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.

Vegetation in tidal marshes of eastern North America shows conspicuous zonation attributable to biotic interactions between plant species and differential tolerance of salinity and flooding. Tidal marshes 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 marsh vegetation in Nova Scotia, and to determine the relationships between variation in plant species composition and environmental factors. We sampled tidal marsh vegetation in six sites designated as reference (intact) sites for salt marsh 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 are similar to those found farther south in Maine and New England, but we also describe three brackish communities of which the *Juncus balticus/Festuca rub*ra 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 further restoration work and identify environmental correlates of plant communities, allowing for better predictions of ecological restoration trajectories in tidal marshes.

Undergraduate Honours

Environmental Science
Saint Mary's University
Carly Wrathall
2013-2014

The restoration of tidal wetlands (salt marshes) in Nova Scotia (NS) has been identified as an important step in enhancing the quality of the natural environment. Salt marshes in NS are important wildlife habitats, are highly productive ecosystems, and play an important role in shoreline protection and carbon storage in the face of climate change and rising sea levels. The collaborative team of CBWES, Intertidal Coastal Sediment Transport (InCoaST) Research Unit at Saint Mary's University (SMU) and Dr. Jeremy Lundholm (SMU) are at the forefront of salt marsh restoration in NS, having initiated and monitored the success of nine large-scale restoration projects, most in the Bay of Fundy (BoF) area. Many of the challenges to restoration in BoF marshes are unique, with macro-tidal conditions, high sediment loads and significant ice disturbance in winter; as a result, ecological knowledge and restoration practices cannot be simply imported from other regions where conditions are more benign. Restoration monitoring by CBWES has indicated that these BoF restoration sites do develop some form of salt marsh vegetation community structure within a few years. This salt marsh vegetation recovery monitoring has never included comprehensive quantitative analysis of primary productivity (as measured by above- and below- ground biomass) of natural and restored marshes. The student will work with CBWES to collect and analyze ecological data on a series of salt marsh restoration projects. The student will be responsible for an independent project comparing the vegetation community patterns and primary productivity of a series of restored and natural salt marshes in the BoF's Minas Basin. This project will greatly enhance our understanding of the form and function of salt marshes in the BoF, evaluate the success of restoration efforts, and our ability to design future restoration projects.

Completed Projects:

Masters of Applied Science

Department of Geography
Saint Mary's University
Ben Lemieux
NSERC Industrial Postgraduate Scholarship
2010-2012

The influence of drainage network and morphological features on the vegetation recovery pattern of a macro-tidal wetland restoration project.

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

Masters of Applied Science

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

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

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

Appendix B - Structured Winter Site Walk: Lawrencetown Lake Restoration and Reference Site

STRUCTURED WALK PHOTOGRAPHS LT (select images):

Figure 1 LT Line 1.

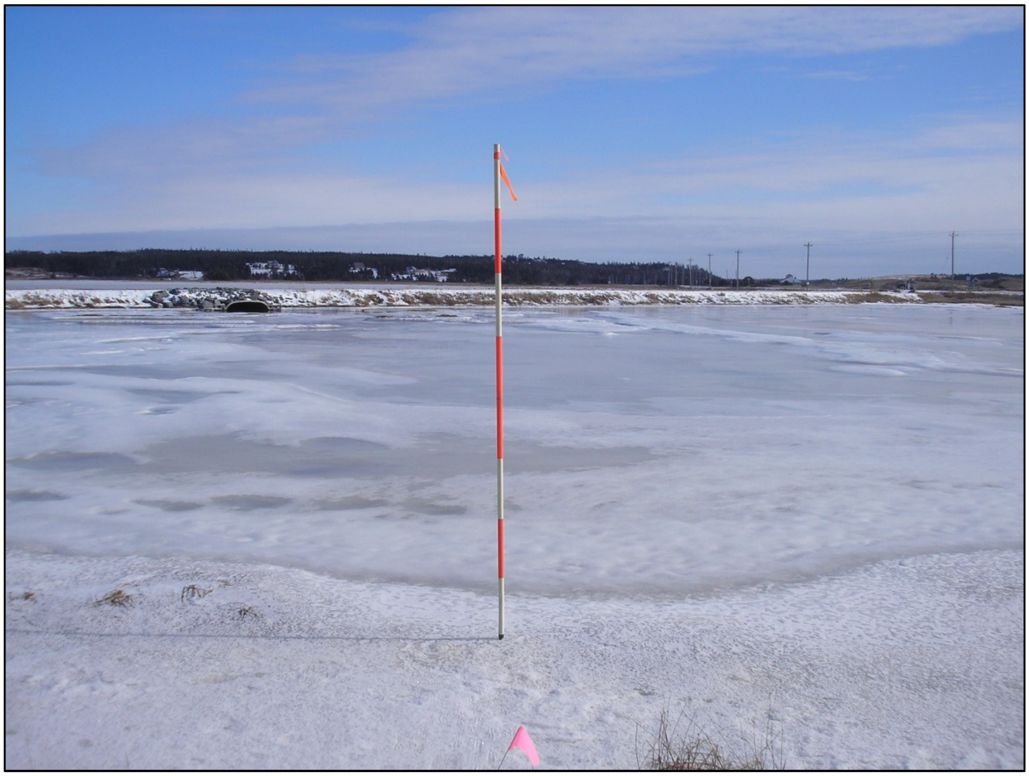

Figure 2 LT Line 3.

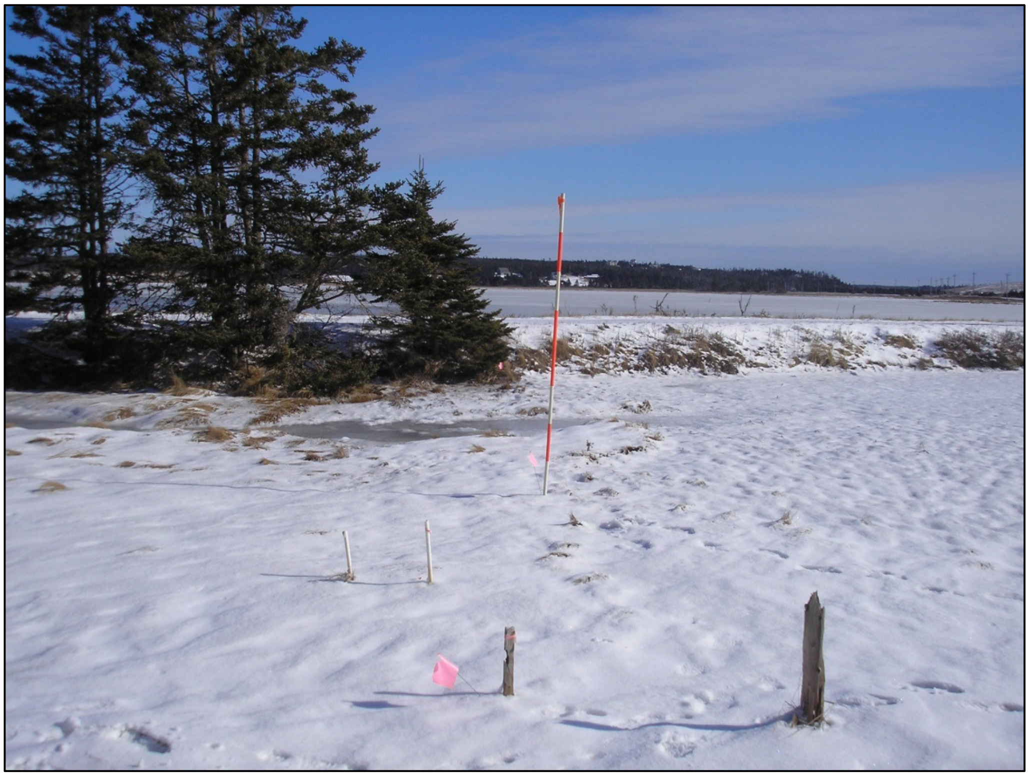

Figure 3 LT Line 5.

Figure 4 LT landscape from Line 5.

Figure 5 Central panne at LT from the culvert.

Figure 6 LT landscape from road showing central panne and culvert.

STRUCTURED WALK PHOTOGRAPHS LT-R (select images):

Figure 7 LT-R Line 1.

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