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

Post-Restoration Monitoring (Year 7) of the Walton River Salt Marsh Restoration Project

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Executive Summary

On 9 September 2005, the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR), in partnership with Ducks Unlimited Canada (DUC), completed construction activities (water control structure removal and dyke breach), at a site along the Walton River, Hants County, to restore tidal flow to a 12 hectare former salt marsh. The primary goals of the Walton River Salt Marsh Restoration Project were to:

- Eliminate the tidal restriction caused by the dyke (former impoundment);
- Improve hydrological conditions within the study site;
- Improve fish passage to and within the wetland area as well as nutrient exchange; and
- Improve wetland habitat conditions to re-establish halophyte vegetation.

CBWES Inc. was commissioned to develop and implement a pre- and post-restoration monitoring program. Baseline data collection (pre-restoration monitoring) was completed by CBWES Inc. in 2005 in advance of construction. A five year post-restoration monitoring program was developed and implemented the following year (2006). The monitoring program was then extended to Year 7 with a reduced program for Year 6. The seventh year of post-restoration monitoring took place during the period of May 2012 through December 2012, with a winter site visit conducted in March 2013. The purpose of the monitoring program, and this years' phase of it, was to:

- Document the efficacy of the compensation being undertaken to restore the Walton River tidal wetland (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
- Document restoration progress and determine project success (restored marsh exhibits similar physical, chemical and biological characteristics as the reference site), by comparing the post-restoration habitat conditions to those that were present prior to restoration and to those of an adjacent reference site.

Data were collected for geospatial attributes, hydrology, soil and sediments, vegetation, nekton and benthic invertebrates at both the restoration site (WAL) and an adjacent salt marsh reference site (WAL-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. The results for the seventh and final year of post-restoration monitoring are summarized below.

Geospatial Attributes: The mean elevation for WAL from the 2012 DEM was 5.66 m (CGVD28) with a range of 3.36 m to 9.52 m and a standard deviation of 0.87 m. The mean elevation for WAL-R was 5.89 m (CGVD28) with a range of 3.53 m to 10.18 m and a standard deviation of 0.93 m. The mean elevation at WAL-R has been higher all years compared to WAL. The updated habitat maps showed that WAL had more panne habitat than WAL-R, and that WAL remained dominated by *Spartina alterniflora* seven years post-restoration. The entire

marsh surface at WAL has been vegetated since 2006. The development of salt pannes at the site has resulted in the conversion of one initially vegetated plot to standing water. The upland boundary of the site has become dominated by *S. patens* and *Juncus gerardii* (characteristic of high marsh conditions), while the majority of the site has continued to be dominated by *S. alterniflora* (low marsh conditions), with the exception of one plot on Line 6. This plot was actually inundated less frequently than most at WAL and is dominated by *S. patens*. The fringe habitat at WAL has not had any changes over the seven years of the monitoring program, nor have there been any changes at WAL-R.

Hydrology: In 2005, immediate post-restoration at WAL, tides equal to or greater than approximately 6.3 m (CGVD28) were required to overtop the fringe marsh and flood the site. Channel development over the subsequent seven years has improved hydrological connectivity such that a tide level of approximately 5 m (CGVD28) will flood into the former borrow pit, bank-full condition is achieved with a 5.8 m (CGVD28) tide level, and marsh-full condition by a 6.4 m tide. At WAL, the majority of the plots were inundated by 63.7 to 81.3 % of the high tides and at WAL-R the majority of plots are inundated by 47.2 to 63.7 % of the high tides. This difference was expected given the difference of the elevation at the two sites. Currently, a mean high tide of 6.37 m (CGVD28) would cover 8.72 ha at WAL and a max high tide of 7.85 m (CGVD28) would cover 9.49 ha.

<u>Depth to Groundwater</u> - For 2012, the mean depth to groundwater at WAL was 2.85 cm with a range of -1 to 10 cm and at WAL-R the mean was 3.36 cm with a range of 0 to 13 cm. T-tests completed for the 2012 data showed no significant differences between WAL and WAL-R, which agreed with temporal trends. When compared to 2010 data, WAL showed no significant difference, while WAL-R showed a significant difference (albeit marginally) between years. When all post-restoration data was analyzed (2006 – 2012) there was a significant difference at both WAL and WAL-R. ANOVA showed significant differences between years at both sites. Therefore, overall the changes between 2010 and 2012 are reflective of the system and not necessarily the restoration project. WAL is in line with the reference site conditions.

<u>Water Quality</u> - Given the close proximity of WAL and WAL-R, and complete coverage of both sites by tidal waters during fish surveys, the data from both sites were pooled. Similar to previous data collected, as the water temperature decreased into the fall, the DO and pH increased. Salinity has fluctuated over the seven years with a range of 16.5 ppt to 31.3 ppt, with most readings greater than 28 ppt. This was expected for salinity in Bay of Fundy waters. The means for the water quality parameters for the 2012 sampling season were: Temperature = 15.7 ˚C; Salinity = 27.9 ppt; Dissolved Oxygen = 9.1 mg/L; and pH = 7.9.

Soils and Sediments

<u>Pore Water Salinity</u> – For all readings, WAL had a mean of 7.58 ppt with a range of 1.84 to 14.26 ppt and a standard deviation of 3.44 ppt. WAL-R had a mean of 9.08 ppt with a range of 1.04 to 14.69 ppt and a standard deviation of 3.28 ppt. T-tests (95% CI) completed between WAL-R and WAL sites in 2012 showed no significant differences when deep salinity readings were tested alone; however, when shallow readings and all readings were tested, both showed a significant difference. For 2012, salinity values were moderately lower than previous years. There was a shift in 2009 from WAL having a greater mean salinity compared to WAL-R. This

would be due to the change in WAL from a hypersaline environment to one closer to WAL-R as the tidal wetland habitat developed. The lower mean salinity at WAL could also be attributed to sampling location differences between the two sites and a change in methodology that allowed stations near the upland edge to be more easily sampled.

Sediment Accretion and Elevation – For WAL RSET-01, the rate of change decreased by 0.6 $cm \cdot yr^{-1}$ in 2012 despite a high rate of accretion (1.98 $cm \cdot yr^{-1}$) measured by the marker horizons. Overall, RSET-01 recorded the highest net change in surface elevation (8.78 cm) with the highest amount of net accretion and positive changes in subsurface processes. The lowest net change in surface elevation was recorded at RSET-02, which was situated in a location which was lower in the tidal frame (6.18 m CGVD28) and was mostly associated with -2.2 cm of subsurface subsidence. The marker horizons all recorded net sediment accretion over the seven year period. At WAL-R, RSET measurements increased in 2011 similar to WAL, with most increases associated with subsurface processes. Comparable and slightly higher rates of accretion were recorded at both WAL-R RSET stations in 2012 indicative of ice or storm deposits.

Soil Characteristics - Organic matter content ranged from 8 to 26% at both sites. At WAL, there was minimal variation in the overall range of organic matter values for most stations. The water content within the core samples ranged from 50 to approximately 65-70% at both WAL and WAL-R with increases observed over time in the high marsh and decreases in the low marsh. The water content data showed that the surfaces of both marshes were at similar states of consolidation. The most notable spatial and temporal variability in sediment properties was observed in the dry bulk density values. Dry bulk density values decreased between 2007 and 2008 at both WAL and WAL-R; however, increased at all stations in 2010 and decreased in 2012. In 2012, there was a notable decrease in grain size at WAL L1S2 and L1S3 and increases at L1S4 and L5S2; however, the grain size classification remained medium silt. There was also much less variability in grain size in 2012. The range of grain sizes (9.67 to 12.17 µm) was comparable to those found at WAL-R (8.6 to 12.90 µm). Grain size has an influence on bulk density with increasing grain size contributing to lower bulk density values which is reflected at both WAL and WAL-R.

Vegetation: Pre-restoration, the main halophyte at WAL was *Juncus gerardii*, which existed at low abundances and only in a few plots. This species has doubled in abundance over the study period (three plots pre versus six plots 2012). Most halophytes now found on the site colonized in 2006, and most have increased in abundance since then (e.g., *Carex paleacea* and *Scirpus maritimus*). *Limonium nashii* was first observed on the site in 2010. *S. alterniflora* rapidly colonized the site in 2006 and remained the dominant species. *S. patens* also appeared on-site in 2006, but increased in abundance and distribution slowly. The abundances and frequencies of early successional/colonizer species such as *Salicornea europea* and *Suaeda maritima* have fluctuated greatly over the years, but were not present pre-restoration. WAL still differs significantly from WAL-R in overall community composition, but this may in part be due to the greater number of plots containing high marsh species at WAL-R compared to WAL, which has extensive coverage of *S. alterniflora*.

Nekton: Individuals from sixteen species were observed and captured during the monitoring program (2005-2012) at WAL and WAL-R. No new species were captured during the 2012 monitoring season at WAL, but gaspereau and juvenile rainbow smelt were captured for the first time at WAL-R. Mummichogs and Atlantic silversides dominated the catch at both sites. When comparing the average relative abundance for each sampling method over the monitoring program, the minnow traps at WAL (24.16) and WAL-R (24.63) were fairly similar. Both sites had the lowest relative abundance for the minnow traps in 2012. The average relative abundance for the seven years of monitoring for the beach seine (WAL 5x greater average) and fyke net (WAL-R 1.5x greater average) methods differed greatly between WAL and WAL-R. The standard length average for mummichogs at WAL and WAL-R were similar for all years post-restoration and included juveniles and adults.

Aquatic Invertebrates: In 2012, twenty-two different species were collected with IATs at WAL and WAL-R, which were a mix of estuarine and freshwater animals. Seven years post-restoration the WAL and WAL-R samples were dominated by freshwater insects (water boatmen, Corixidae), and by the estuarine amphipod, *Gammarus mucronatus*. *Hydrobia totteni* and Copepods were also present in the samples. Corixidae sp., *Gammerus mucronatus* and species from the sub-class Copepoda were the individuals that were present most often at WAL. At WAL-R, Corixidae sp. had the greatest number of individuals during the monitoring program. However, there was no significant difference post-restoration between sites, nor over time, when ANOVA was completed.

Summary

The seven year monitoring program collected data for geospatial attributes, hydrology, soil and sediments, vegetation, nekton and benthic invertebrates at both the restoration site (WAL) and an adjacent salt marsh reference site (WAL-R). The seventh year of post-restoration monitoring has again shown that changes are still occurring at WAL although these changes have been subtle.

Restoration activities (water control structure removal, dyke breach (five locations) and digging a trench for the main channel) at WAL in 2005 have resulted in a more natural hydrological regime, restoring 9.72 ha of tidal wetland area. The observed changes over the seven years of post-restoration monitoring included improved pore water regime, expansion of halophytic vegetation and improved fish passage and usage. These changes were positive responses to the intervention at WAL and were not observed at WAL-R.

While it is difficult to predict how successful this restoration will be in the long term, it is clear that the major objectives (eliminate the tidal restriction caused by the dyke; 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 (low marsh versus high marsh) between WAL and WAL-R, the restoration activities undertaken at WAL in 2005 have resulted in the restoration of a self-sustaining and resilient salt marsh system.

Acknowledgments

We would like to extend our thanks to Dr. Danika van Proosdij and Dr. Jeremy Lundholm (Saint Mary's University - SMU) for all their assistance on this monitoring project and for their support. We also would not have been able to access the restoration and reference sites if it were not for the support of neighbouring property owners Mr. Ross and Mr. and Mrs. Burgess respectively. Thank you; we really appreciate it.

We wish to thank Greg Baker (SMU: MP_SpARC), Emma Poirier (SMU: Intertidal Coastal Sediment Transport Research Unit (In_CoaST)), and Patrick Stewart and Heather Levy (Envirosphere Consultants Ltd.) for their assistance with data collection, sample processing, provision of data and data analysis.

Financial and in-kind supporters of this project include: NSTIR; Ducks Unlimited Canada (DUC); Nova Scotia Department of Natural Resources (DNR); SMU's Community-Based Environmental Monitoring Program, Maritime Provinces Spatial Analysis Research Centre (MP_SpARC), and In_CoaST; and the Nature Sciences and Engineering Research Council of Canada (NSERC – Undergraduate Student Research award).

1.0 Introduction

The Walton River Salt Marsh Restoration Project was one of the first of its kind in Nova Scotia (NS), restoring tidal flow to 12 ha (9.72 ha inside the remaining dyke structure) of historical salt marsh on the Walton River, Hants County. It was determined in 2005 that restoration of a more natural hydrological regime to the Walton River Restoration Site would result in the re-establishment of a salt marsh habitat similar to that which existed prior to dyking. The restored tidal flow would restore fish access to the marsh surface and increase fish habitat, provide additional coastal wildlife habitat and improve productivity and transport of materials (nutrients) within the estuary.

This project was brought to fruition by the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR) with Ducks Unlimited Canada (DUC) partnering on the construction activities. The construction activities (water control structure removal and dyke breach) were completed between 29 August and 9 September 2005. The restoration of tidal flow to the Walton River Salt Marsh Restoration Site and completion of the long-term monitoring program fulfills the compensation requirements noted in NSTIR's Harmful Alteration Disruption or Destruction (HADD) Compensation Proposal and *Fisheries Act*-Section 35(2) HADD Authorization for Highway 101 construction in the St. Croix and Gaspereau River watersheds (Bowron and Chiasson 2006).

The purpose of the 2012 post-restoration monitoring for this project was to conduct the seventh and final year of the program for the Walton River Salt Marsh Restoration Site. The intent of this program was to document and determine the nature of the changes at the restoration site (WAL) in response to the restoration activities. These changes include the return of tidal wetland features and functions, such as the natural connection between the restoration site and the Walton River; fish access to the area inside the former dyke, including the marsh surface and salt pannes; improved productivity and transport of materials and the re-establishment of a self-sustaining system over time.

CBWES Inc. conducted an ecological baseline study of the restoration site and an adjacent unrestricted salt marsh in 2005 and developed a tidal wetland post-restoration long-term monitoring program (Bowron and Chiasson 2006). This program has been followed for the seven years of post-restoration monitoring (2006 through 2012: Bowron et al. 2007; Bowron et al. 2008; Bowron et al. 2009; Neatt et al. 2010; Neatt et al. 2011) with minimal activities conducted during the sixth year (2011) of monitoring. The minimum amount of long-term monitoring was completed in 2010 with the fifth year of post-restoration monitoring; however, it was recommended that monitoring continue to Year 7. This was recommended in order to better quantify environmental changes and verify project success (Wolters et al. 2008; Garbutt and Wolters 2008; Mossman et al. 2010).

All aspects of this project were conducted and supervised by CBWES Inc., under contract to NSTIR. Field and laboratory work was carried out by: Tony Bowron, Nancy Neatt, Jennie Graham, Ben Lemieux, Amy Lawrence, Christa Skinner and Michelle Whidden (CBWES Inc.); Dr. Danika van Proosdij, Dr. Jeremy Lundholm, Greg Baker (MP_SpARC), Brenden Blotnicky

(In_CoaST: SMU); and Patrick Stewart and Heather Levy (Envirosphere Consultants Ltd). Monitoring for year-seven was conducted between May 2012 and March 2013.

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[1]. These projects, in particular, the design and monitoring activities, have been presented by CBWES staff in poster and oral presentation formats at a number of regional, national and international scientific conferences[2]. Please contact CBWES for more information on these presentations. CBWES is committed to continuing to participate in important events such as these.

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

To date, two peer-reviewed papers have been published focusing on separate restoration projects. One was published in *Restoration Ecology* on the Cheverie Creek Restoration Project titled "*Macro-Tidal Salt Marsh Ecosystem Response to Culvert Expansion*" (Bowron et al. 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 titled "Chapter 13 – Salt Marsh Tidal Restoration in Canada's Maritime Provinces" was recently published in the book *Tidal Marsh Restoration: A Synthesis of Science and Management* (Roman and Burdick 2012). Two more papers for peer-review publication are currently being developed examining the relationship between plant community structure and environmental conditions (abstract presented in Appendix A), and whether or not there is sufficient data to allow a shift from the current paired reference-restoration site approach to a reference condition approach (use of existing data from multiple reference sites).

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

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

1.2 Report Organization

The focus of this report was to describe the 2012 monitoring activities, continue the process of comparing the post-restoration habitat conditions to the conditions that were present prior to dyke breaching and to compare those exhibited by the reference site, and to summarize what has happened over the past seven years at WAL. This report draws from, and builds on, the information presented in the pre-restoration monitoring report (Bowron and Chiasson 2006) and the previous five years of post-restoration monitoring reports (Bowron and Neatt 2007; Bowron et al. 2008; Bowron et al. 2009; Neatt et al. 2010; Neatt et al. 2011). Just as the monitoring program itself is a continuation of the data collection activities, this report is meant to continue to describe the ongoing monitoring activities that are part of this project and to present the results of the comparison of the current years habitat conditions to those of the reference site and of previous years.

It should be noted that much of the background information in this report, such as the site descriptions and the introductions for each of indicator categories, have been taken from the previous WAL project reports. This was done in order to provide the reader with all the information necessary to understand the many elements of the project without having to refer to previous reports.

Information on the study and reference sites 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 seventh 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 recommendations for future restoration monitoring. Appendices in the 2013 report provide: (A) CBWES supported student research project descriptions; (B) photographic documentation of 2012/13 winter conditions; and (C) DUC's waterfowl monitoring report.

2.0 Description of Restoration and Reference Sites

2.1 Walton River Restoration Site (WAL)

The Walton River is a tidal river located on the southern shore of the Minas Basin, in Hants County, NS (Figure 1 and Figure 2). Historically dyked, the Walton River receives tidal flow through a causeway-bridge highway crossing (Highway 215) near the mouth of the River, with an extensive salt marsh system bordering the tidal component of the river. The 12 ha restoration site (9.72 ha inside the remaining dyke structure) is located on the north side of the river, 1.2 km upstream from the Walton Bridge. The site was dyked in 1990 by DUC to create a freshwater impoundment (pond) for waterfowl and wildlife (Figure 3). High maintenance costs associated with maintaining the dyke and water control structure and the challenge of preventing saltwater intrusion into the impoundment resulted in the consideration of the site for restoration.

Restoration was undertaken by DUC on behalf of NSTIR on 29 August – 9 September 2005, to restore the natural tidal regime and habitat type (salt marsh) to this site. Restoration activities included removing the water control structure; breaching the dyke in five locations (75 – 125 m long); and reconstructing a secondary tidal channel along the south side of the marsh (Figure 10). Material from the dyke was back-filled into the borrow pit with care to avoid complete in-filling in order to create a channel (Figure 4). A central tide channel, constructed by digging an approximate 2 m wide x 0.5 m deep trench within the footprint of the dyke to the borrow pit, became the main entrance and exit for tidal waters and fish to the site (Figure 5 and Figure 6).

Once drained, WAL was essentially mudflat habitat and very water logged. Post-restoration, WAL experienced rapid re-colonization by salt marsh vegetation (*Spartina alterniflora*: smooth cordgrass) which started near the breaches and channel banks, and progressed to full site coverage within three years (Figure 7 and Figure 8), filling in the channel banks (borrow pit, main channel) by Year 5 (Figure 9). During the past four years (2009-2012) there has been an increased presence of *Carex paleacea* (Salt marsh sedge), *S. pectinata* (Freshwater cordgrass), *Juncus gerardii* (Black grass), *Limonium nashii* (Sea lavender) as well as *S. patens* (Salt meadow hay). The fringe marsh is characterized by the typical salt marsh zonation with *S. alterniflora* occupying the low marsh and *S. patens* occupying the adjacent high marsh (Figure 13). The site has a network of channels connecting formed pannes to tidal waters on lower tides. These pannes have become fully established and retain water, providing fish habitat all year long (Figure 10).

WAL is occasionally grazed by neighbouring cows, as they walk around the periphery of the site, feeding on the upland transitional vegetation and *S. alterniflora* along the dyke breaches. Initially they seemed to impede vegetation re-colonization, and although slower, the most affected breach has filled in with vegetation (Figure 12). Various wildlife species have been viewed near, on and around WAL including bald eagles, white egrets (Figure 11), American black ducks, kingfishers, herons, beaver, whitetail deer and foxes.

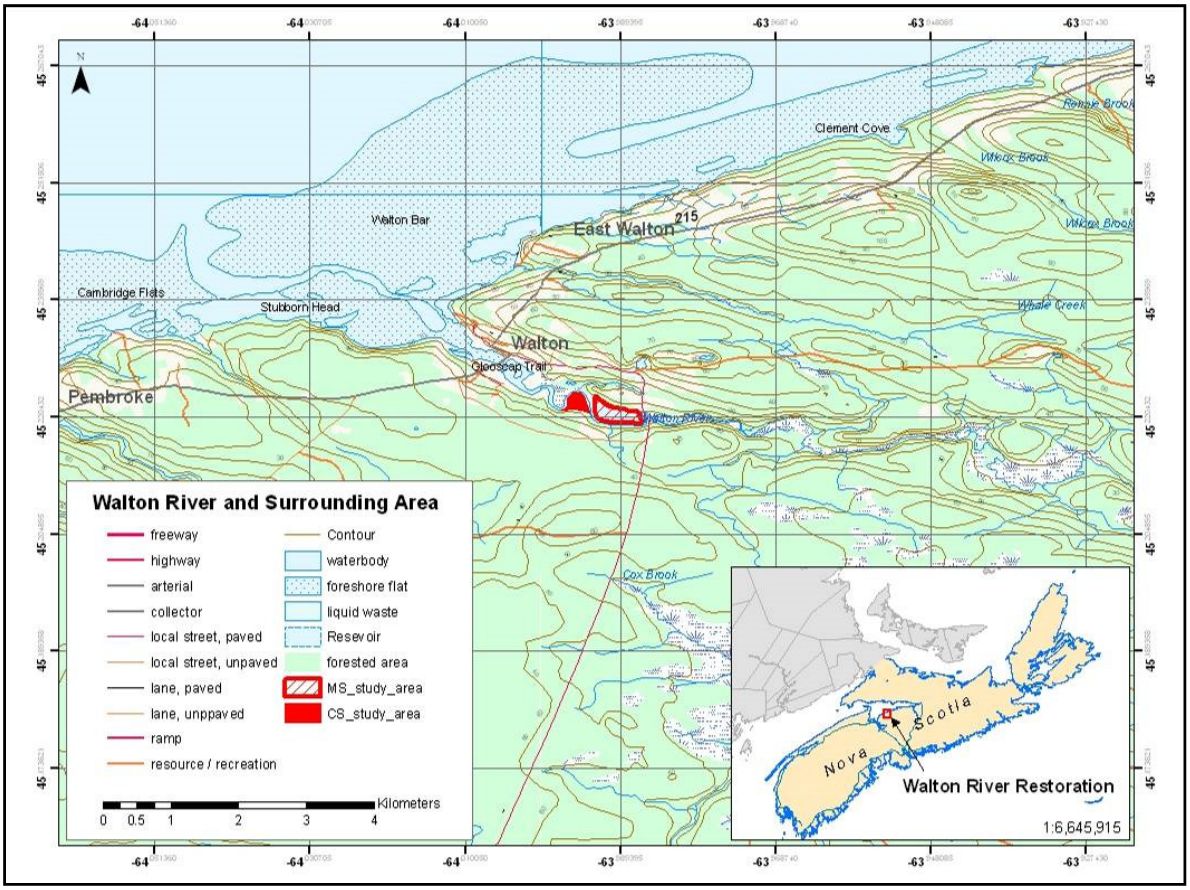


Figure 1: Location of WAL (restoration site: red outline) and WAL-R (reference site: solid red) on the Walton River, Hants County, NS.

Figure 2: Google earth image showing Walton River, with the reference site (left) and restoration site (right) in the black box.

Figure 3: 2004 aerial photograph of the impoundment pre-restoration.

Figure 4: Earthworks at WAL in fall of 2005 showing partial infilling of borrow pit.

Figure 5: The central tide channel ("main channel"), constructed by digging an approximate 2 m wide x 0.5 m deep trench. Black arrow is pointing towards river. Photograph by T. Bowron, fall 2005.

Figure 6: Main channel in August 2012. Photograph by T. Bowron, August 2012.

Figure 7: Second breach at WAL. Photograph by T. Bowron, fall 2005.

Figure 8: Second breach at WAL colonized with vegetation. Photograph by N. Neatt, August 2012 taken from approximately same location as Figure 7.

Figure 9: Borrow pit at second breach showing channelization and banks colonized with *Spartina alterniflora*. Photograph by N. Neatt, August 2012.

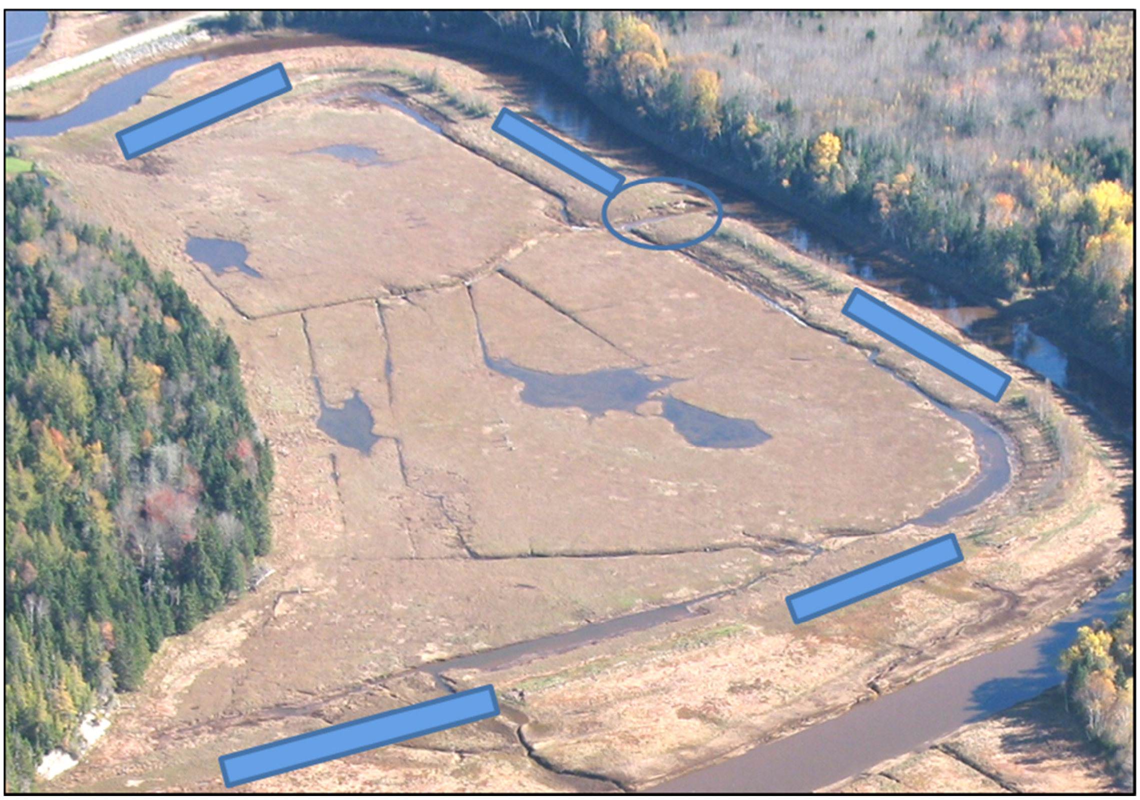


Figure 10: WAL 2012 showing the five breaches (solid blue), main channel (blue outline) and the channel network and pannes. Breaches are numbered 1 - 5 clockwise, starting from the top left corner. Aerial photography by Gaiamatics Solutions Inc. 28 October 2012.

Figure 11: White egret perched on a dead tree on the marsh surface at WAL near one of the pannes. Photograph by N. Neatt, August 2012.

Figure 12: Breach 1 at WAL showing re-colonization along the breach in 2012. Insert shows cows from local farm and lack of vegetation on breach 1 in 2008. Photographs by CBWES Inc.

Figure 13: Fringe marsh at WAL (WAL-F) showing low marsh and high marsh zonation. Photograph by N. Neatt, August 2012.

2.2 Walton River Reference Site (WAL-R)

The reference site for this project is located immediately downstream of WAL on the south side of the river (Figure 1 and Figure 2). WAL-R is smaller in spatial extent than WAL (4.95 ha; Figure 14); however, the ecological and social history of this site, which closely parallel that of WAL, combined with its proximity make it an ideal reference site. Typical salt marsh species found on other salt marshes in the Bay of Fundy can be found on this site, such as *S. alterniflora*, *S. patens*, and *J. gerardii* (Figure 15). This site has a well-developed tidal creek and panne system and the marsh surface completely floods on a spring tide. Large scale changes that have occurred at WAL during the monitoring period (2005 – 2010) have not occurred at WAL-R.

Figure 14: WAL-R aerial photo showing channels. Imagery by Gaimatics Solutions Inc., 28 October 2012.

Figure 15: WAL-R landscape line 1. Photograph by N. Neatt, 7 August 2012.

3.0 Long-term Monitoring Program and Methods

3.1 Monitoring Program

A long-term monitoring program was developed for the Walton River Salt Marsh Restoration Project in 2005 (Bowron and Chiasson 2006; Bowron et al. 2011a; Neckles et al. 2002; van Proosdij et al. 2010), to document changes in habitat conditions (re-activation of tidal creek and panne network; fish access to the marsh surface and pannes; establishment of salt marsh vegetation) at WAL following restoration activities, to determine if additional intervention was required and to determine whether a self-sustaining system had been established. This was accomplished by comparing yearly results to an established baseline condition at WAL, as well as to a reference site where the monitoring program was replicated each year.

Salt marsh monitoring should commence prior to restoration (construction) for a period that allows data to be collected for all necessary indicator categories (typically one year). For a completely restricted site such as WAL (barrier breach and full habitat conversion), once restoration (earthworks) have been completed, monitoring should occur annually for a consecutive five years post-restoration. Following hydrological restoration, changes in abiotic and biotic conditions can occur very rapidly (one to three years), while the site as a whole may require considerably more time to mature (stabilize). For example, channels, creeks, pannes and vegetation community structure within a site such as this can experience significant change within a season, whereas the hydrology (flood pattern), sediment conditions (erosion, deposition) and typical habitat zonation patterns (high and low vegetation communities) may take years to develop and stabilize. For a partially restricted site, which is a modification/expansion of existing habitat conditions, a minimum of three consecutive years post-construction monitoring, and ideally every two to three years (depending on the site) thereafter should occur until long-term success criteria for the restoration project are achieved.

The monitoring program at WAL utilized six salt marsh indicators (geospatial attributes, hydrology, soils and sediments, vegetation, fish and invertebrates) which are measures of wetland structure and function, and collectively provide basic information on ecosystem response to restoration. The suite of indicators were drawn primarily from a tidal wetland restoration monitoring protocol (GPAC) for assessment of tidal restoration of salt marshes in the Gulf of Maine and Bay of Fundy (Neckles and Dionne 2000; Neckles et al. 2002; Weldon et al. 2005), to obtain consistent monitoring methods between regions. Each indicator category contains a number of physical and biological parameters for which data is collected and Table 1 identifies which parameters had data collected during the 2012 monitoring season. Not all parameters are sampled on an annual basis (e.g., sediment characteristics) and some parameters (i.e., sediment elevation and benthic invertebrates) are sampled annually, but are not analyzed until a multi-year data-set has been collected. Figure 16 illustrates the location of the permanent transect lines and location of data collection for the various parameters.

Table 1: WAL monitoring program including core and additional ecological indicators, methodologies, and sampling frequency (annual application indicated by X – all sites; W – Restoration Site; R – Reference Site).

Category	**Parameters**	**Sampling Method**	**Annual Sampling Frequency**	**Pre- (2005)**	**Post-Restoration (2006-2012)**						
					1	**2**	**3**	**4**	**5**	**6**	**7**
Hydrology	Tidal Signal	Daily maximum water level (manual water level recorder), Continuous (5 minute intervals) water level recorders (Solinst Levelogger (Model 3001)	Daily maximums: WAL: 18 tides 08/05 to 10/05 Continuous water level: WAL & WAL-R: 24/11/06 to 19/12/06; 17/11/08 to 16/12/08; 15/07/10 to 18/08/10; 25/05/12 to 11/07/12	W	X		X		X		X
	Depth to Groundwater	Groundwater wells	WAL & WAL-R: monthly from 9/05 to 10/05; 7/06 to 9/06; 7/07 to 9/07; 7/08 to 9/08; 06/09 to 09/09; 08/10 to 09/10; 06/12 to 09/12	R	X	X	X	X	X		X
	Water Quality	YSI 650 MDS and YSI 556 MPS pH Handheld Dissolved Oxygen Instruments	WAL: 19/9/05, 20/10/05; 14/7/06, 10/9/06, 11/11/06; 13/6/07, 31/7/07, 27/9/07, 29/10/07; 16/9/08, 16/10/08; 23/6/09, 18/9/09, 20/10/09; 9/09/10, 8/10/10; 19/09/12, 17/10/12 WAL-R: 20/9/05, 21/10/05; 16/8/06, 9/10/06, 10/11/06; 2/8/07, 26/10/07; 17/9/08, 15/10/08; 24/6/09, 21/9/09, 19/10/09; 10/09/10, 7/10/10; 17/09/12, 17/10/12	X	X	X	X	X	X		X
Soils & Sediments	Marsh Surface Elevation	Digital Elevation Model (DEM). Total Station; Trimble R8 GNSS RTK	Once per required sampling year.	X			X		X		X
	Pore Water Salinity	Sipper; Refractometer; FieldScout EC 110 Meter	WAL & WAL-R: monthly from 9/05 to 10/05; 7/06 to 9/06; 7/07 to 9/07; 07/08 to 09/08; 06/09 to 09/09; 08/10 to 09/10; 06/12 to 09/12	X	X	X	X	X	X		X
	Sediment Elevation	Rod Sediment Elevation Tables (RSET)	WAL: 2 stations, installed 10/05, measured 10/05, 06, 07, 08, 11/09, 10/10, 11/11, 11/12 WAL: 3rd station installed 10/06, measured 10/06, 07, 08, 11/09,	X	X	X	X	X	X	X	X

Category	Parameters	Sampling Method	Annual Sampling Frequency	Pre- (2005)	Post-Restoration (2006-2012)						
					1	2	3	4	5	6	7
			10/10, 11/11, 11/12 WAL-R: 1 station installed 10/05, measured 10/05, 06, 07, 08, 11/09, 10/10, 11/11, 11/12 WAL-R: 2nd station installed 10/06, measured 10/06, 07, 08, 11/09, 10/10, 11/11, 11/12								
	Sediment Accretion	Marker Horizons (3 per RSET) and 3 along Lines 1 and 6. Sampled using a cryogenic corer (Cahoon et al. 1996).	Marker horizons – WAL: installed 9/05; 10/05, measured 10/06, 10/07, 10/08, 11/09, 10/10, 11/11, 11/12 WAL-R: installed 10/06; measured 10/07, 10/08, 11/09, 10/10, 11/11, 11/12	Installed	X	X	X	X	X	X	X
	Sediment Characteristics (bulk density, organic matter content, sediment type)	Sediment Cores (soil samples): Bulk Samples: 5 cm x 40 cm Paired Samples: (30 ml cut syringe w/ 5 cm x 15 cm core).	Bulk samples: WAL & WAL-R: 6 samples, 11/05 Paired samples: WAL & WAL-R: 6 paired samples, 12/07, 9/08, 9/10, 08/12	X	X		X		X		X
Vegetation	Composition Abundance Height	Point Intercept method (1 m^2 plots)	WAL: 40 plots (13 on fringe marsh); annually 8/05, 8/06, 8/07, 8/08, 8/09, 7/10, 8/12 WAL-R: 27 plots, annually 8/05, 8/06, 8/07, 8/08, 8/09, 7/10, 8/12	X	X	X	X	X	X		X
	Habitat Map	Aerial Photograph, DGPS/GIS, Total Station, Trimble R8 GNSS RTK, Low-altitude Aerial Photography (Blimp), Flight	Elevation survey – 28&29/11/10 Blimp – 12/11/10 Flight – 28/10/12	X	X		X		X		X
Nekton	Composition Species Richness Density Length	Minnow Traps in pannes, tidal creeks and main channel (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.	WAL: 19/9/05, 20/10/05; 14/7/06, 10/9/06, 11/11/06; 13/6/07*, 31/7/07*, 27/9/07, 29/10/07; 16/9/08, 16/10/08; 23/6/09, 18/9/09, 20/10/09; 9/09/10, 8/10/10; 19/09/12, 17/10/12 WAL-R: 20/9/05, 21/10/05; 16/8/06, 9/10/06, 10/11/06; 2/8/07, 26/10/07;	X	X	X	X	X	X		X

Category	**Parameters**	**Sampling Method**	**Annual Sampling Frequency**	**Pre- (2005)**	**Post-Restoration (2006-2012)**						
					1	**2**	**3**	**4**	**5**	**6**	**7**
			17/9/08, 15/10/08; 24/6/09, 21/9/09, 19/10/09; 10/09/10, 7/10/10; 17/09/12, 17/10/12 * minnow traps only								
Benthic & Other Aquatic Invertebrates	Abundance and Species Richness (intertidal benthic)	Reference Condition Approach (RCA) – 9.2L sediment sample	WAL – 30/8/05; 30/8/06; 3/9/07; 3/9/08, 26/8/09; 30/8/10	X	X	X	X	X	X		
	Abundance and Species Richness (aquatic)	Invertebrate Activity Traps (IAT) – inverted pop bottle set for 24 hours over a neap tide.	WAL – 08/07; 07/08, 08/08; 07/09, 08/09; 07/10, 08/10; 07/12, 08/12 WAL-R – 09/05; 08/07; 07/08, 08/08; 07/09, 08/09; 07/10, 08/10; 07/12, 08/12	R		X	X	X	X		X
Winter Conditions	Ice/snow conditions	Structured Winter Walk; photographs along each Line	Once per year. 15/4/11, 6/3/13	X	X	X	X	X	X	X	X
Waterfowl (conducted by DUC)	Abundance and Species Richness	Bird counts	Appendix C	X	X	X	X	X	X		

3.2 Methods

Sampling was conducted at both WAL and WAL-R using transects (Lines) established in a non-biased, systematic sampling design, using a combination of 100 m field tape, compass and Leica TCR-705 Total Station[3]. Six Lines were established at WAL, 70 m apart, (as measure along the upland) running perpendicular to the main river channel, and marked with two semi-permanent wooden stakes (Front and Back stakes) at the upland (Figure 16). Similarly, four Lines were established at WAL-R, but set 50 m apart (Figure 16). The Lines served to locate the sample stations for each of the key physical and biological parameters monitored. Data was collected for the physical and biological parameters at sampling stations established 20 m along each Line at WAL and 40 m at WAL-R.

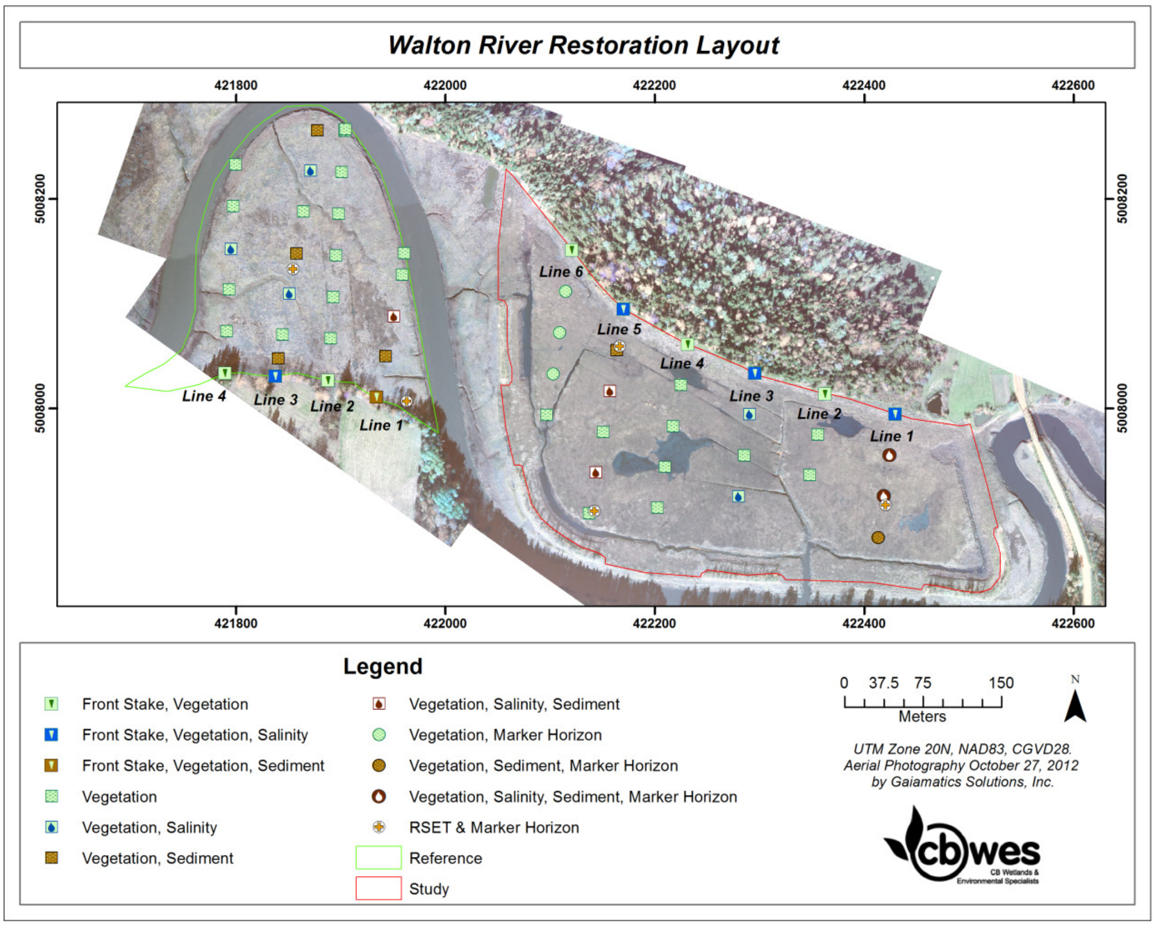


Figure 16: Location of transects and main sampling stations at WAL and WAL-R.

3.2.1 Geospatial Attributes

Digital Elevation Model (DEM) and Habitat Map

The habitat map and DEM for WAL and WAL-R were updated during the monitoring program as conditions at the respective sites changed and additional mapping activities undertaken. The original DEM and baseline habitat map for WAL and WAL-R were produced using ArcGIS

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

command TOPOGRID with 2005 survey data (Leica TCR-705 Total Station) and contours from the 1:10 000 Nova Scotia Topographic Database used as inputs (Bowron and Chiasson 2006). It was based on this original DEM that the estimate of restorable area was determined, while the habitat map provided a foundation for the monitoring activities, illustrating changes in habitat condition (vegetation community structure and important habitat features) over the extent of the monitoring program.

The DEM for both sites were updated in 2008 (Bowron et al. 2009), 2010 (Neatt et al. 2011) and again in 2012 by conducting new elevation surveys of the sites in each year. To construct the 2008, 2010 and 2012 DEMs contours were extracted from the previous year's surface and used as secondary inputs for the new DEM. This method maintains the integrity of the creek bank and upland edges while platform elevations are derived primarily from that year's survey data. The creek network was delineated from low-altitude aerial photography[4] collected by CBWES in November 2010, which substantially improved the quality of the DEM hydrology for 2010 and 2012. In 2010 and 2012 additional analysis were performed to track changes in the primary channel that has developed at WAL. Triangular Irregular Networks (TIN) surfaces were created for each year and profiles extracted along three surveyed transects surveyed.

The 2010 habitat map for WAL was created in an ArcGIS environment by using the orthorectified mosaic image as the base layer. Vegetation data was overlayed on top of the mosaic and polygons, and the different habitat types were then delineated and labeled using vegetation data and image interpretation. The 2012 habitat map was similarly constructed, but used the orthorectified mosaic image built by images from the Gaiamatics Solutions Inc. flight rather than CBWES' blimp-based system which was grounded in 2012 because of the unavailability of helium.

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. When attempting to understand changes in the water table level, depth to ground water can be a valuable parameter to monitor as it provides information on the degree of waterlogging or drainage that is occurring on a marsh, which can assist in understanding changes in vegetation communities (Roman et al. 2001). 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 hydroperiods (frequency and duration of tidal flooding) for WAL and WAL-R 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

[4] The low altitude photography was taken from a small format aerial photographic platform using a helium filled blimp with a suspended camera (Canon Eos Rebel XSi) and lens system (Canon EFS 10-22 mm ultra wide zoom) controlled by an operator on the ground using a remote control.

Model 3001 Levelogger Golds[5] (water elevation and temperature) and a Solinst Barologger (atmospheric pressure and temperature).

At WAL, a Levelogger was placed in a still well (Figure 17) in the main channel of the site to determine the water levels within the creek network and marsh surface of the site. A second Levelogger was placed in the main channel of the Walton River, aligned with Line 3 at WAL-R to measure water levels within the River.

The Barologger collects atmospheric pressure and temperature data, which was required for post-processing of the Levelogger data. With a functioning radius of 30 km, a single Barologger was installed on the upland property adjacent to the Cheverie Creek Salt Marsh Restoration Project (CHV: Bowron et al. 2013). The instrument was installed in the upland adjacent to the restoration site to avoid submergence by water.

The Leveloggers were deployed on 25 May 2012 and retrieved 11 July 2012 to capture tide levels throughout at least one neap to spring tide cycle. The Leveloggers and Barologger were programmed to take measurements at five-minute intervals throughout the sampling period. The positions (elevations) of each of the units were surveyed using a Trimble R8 GNSS RTK surveying system. Following retrieval, the data from the loggers were downloaded into the Solinst Software Version 3[6] for post-processing and analysis.

Using the tidal elevation information from the Leveloggers, a set of tide signal graphs were created in Microsoft Excel by creating line graphs, placing the date and time on the x-axis and tide height on the y-axis. The hypsometric curves for the restoration and reference sites 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.

Figure 17: Solinst Levelogger (Model 3001) on the left and still well on the right. Photographs by N. Neatt, 2007.

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

Depth to Water Table

Field Methods

The ground water wells used to measure depth to water table were made following the specifications in Roman et al. (2001). They were made from ¾" plastic tubing, cut into 70cm lengths (10 cm aboveground and 60 cm belowground), and 1/4" holes were drilled into the belowground section of the well. This was to allow water to percolate into the well. The bottoms of the wells were covered with duct tape and the tops were capped. Each groundwater well was set on the Line, 1 m towards the creek from the associated vegetation station. Sand was used to fill in any space between the well and the footprint made during installation. To determine the depth to water table, a ¼" metal rod, fixed with a flexible tube at one end, and a meter stick were used. The metal tubing was lowered into the well, while simultaneously forcing air through, using the flexible tubing, until bubbles were heard. The position of the top of the well was marked on the metal rod, which was then removed and the distance from the mark to the bottom of the rod was measured to give the depth to water table. A single measurement from each well per sampling event was taken approximately 2 hours on either side of the low tide throughout the growing season. Specifically, the wells in 2012 were measured monthly on 13 June, 11 July, 7 August and 12 September at both WAL-R and WAL. There were five wells at WAL-R and nine at WAL.

Statistical Analysis

For both WAL and WAL-R, descriptive statistics (mean, range, and standard error) were calculated for all sampling stations. These statistics were used to create a histogram and line graph to illustrate temporal patterns. In addition, t-tests were used to determine statistically significant changes in depth to groundwater, either spatially or over the course of the monitoring program. For tests comparing WAL and WAL-R a two-sample test was run, assuming unequal variances. For tests tracking change over time (pre-versus post-restoration conditions) a paired two-sample test was used. In addition a one sample ANOVA was run to test variation between all years simultaneously. All t-tests were run at a 95% Confidence Interval ($p<0.05$) in Microsoft Excel software.

Water Quality

Water quality (salinity, temperature, dissolved oxygen (DO), pH) of surface floodwater was sampled using a YSI 650 Handheld Dissolved Oxygen Instrument[7] in conjunction with nekton sampling as prescribed by the Community Aquatic Monitoring Project (CAMP: Weldon et al. 2005). Measurements were taken after each beach seine pull. If only the fyke net was used, the floodwaters were sampled at slack high tide.

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; Crain et al. 2004). Measuring pore water salinity throughout the growing season and in conjunction with depth to

[7] http://www.ysi.com/productsdetail.php?650MDS-13

water table monitoring 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.

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); however, this will vary depending on the source material.

Pore Water Salinity

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 2012 monitoring season a FieldScout EC 110 Meter 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 a handheld temperature compensated optical refractometer. When using the FieldScout EC 110 Meter, measurements were taken *in situ*, and readings recorded in the field.

As with depth to water table, pore water salinity should be conducted throughout the growing the season. Sampling during the 2012 field season took place once a month on 13 June, 11 July, 7 August and 12 September at WAL-R (five stations) and WAL (nine stations). At each station both shallow (15 cm) and deep (45 cm) pore water measurements were taken.

For WAL and WAL-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, both spatially and over the course of the monitoring program. All t-tests were run at a 95% Confidence Interval ($p<0.05$) in Microsoft Excel software.

Sediment Accretion and Elevation

Monitoring sediment accretion and changes in surface elevation was conducted using a series of feldspar clay marker horizons (measures accretion) and Rod Sediment Elevation Tables (RSET) (measures elevation) installed at each site. Both the RSETs and the marker horizons were installed (Figure 18) and measured according to the methods developed by Dr. Cahoon and Lynch (USGS 2005). In 2005 (October), two RSETs were installed at WAL and a single RSET installed at WAL-R (Figure 22). In 2006 an additional RSET was installed at each site (Figure 22). The baseline measurements were taken in 2005 and 2006 at the time of installation. The RSETs and marker horizons were then measured annually in October of 2006, 2007, 2008, 2009, and 2010. In 2011 and 2012 the RSETs and marker horizons were measured in November. Measurement directions 1, 3, 5 and 7 were used for the RSET readings. A compass reading was taken for each position and measurements taken for all nine pins. To take the baseline measurements, each pin was lowered to the surface of the marsh (moving aside any materials which were not attached to or incorporated into the sediment) and the distance from the top of the RSET arm to the top of each pin was measured (Figure 19).

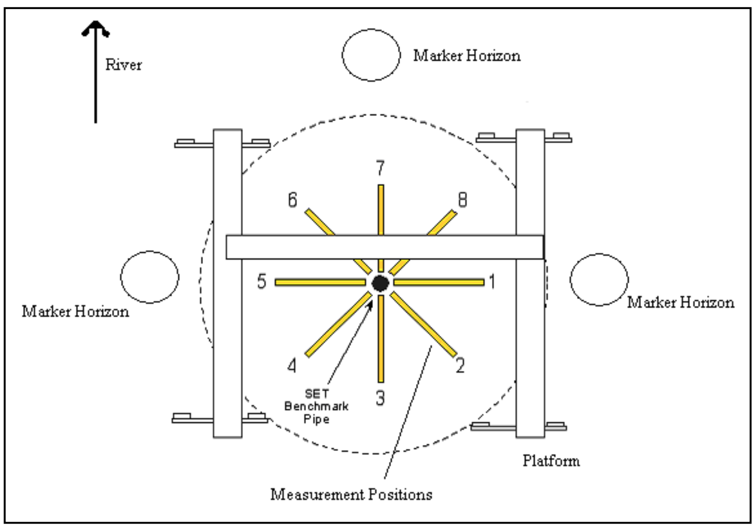


Figure 18: RSET and feldspar marker horizon layout (modified from USGS 2005).

Figure 19: The nine measure pins of the RSET. Photograph by C. Skinner, August 2012.

Marker horizons were established pre-restoration with the first marker horizon measurements taken during year-one post-restoration monitoring. Three 0.5 m^2 marker horizons were established with each RSET station. Marker horizons were arranged around the outside of the RSET sampling station with one on the downstream, one on the upstream and the third towards the main river channel (Figure 18). The marker horizons were established simultaneously with the first (baseline) set of RSET measurements. In order to capture any initial deposition of sediment on WAL immediately following the removal of the dyke, a series of single 0.5 m^2 marker horizons were installed on 2 September 2005. Three markers were installed along Line 1 and three markers along Line 6 (Figure 22). Markers were paired with vegetation sampling locations along the respective lines. These six additional markers were measured from pre- up to and including five years post-restoration. The marker horizons were measured with a Cryogenic corer (Figure 20) to determine the amount of deposition that had occurred (Cahoon et al. 1996). The Cryogenic Corer consists of three main parts: a small stainless steel self-pressurized liquid nitrogen Dewar (15L), stainless steel tubing with attached inner sleeve (copper tubing) and an outer sleeve or “bullet” over the inner sleeve (Figure 20).

To collect cores with the Cryogenic Corer, the bullet is pushed into the marsh surface three to four inches and the valve on the Dewar opened. Once a white cloud of gas is observed from the top of the bullet, the flow of liquid nitrogen can be stopped and the core can be pulled out of the marsh. A measurement can then be taken from the feldspar to the top of the soil surface (in millimeters) (Figure 21). Four readings were taken per core as the distances to the feldspar can vary. If the feldspar is observed on the marsh surface then zeros are recorded. If a marker horizon cannot be found with one core then another should be taken. If after three cores the marker horizon could not be located, then it was deemed missing or compromised (eroded).

Figure 20: Marker horizon sampling with the cryogenic corer (with stainless steel tubing and copper “bullet”) at Lawrencetown Lake Reference Site. Photograph by B. Lemieux, December 2011.

Figure 21: Core or "marsh-cicle" on bullet used for marker horizon calculations. Top of core is to the left. Photograph by B. Lemieux, November 12.

To determine the change in surface elevation between sampling years (e.g., 2009 and 2010), the difference in elevation at each pin is first calculated by subtracting the value in 2010 from the value in 2009. It is important that the same point is measured (e.g. same measurement direction and pin position). If the value is negative, the elevation of the surface has lowered and if it is positive, the surface has increased. A mean is derived from all 36 net change values to give a mean net change in surface elevation in cm per year or in this example, from 2009 to 2010.

This value is used in conjunction with the marker horizon data to gain an understanding of the sedimentary processes occurring on the marsh surface. A mean is determined from these three cores taken around the RSET (Figure 18) and represents the amount of sediment and organic matter that has accumulated or accreted on the marsh surface since the marker horizon was established. Net mean accretion per year is determined by subtracting the accretion value of the previous year from the current year.

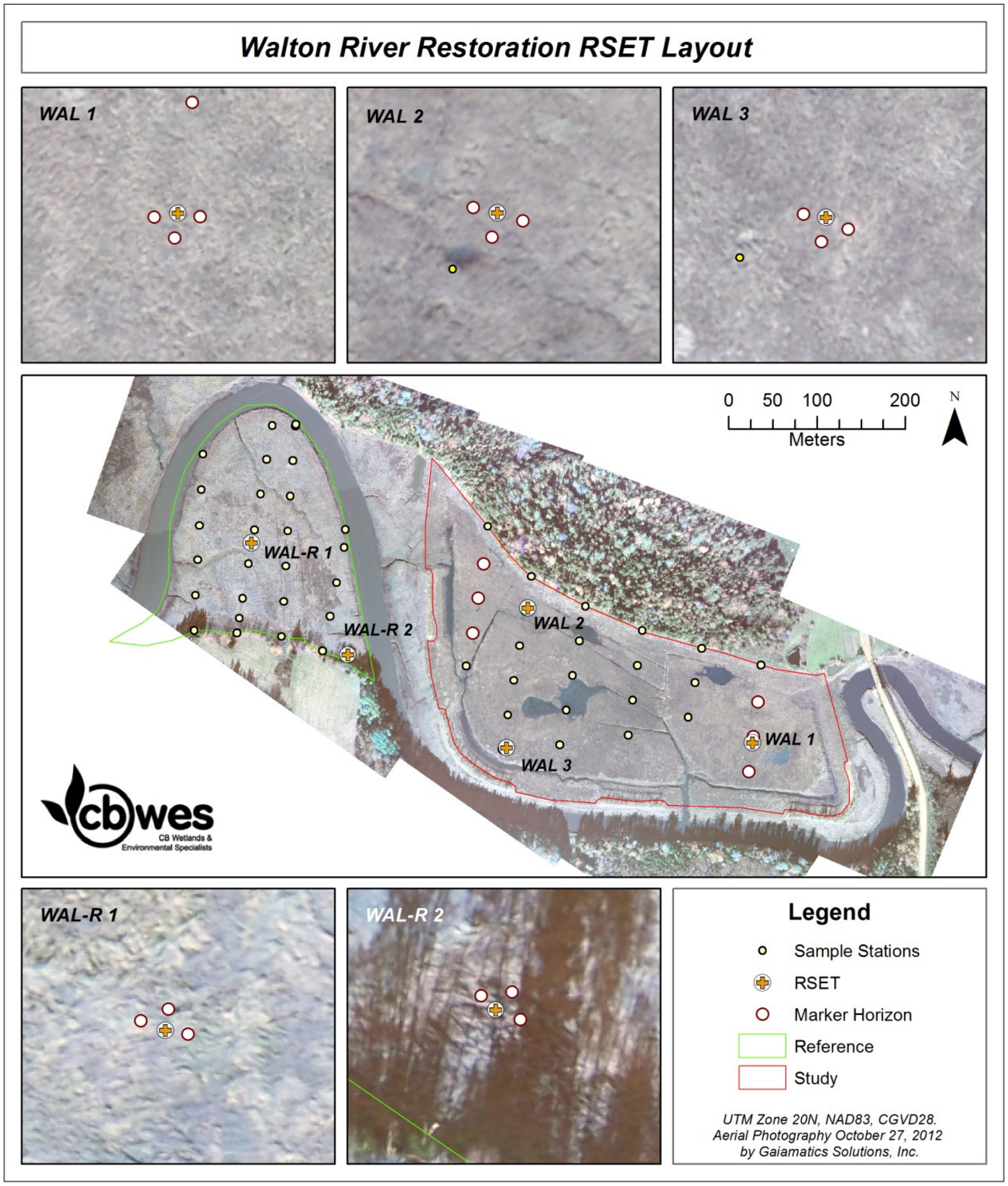


Figure 22: Locations of the RSETs at WAL and WAL-R.

Analysis
The calculations from the RSETs and marker horizons, as well as the results and discussion were prepared by Dr. Danika van Proosdij (SMU) and presented in Section 4.3.

Soil Characteristics

Field Methods
Soil samples were collected on 7 August 2012 at both WAL and WAL-R. Samples were taken at six locations at WAL and six locations at WAL-R (Figure 16). 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 bags, sealed, labeled and transported in a cooler with ice back to the lab where they were stored in a freezer until processing. Some soil compaction did occur during the coring process, but every attempt was made to avoid further compaction of the samples during transport and storage prior to freezing. The metal tubes were capped on both ends using plastic caps and immediately labeled. Some compaction did occur during the sampling process but no further compaction/disruption should have occurred prior to the samples freezing.

Laboratory Methods
Cores were processed at the In_CoaST for bulk density, water and organic matter content and grain size analyses for the 2007 samples were performed at the Coastal Wetlands Centre at Mount Allison University using a Coulter Laser instrument. The 2010 cores were analyzed within the In_CoaST 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).

<u>Sample preparation and documentation:</u> 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.

<u>Bulk density:</u> 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:

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

Organic content (using a loss-on-ignition (LOI) 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 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 samples were dried at 65°C to prevent fusing of clays and crushed using a mortar and pestle. A small subsample was placed in a 20 ml beaker and treated with 5 ml of 30% hydrogen peroxide within a fume hood to remove organic matter without damaging the particles. The beaker was then filled with an 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 (low marsh, mid marsh, high 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 WAL and WAL-R on 7 August 2012 using 1 m^2 plots positioned at intervals along each Line (Figure 16). The first vegetation plot of each Line was located at the front stake, with subsequent plots positioned at 20 m intervals at WAL and 40 m intervals at WAL-R. This arrangement yielded a total of 27 vegetation sampling stations for WAL-R and 27 at WAL. There were also 13 vegetation sampling stations (continuance of each Line) located outside the dyke on the fully established fringe salt marsh at WAL (Walton Restoration Fringe: WAL-F).

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 river) 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 were 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

Species richness per plot and the percentage of the ground not covered by plants were compared between the two sites using repeated measures ANOVA. Additionally, richness and abundance were also calculated including only halophytic species. Species included in this category were *Atriplex glabriscula*, *Carex paleacea*, *Distichlis spicata*, *Juncus gerardii*, *Limonium nashii*, *Plantago maritima*, *Puccinellia maritima*, *Ranunculus cymbalaria*, *Ruppia maritima*, *Salicornia europaea*, *Scirpus maritima*, *S. alterniflora*, *S. patens*, *S. pectinata*, *Suaeda maritima*, *Triglochin maritima*. Only species found in more than one plot are included in the ordination and summary table (Table 17 and Figure 55). These were also analyzed using repeated-measures ANOVA. To compare species composition and abundance between sites, we used non-metric multidimensional scaling (NMDS) on Bray-Curtis distances among plots to graph plot differences in vegetation. These analyses were performed using statistical program R (v. 2.11.1)[8] using the vegan package for ordination.

The vegetation data was analyzed by Dr. Jeremy Lundholm (SMU) and 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).

Fish are a challenging group to quantify due to their mobility and temporal variability, as well as the difficulties of sampling in, what can be, a heavily vegetated environment with a varied hydrological regime. Two species commonly found in salt marsh habitats are the mummichog (*Fundulus heteroclitus*) and Atlantic silverside (*Menidia menidia*). The mummichog or salt water minnow is a resident of salt marshes and Atlantic silversides are known to swim into salt marshes at high tide searching for food, and both are prey for larger fish within the tidal rivers and salt marshes during high tide (Gibson 2003). Similar to mummichogs, the *S. alterniflora*

[8] http://www.r-project.org

dominated low marsh areas of salt marshes is one of the substrates Atlantic silverside use for reproduction (egg attachment) (Fay et al. 1983). Atlantic silverside may also be important exporters of secondary production and biomass from marsh and estuarine systems to offshore areas as they usually die after spawning or during their second winter of life (Fay et al. 1983).

Fish surveys were carried out on 19 September and 17 October 2012 at WAL and on 17 September and 17 October 2012 at WAL-R, using a combination of beach seine, minnow traps and fyke net. The beach seine and fyke net, which sample for all species and size ranges of fish utilizing the marsh surface, require a spring tide to ensure adequate depth and duration of tidal water of the marsh surface (depth of water on marsh surface > 1 m). Tide levels during the summer months were not conducive to fish surveying, due to inadequate depth; therefore, fish surveys only occurred during the fall of 2012. At WAL-R two beach seine pulls were completed during the fish survey in September. Tidal conditions (water level, velocity, waves) on the designated sampling dates in September and October for WAL and in October for WAL-R did not support sampling with the beach seine. On these dates, sampling was conducted using only the fyke net and minnow traps. Figure 25 shows the sampling locations for the beach seine, fyke net and minnow traps.

Sampling with the beach seine 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 returning the entire seine to the shore. A minimum of two (typically three) “pulls” of the beach seine were performed during each survey event. Beach seine sampling at WAL-R was conducted from the upland edge at Line 1 and between Line 1 and 2 (Figure 25).

The fyke net design and [modified] methodology followed was that used by Dionne et al. (1999). The fyke net was set at low tide with the wings at approximate 45 degree angles and retrieved when the water drained low enough to approach the net while still ensuring the cod end was still under water. The fyke net was deployed at a different location each sampling event, near the main channel and across a secondary channel leading to a panne between Lines 2 and 3 at WAL and top of channel at Line 1 and 3 on WAL-R (Figure 23 and Figure 25).

Smaller species utilizing the salt pannes and tidal creeks were sampled using the minnow traps baited with bread (Figure 24). Traps were set at WAL in pannes near Lines 2 and 3 and in the burrow pit near Line 1 (Figure 25). At WAL-R, traps were set within channels at Lines 1 and 4 as well as pannes at Line 2 (Figure 25). Traps were deployed in advance of high tide and retrieved once the tide level had dropped (approximately 3.5 hours).

All captured specimens were held in buckets, identified to species using identification guides (Audubon Society 1993; Graff and Middleton 2002; Scott and Scott 1988), counted (to a maximum of 300 per species), and measured for length (15 individuals per species). Photographs, and if necessary a single representative, of unknown species were taken for identification purposes, while all remaining individuals were returned to the site of capture.

Figure 23: Fyke net at WAL set across a secondary channel on 17 October 2012. Photograph by N. Neatt.

Figure 24: Minnow trap at St. Croix River Restoration site. Photograph by B. Lemieux, September 2012.

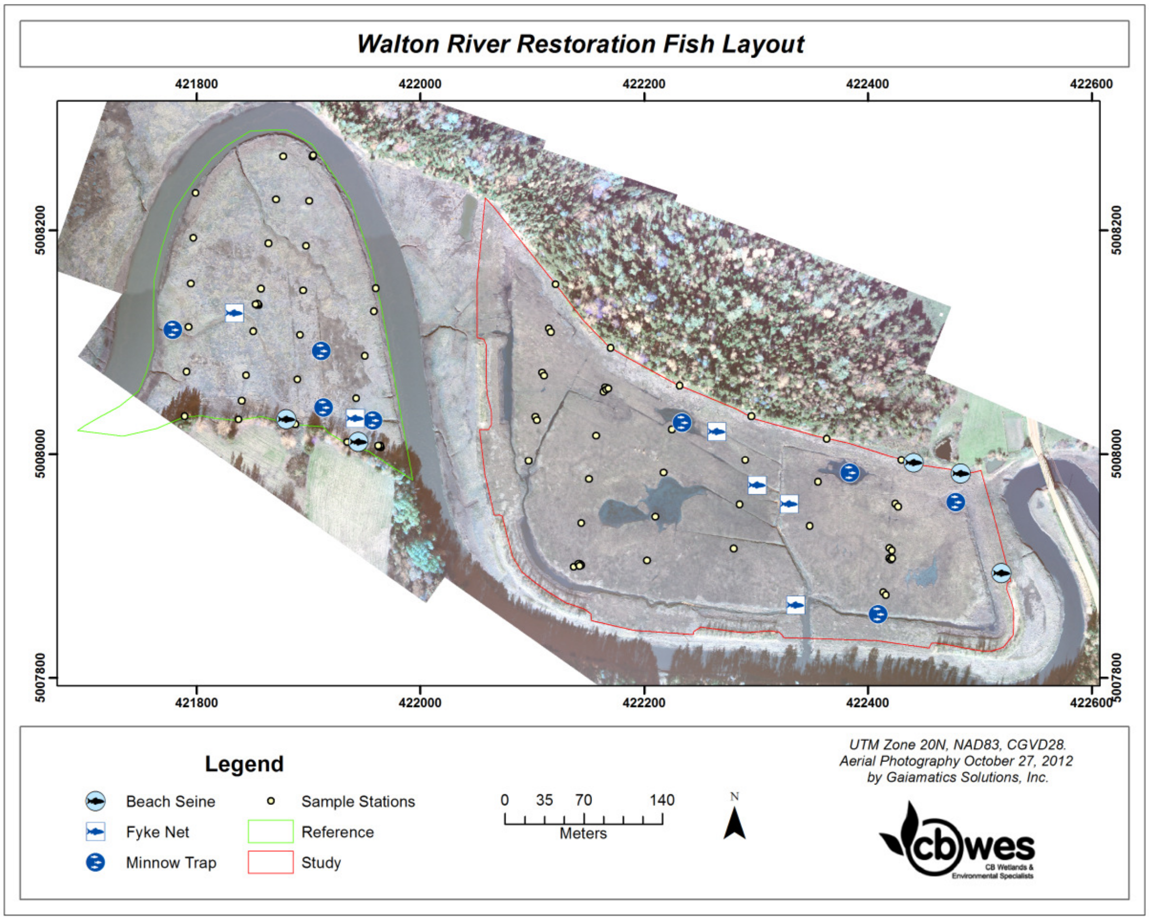


Figure 25: Locations for nekton sampling at WAL and WAL-R.

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

Benthic Invertebrates

Data associated with benthic invertebrates were collected for a number of parameters from 2005 to 2010 as prescribed by the Reference Condition Approach (RCA) (Reynoldson et al. 1997; Reynoldson 2005; Westhead 2005). Biota and sediment samples associated with the benthic invertebrate sampling were taken at three locations: main river channel adjacent to WAL, main river channel opposite WAL-R, and one downstream on the Walton coastal flat. The full methodology used in RCA data collection and analyses can be found in Bowron and Chiasson (2006).

The RCA benthic invertebrate data from 2005 through 2008 were pooled and analyzed following the third year of post-restoration monitoring according to the RCA methodology developed by Reynoldson et al. (1997; Reynoldson 2005). This analysis was presented in Bowron et al. (2009). The full RCA data set (2005 through 2010) was analyzed in 2010 and presented in Neatt et al. (2011). The 2010 analysis included a comparison between years and between sites, as well as a comparison of the overall results to those of a similar study conducted within the Minas Basin by Westhead (2005). In addition to the samples collected at Walton, three samples were taken at the Cheverie Creek (CHV) and Bass Creek (CHV-R) sites for the Cheverie Creek Salt Marsh Restoration Project (Bowron et al. 2011b). All sites were analyzed together.

Aquatic Invertebrates

Sampling of other aquatic invertebrates within the water column of the pannes occurred at WAL and WAL-R. Two samples were taken at each site on 25 July and 16 August 2012 using Invertebrate Activity Traps (IAT; passive sampling). The IAT were left to sample a 24 hour period during a neap tide cycle. These traps were constructed from 2 L clear plastic bottles; the top portion was cut off, inverted and taped in place with duct-tape (Figure 26). The IAT were placed in four pannes (two at WAL and two at WAL-R), submerged and anchored to ensure the trap remained within the panne. The samples were emptied into a 0.5 mm sieve and the remaining materials and organisms were field preserved in 70% isopropyl alcohol (Bowron and Chiasson 2006). Envirosphere Consultants Ltd. then performed the species identification.

Figure 26: Invertebrate Activity Trap (IAT). Photograph by T. Bowron, 2005.

3.2.7 Structured Winter Site Walk at WAL and WAL-R

On 6 March 2013, a structured winter site-walk was conducted at WAL and WAL-R. Landscape photographs were taken along each Line from the associated back stake. In areas where the Line could not be viewed through the trees at the back stake, the photograph was taken from the front stake. At WAL the structured walk included the perimeter of the site (dyke), with photographs being taken of key features such as ice, areas of erosion, river channel and the main tidal channel within the second breach. The walk began and ended at the beginning of the first breach (closest to the bridge). At WAL-R, the structured walk was completed along the upland edge of the marsh, starting at the eastern edge of the site (Line 1) and ending at the western edge (Line 4). Again, landscape photographs were taken along each Line from a reproducible location (back stake or front stake). The 2012/2013 winter site walk was conducted by Tony Bowron (photographer) and Ben Lemieux.

4.0 Results of the 2012 Monitoring Program

4.1 Geospatial Attributes

Digital Elevation Model (DEM) and Habitat Maps

Figure 27 shows the 2012 DEM for WAL and WAL-R. The mean elevation for WAL from the 2012 DEM was 5.66 m (CGVD28) with a range of 3.36 m to 9.52 m and a standard deviation of 0.87 m (Table 2). The mean elevation for WAL-R was 5.89 m (CGVD28) with a range of 3.53 m to 10.18 m and a standard deviation of 0.93 m (Table 2). The mean elevation at WAL-R has been higher on Years 3, 5 and 7 compared to WAL (Table 2). The mean elevation at WAL has shown a decrease each year new data has been collected and the range has increased. This change reflects an increased ability to survey the borrow pit and other hydraulic features that were inaccessible in the first few years of monitoring, as shown in the transect profiles by the decrease in elevation of the borrow pit more so than a large decrease in elevation of the marsh surface (Figure 28). However, WAL has been dewatering and consolidating during the monitoring program which accounts for some decrease in elevation. The Line 5 comparison shows this as the elevation of the Line has levelled out. This is also shown with a similarity in soil water content at Year 7 as well as a decrease in bulk density (*Section 4.3: Soils and Sediment*). At WAL-R, the elevation means and ranges have remained stable over the seven years of the monitoring program.

The habitat maps for WAL and WAL-R can be found in Figure 29 and Figure 30 respectively. These were constructed using a combination of orthorectified aerial imagery and vegetation survey data for each site. The habitat at WAL consists of five large pannes, directly connected to the channels (relic drainage ditches). There is one main channel to the site which connects to the borrow pit and other drainage channels. WAL appeared to have much more water on site than WAL-R and WAL seven years post-restoration was dominated by *S. alterniflora*. The habitat at WAL has been changing, as illustrated by Figure 31. This figure shows that WAL has been colonized by halophytic vegetation since 2006, and the expansion of pannes has changed one of the plots to standing water. The upland portion of the site has become dominated by *S. patens* and *Juncus gerardii* and the rest of the site is *S. alterniflora* dominated except for a single plot on Line 6 of *S. patens*. When looking at Figure 34, this plot on Line 6 was actually inundated less frequently than most at WAL. As for the fringe habitat at WAL, there have not been any changes over the seven years of the monitoring program.

The habitat at WAL-R has four channels/creeks that allow water onto the site, with a few small pannes and two linear panne habitats (possible relict drainage ditches: Figure 30). Unlike WAL, WAL-R is dominated by *S. patens*.

Table 2: DEM and survey statistics for WAL and WAL-R for Years 1, 3, 5 and 7 post-restoration.

DEM and Survey Stats		2006	2008	2010	2012
Study	DEM Mean	6.20	6.00	5.78	5.66
	DEM Max	9.10	9.32	9.31	9.52
	DEM Min	5.13	3.27	3.45	3.36
	DEM Standard Deviation	0.30	0.41	0.68	0.87
Reference	DEM Mean	6.10	6.09	6.08	5.89
	DEM Max	10.0	10.07	10.04	10.18
	DEM Min	3.50	3.43	3.47	3.53
	DEM Standard Deviation	0.80	0.78	0.77	0.93
Study	Survey Mean	6.19	5.73	6.01	5.76
	Survey Max	7.68	7.60	8.57	7.57
	Survey Min	5.53	3.29	3.10	3.58
	Survey Standard Deviation	0.48	0.83	0.93	0.74
Reference	Survey Mean	6.09	6.13	5.98	6.10
	Survey Max	7.58	7.25	7.58	7.24
	Survey Min	3.69	4.12	3.32	4.74
	Survey Standard Deviation	0.63	0.46	0.71	0.36

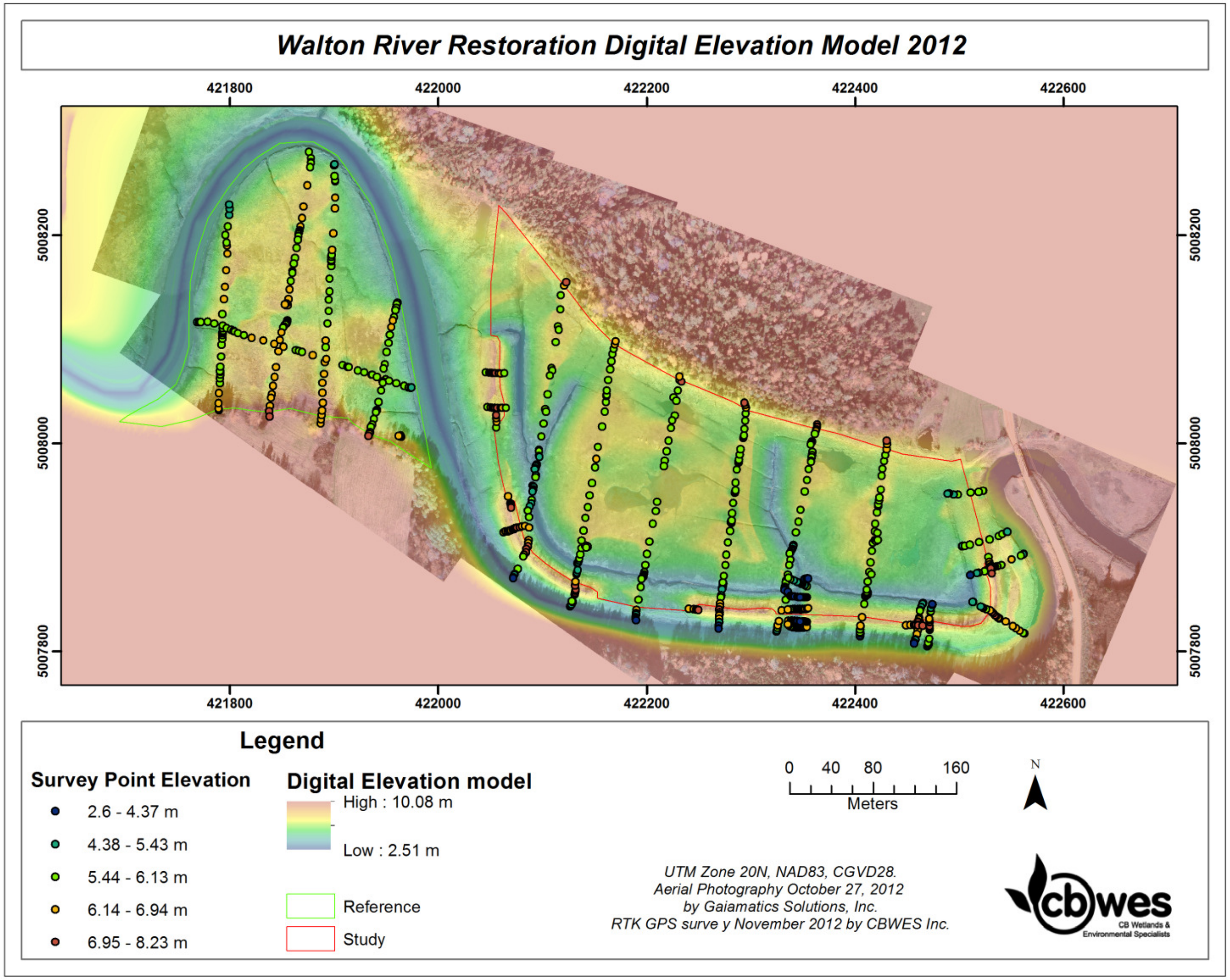


Figure 27: DEM of WAL and WAL-R. The blue colors indicate low elevation and the red colors indicate high elevations.

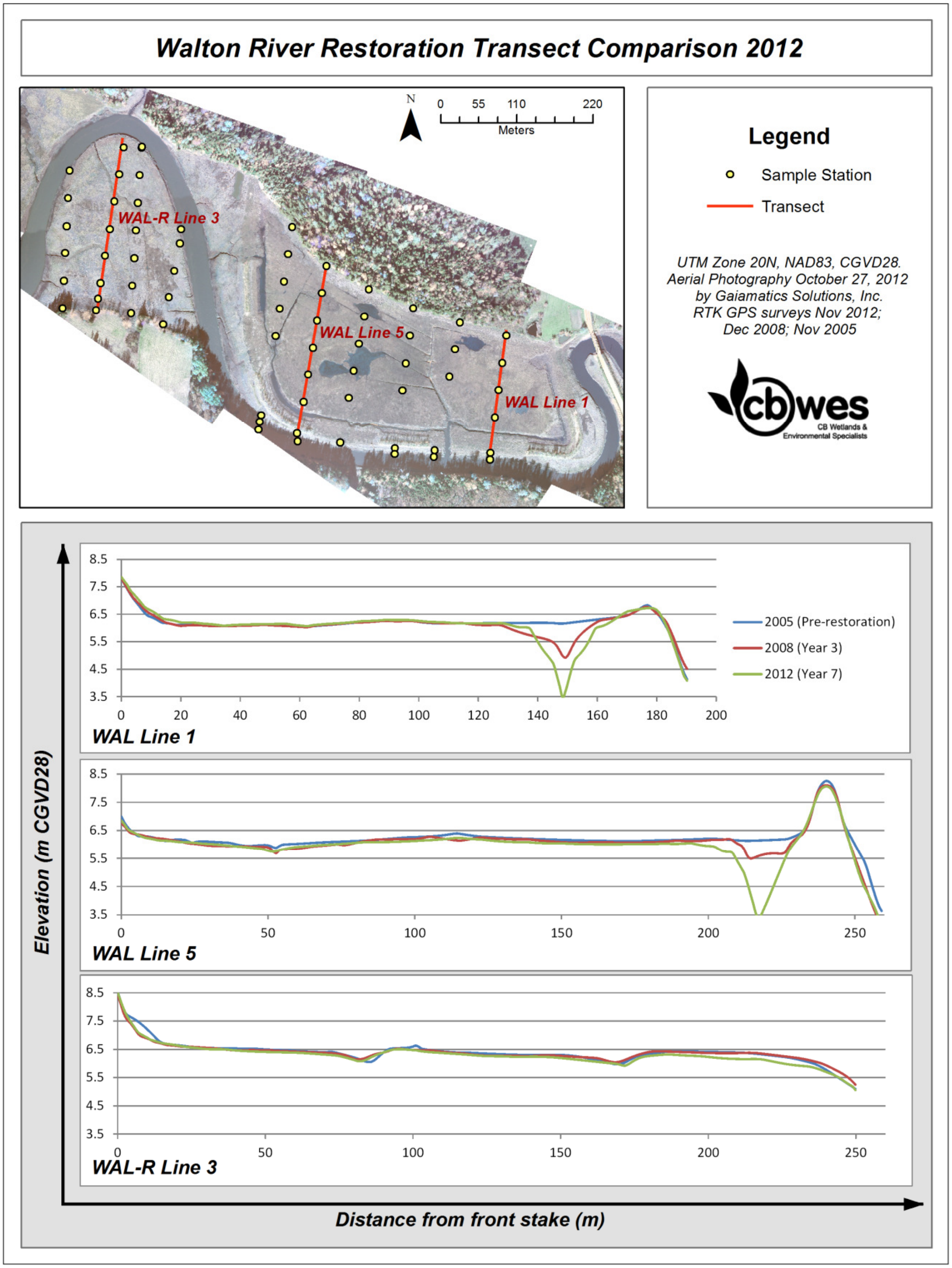


Figure 28: Transect comparisons between 2005 (Pre), 2008 (Year 3) and 2012 (Year 7) for Line 1 and 5 at WAL and Line 3 at WAL-R.

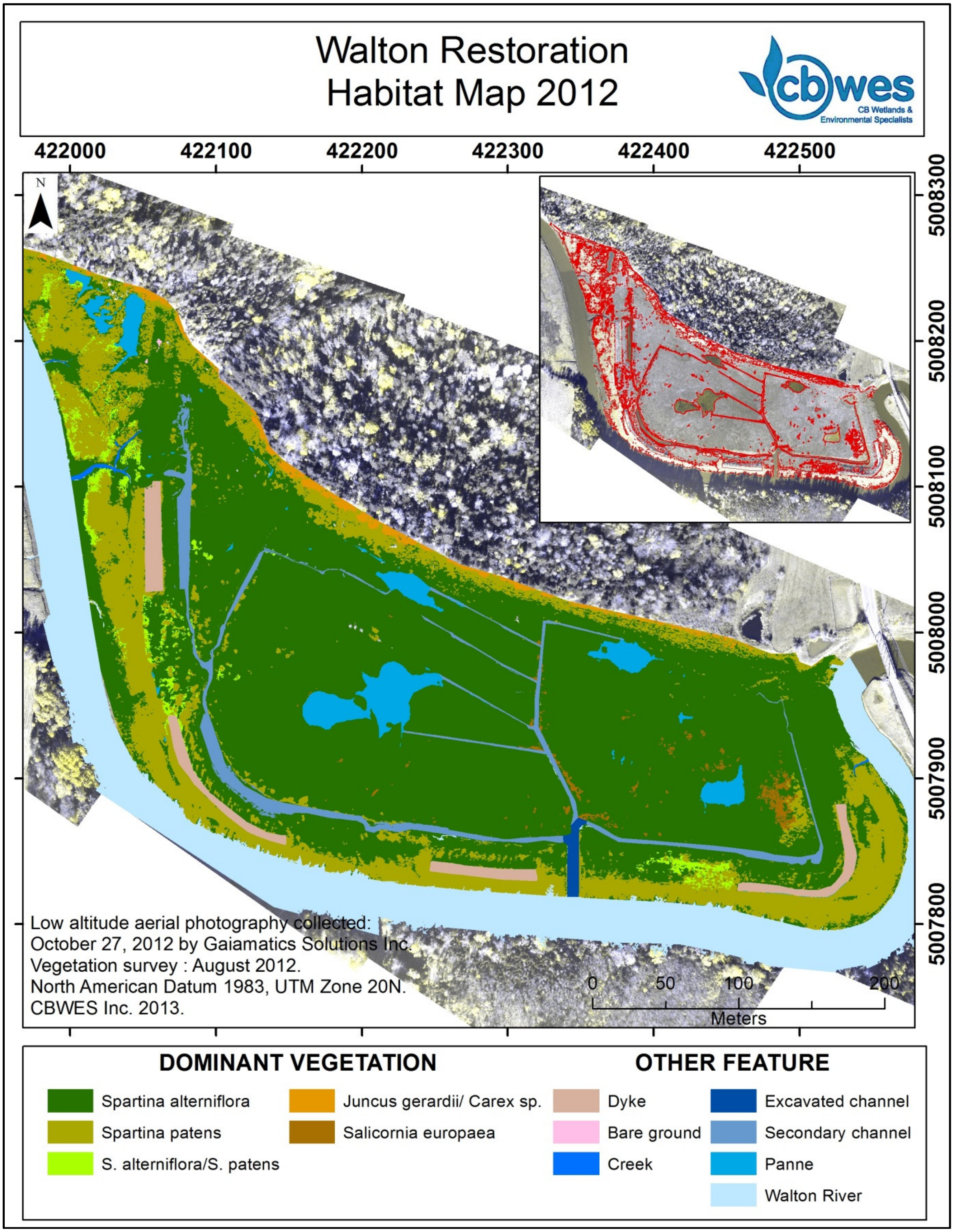


Figure 29: Habitat map of WAL showing vegetation community structure, tidal creek network, and pannes.

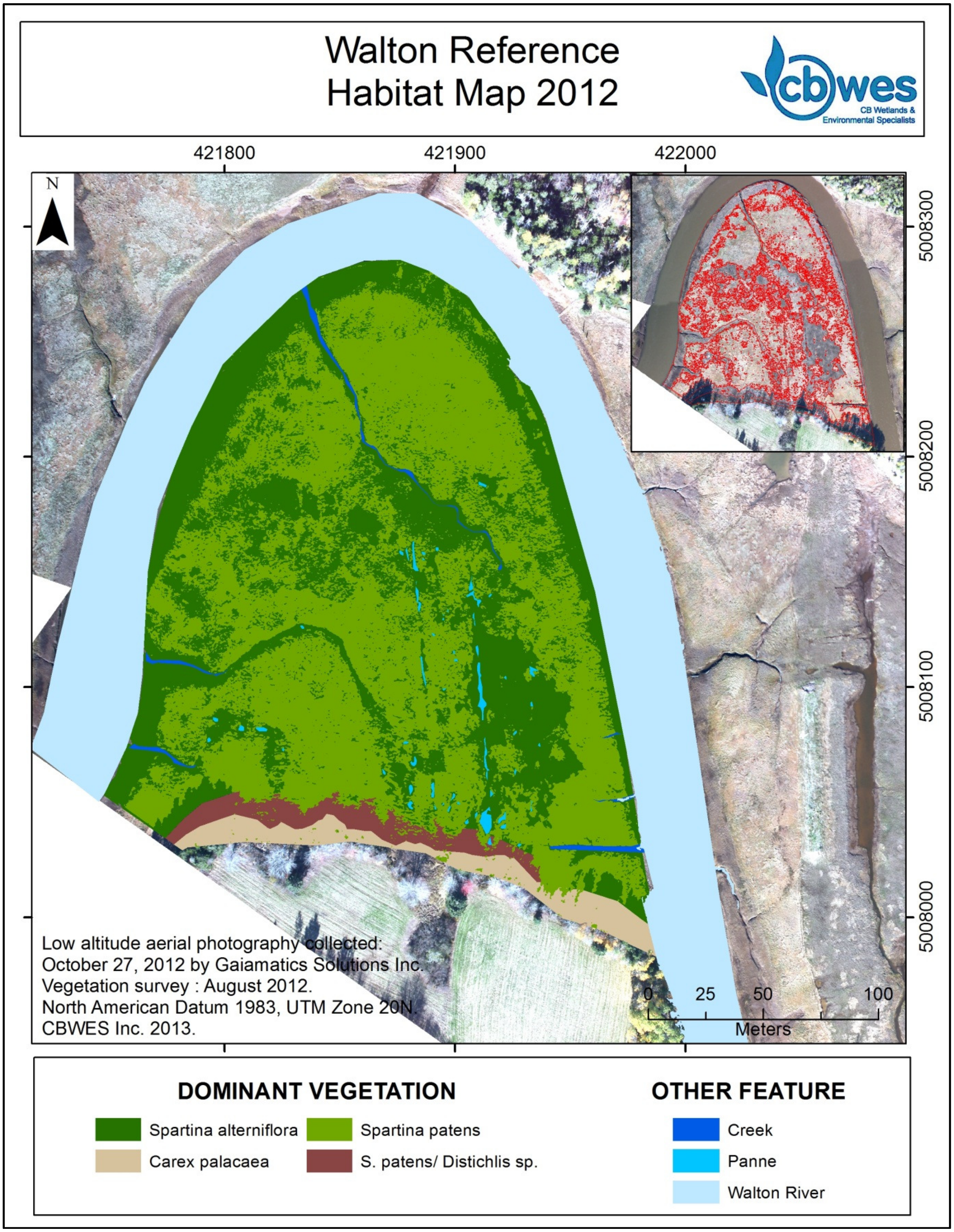


Figure 30: Habitat map of WAL-R showing vegetation community structure, tidal creek network, and pannes.

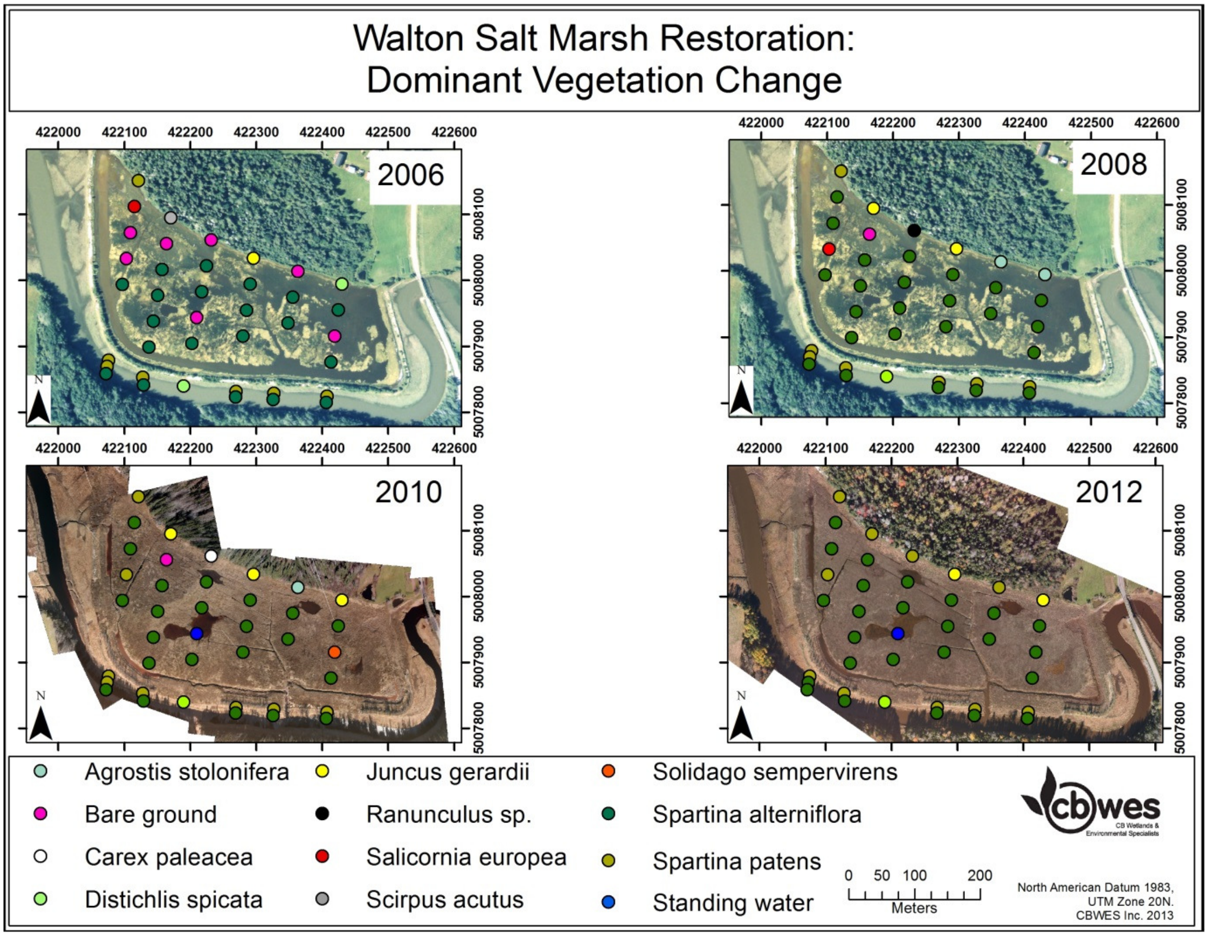


Figure 31: Maps for Year 1 (2006), 3 (2008), 5 (2010) and 7 (2012) post-restoration showing dominant vegetation changes per plot.

4.2 Hydrology

Hydroperiod and Tidal Signal

The highest recorded tide elevation for the data collection period (25 May to 11 July 2012) was 7.85 m (CGVD28: Table 3, Figure 33 and Figure 34), which would cover the entire marsh surface at WAL (9.49 ha). A mean high tide of 6.37 m (CGVD28), recorded during this period, would cover 8.72 ha. The total flooded area at WAL has remained relatively constant, with slight increases and decreases depending on the recorded tide elevation and the DEM for each year (Table 3). In 2005, immediate post-restoration at WAL, a tide elevation equal to or greater than approximately 6.3 m (CGVD28) was required to overtop the fringe marsh and flood the restoration site. Channel development has increased flooding to the site such that by year five post-restoration a tide level of approximately 5 m (CGVD28) will flood into the borrow pit; bank-full condition is achieved with a 5.8 m (CGVD28) tide level; and marsh-full by a 6.4 m tide. Figure 33 shows that the water levels and the timing of peak tide were similar in the River as they were within WAL.

Comparison of the 2005 and 2010 hypsometric curves demonstrates the effect the development of the main channel, and subsequent improved connectivity of the borrow pit and drainage ditches, has had at WAL. This was evident with the 2005 to 2008 comparison (van Proosdij et al.

2010); however, was more pronounced five years post-restoration. The shape of the curve for WAL now more closely resembles WAL-R.

Figure 34 illustrates the possible extent of flooding scenarios for the minimum, mean and maximum tides recorded in 2012. The creek development, as discussed below, allow for the site to be utilized as habitat (2.36 ha; Table 4) on a minimum high tide (5.18 m; CGVD28), similar to the low marsh at WAL-R (Figure 34). The banks of the borrow pit and channels are colonized by *S. alterniflora* seven years post-restoration and are available viable fish habitat during lower high tide events (Figure 9, Figure 39 and Figure 35). Figure 34 also illustrates the inundation frequency per plot for WAL and WAL-R. At WAL, the majority of the plots are inundated by 63.7 to 81.3 % of the high tides and at WAL-R the majority of plots are inundated by 47.2 to 63.7 % of the high tides. This difference is expected given the difference of the elevation at the two sites (Table 2 and Figure 27).

Table 3: Tide level recorder, DEM and survey stats for ears 1, 3, 5 and 7 post-restoration.

		2006	2008	2010	2012
TLR	Recording Period Start	24-Nov	18-Nov	15-Jul	25-May
	Recording Period Finish	19-Dec	16-Dec	18-Aug	11-Jul
	Recording Period Duration (Days)	31	28	34	46
	Minimum Water level recorded	-0.42	3.08	3.22	3.21
	Maximum recorded	7.95	7.54	7.90	7.85
	Study Area covered at Max tide height (ha)	9.62	9.59	9.62	9.49
Study	DEM Mean	6.2	6.00	5.78	5.66
	DEM Max	9.1	9.32	9.31	9.52
	DEM Min	5.13	3.27	3.45	3.36
	DEM Standard Deviation	0.3	0.41	0.68	0.87
Reference	DEM Mean	6.1	6.09	6.08	5.89
	DEM Max	10.0	10.07	10.04	10.18
	DEM Min	3.5	3.43	3.47	3.53
	DEM Standard Deviation	0.8	0.78	0.77	0.93
Study	Survey Mean	6.19	5.73	6.01	5.76
	Survey Max	7.68	7.60	8.57	7.57
	Survey Min	5.53	3.29	3.10	3.58
	Survey Standard Deviation	0.48	0.83	0.93	0.74
Reference	Survey Mean	6.09	6.13	5.98	6.10
	Survey Max	7.58	7.25	7.58	7.24
	Survey Min	3.69	4.12	3.32	4.74
	Survey Standard Deviation	0.63	0.46	0.71	0.36

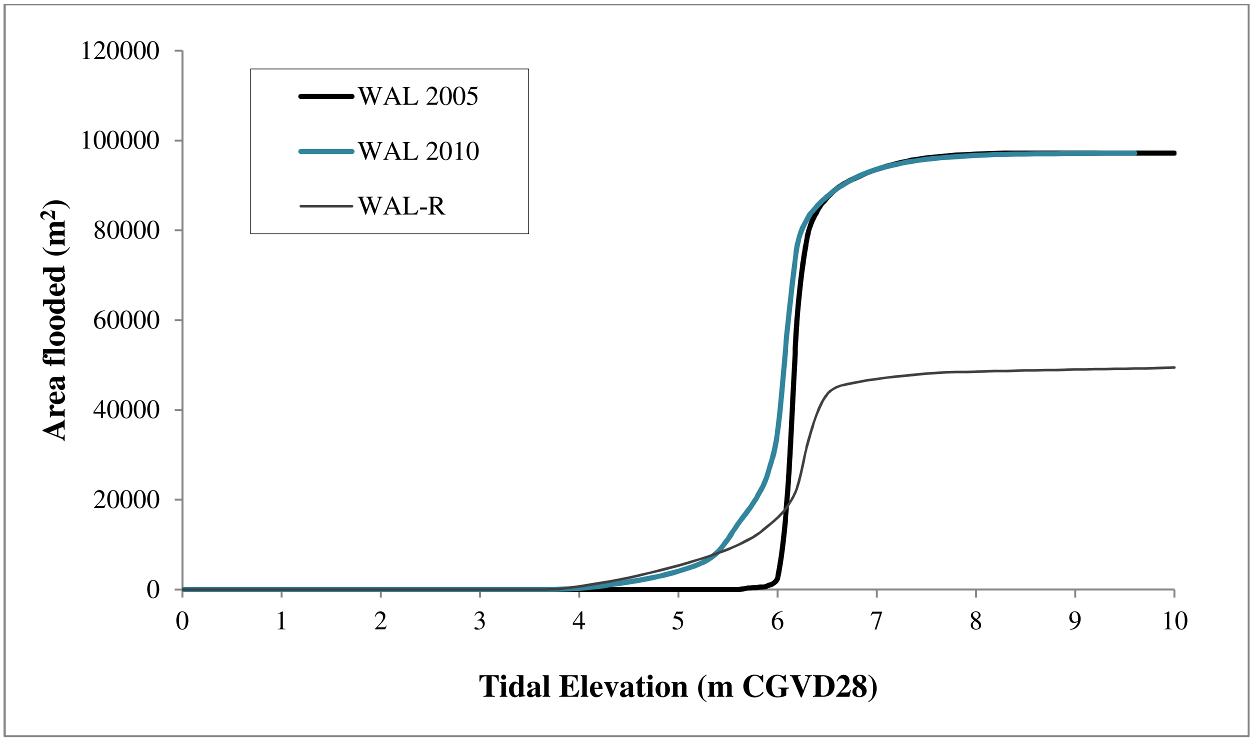


Figure 32: Hypsometric curve at WAL immediate post-restoration and in 2010 compared to WAL-R.

Table 4: Minimum, mean and Maximum high tide levels for 2012 and the amount of area flooded at WAL for each scenario.

	Study	River	Study Area Flooded (ha)
Max High Tide	7.85	7.87	9.49
Mean High Tide	6.37	6.38	8.72
Min High Tide	5.18	5.20	2.36
Mean Water Level	4.82	4.04	Borrow Pit
Min Water Level	4.34	3.21	Borrow Pit

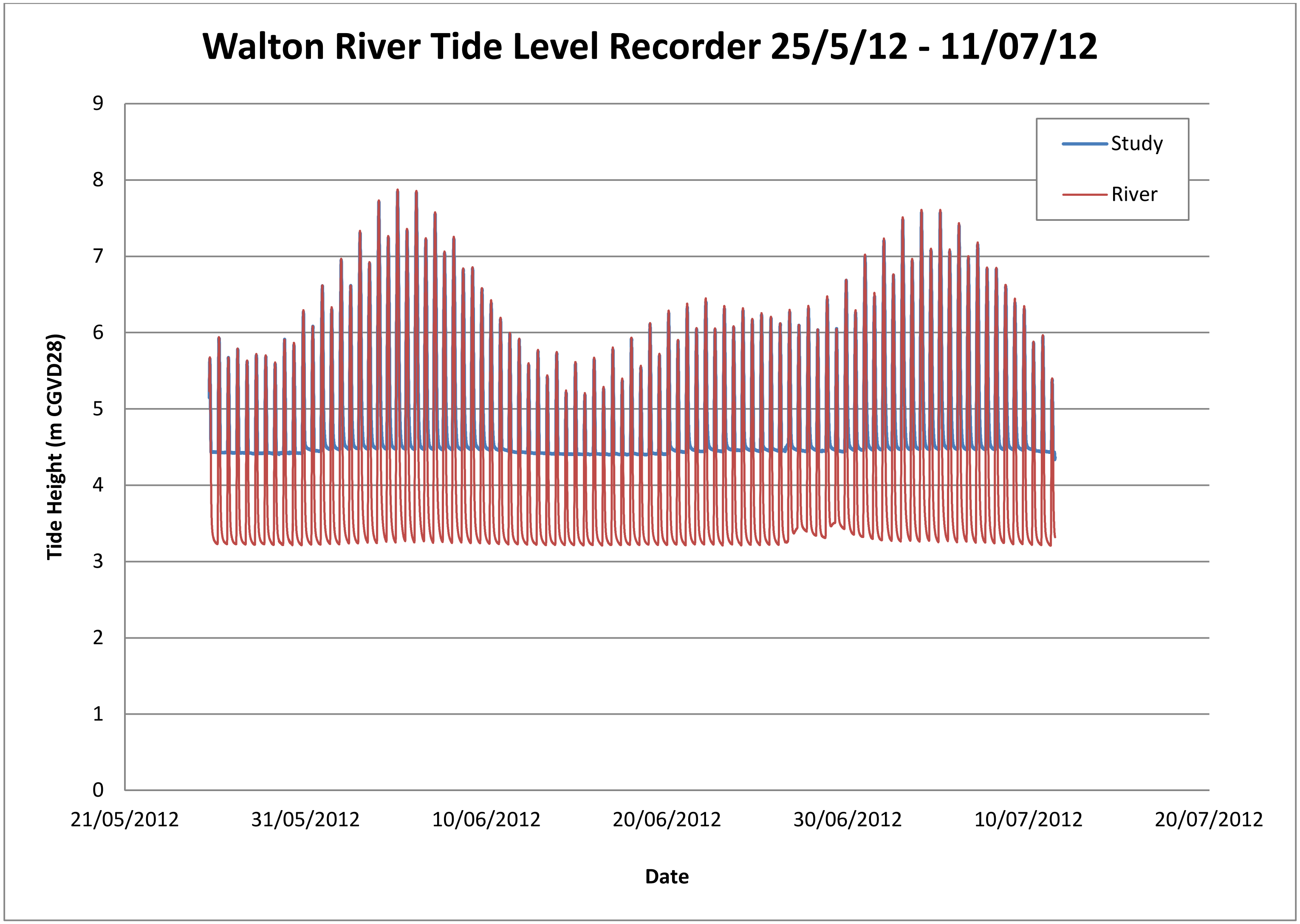


Figure 33: Tide level data (minimums and maximums) recorded with the Solinst Levelogger (Model 3001) for WAL and the Walton River.

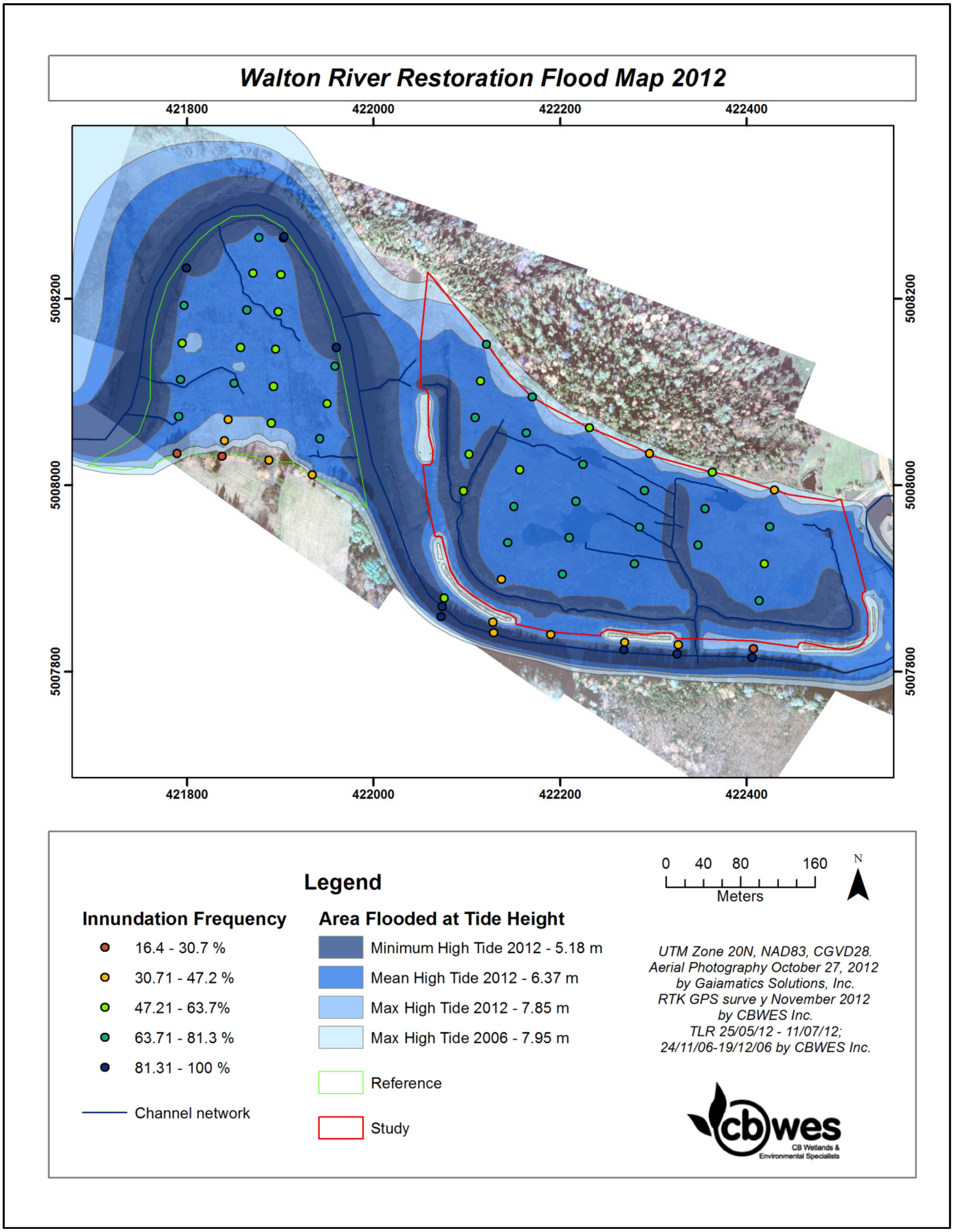


Figure 34: Flood map of WAL and WAL-R showing inundation frequency for each sampling station.

Figure 35: a) Reach of the re-activated relict channel (main channel) during ebb spring tide and during same tide b) the ditches on the marsh surface draining on the ebb tide 17 October 2012; c) borrow pit on west side of main channel at low tide in August; and borrow pit at second breach d) low tide in August and e) ebb spring tide on 17 October 2012. Photographs by CBWES Inc.

Figure 36: Rising spring tide in September 2006. The borrow pit (to the right) has filled in first as water entered through the main channel of the site and as the water rose in the River (on the left) water began to enter through the first breach. Photograph by T. Bowron.

Figure 37: Spring tide event flooding the entire marsh at WAL. Photograph by N. Neatt 17 October 2012 at approximately 3 pm. Predicted tide elevation at Hantsport, NS was 7.88 m (CGVD28).

Channel Morphology

Restoration of WAL in 2005 included the excavation of a small trench (2 m wide x 0.5 m deep: Figure 39a) in the approximate location of a relict creek/channel. Figure 39 shows the progression at this location from trench to a deep and wide main channel at WAL. At seven years post-restoration the thalweg has eroded down approximately 2.5 m and the head of the channel has eroded back approximately 35 m. As shown by Figure 40 the bottom of the main channel has been flattening and widening. The width of the channel, seven years later (2012), was approximately 13 m at both the middle and mouth of the channel (Figure 40). The channel development (erosion) occurred very rapidly (<1 year), and aside from some recent minor bank slumping, the channel has remained relatively stable throughout much of the monitoring period (Figure 39e). In 2009 it was found that any further changes (erosion) of the main channel would occur via slumping. This was found through additional monitoring that took place as part of a cooperative SMU research project. A Nortek Acoustic Doppler Current Profiler (ADCP) was installed in the main channel at WAL to measure flow velocities. The recorded flow speeds were greater than 0.5 m s-1 in the main channel with no sediment plumes, which would indicate bed erosion (van Proosdij et al. 2010).

Restoration of this main channel has improved the hydrology of the site, as the hybrid creek network (borrow pit, drainage ditches and natural channels) has been re-activated. By Year 5 (2010) the pannes had become distinct in their size and shape as opposed to areas with standing water and have become habitat for fish and invertebrates, as shown in later sections (*Section 4.5: Nekton and 4.6: Aquatic Invertebrates*). The pannes are re-charged on a greater number of tides and a greater number of (lower) tides are able to flood portions of the site as bank-full is achieved with a 5.8 m (CGVD28) tide level (discussed above: Figure 32). The borrow pit has also been changing with the increased tidal influence. The borrow pit, throughout the site, has been infilling and channelizing (reduced depth and width) over the course of the monitoring period; however, the section to the east has been experiencing this change much more rapidly than the rest of the site. Additionally, there is an area on breach three (Figure 10) that has been eroding very slowly over the duration of the monitoring program. It is difficult to predict over the long term if this area will become a second channel connecting the site to the River (Figure 38).

Figure 38: Erosion on Breach 3 at WAL in A) winter of 2013; B) winter of 2012 and C) winter of 2012 from the fringe marsh. Photographs by CBWES.

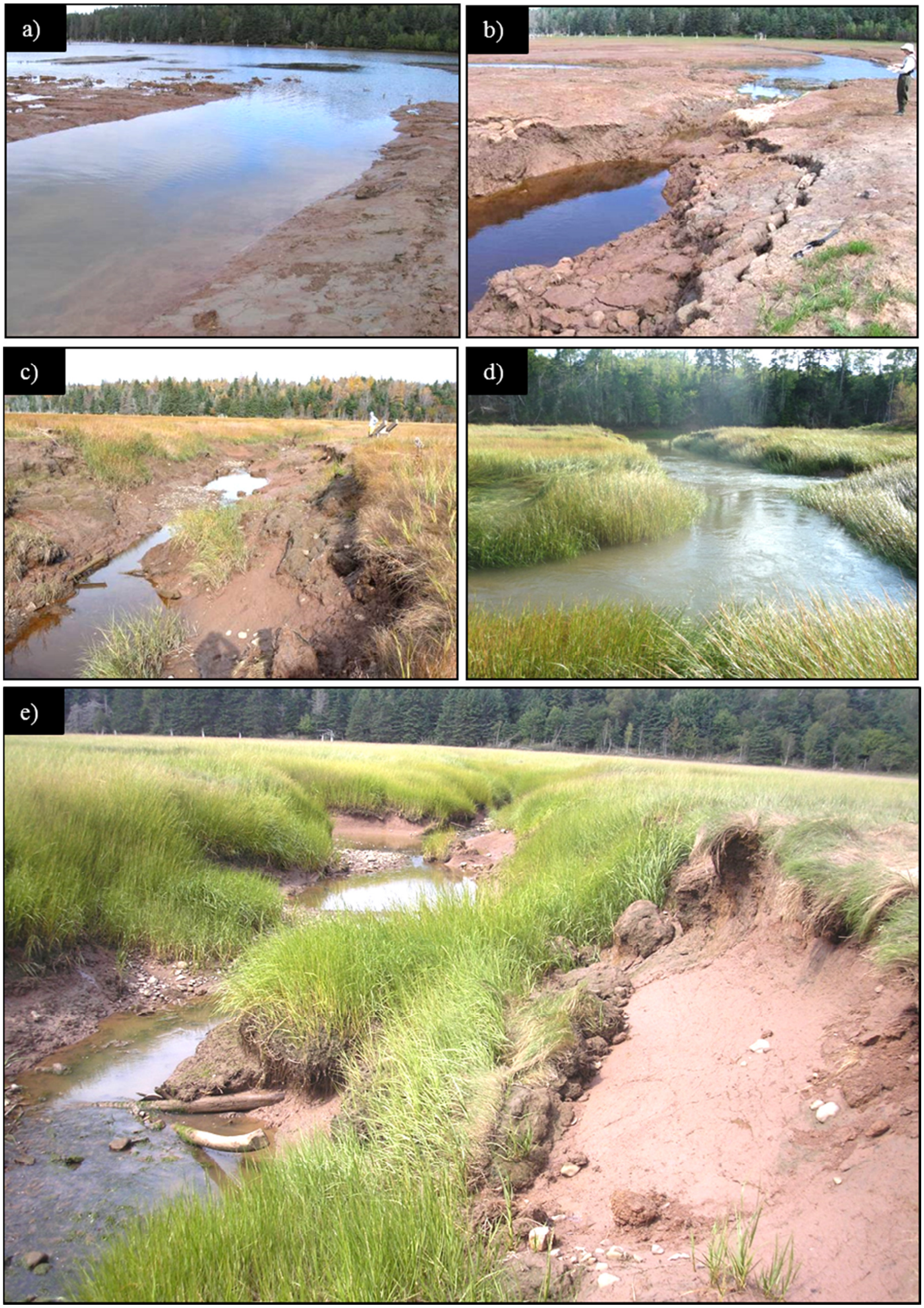


Figure 39: Main channel development at the second breach of WAL in a) fall 2005, b) spring 2006, c) fall 2009, d) fall 2010 (ebb tide) and e) summer 2012. Photographs by CBWES Inc.

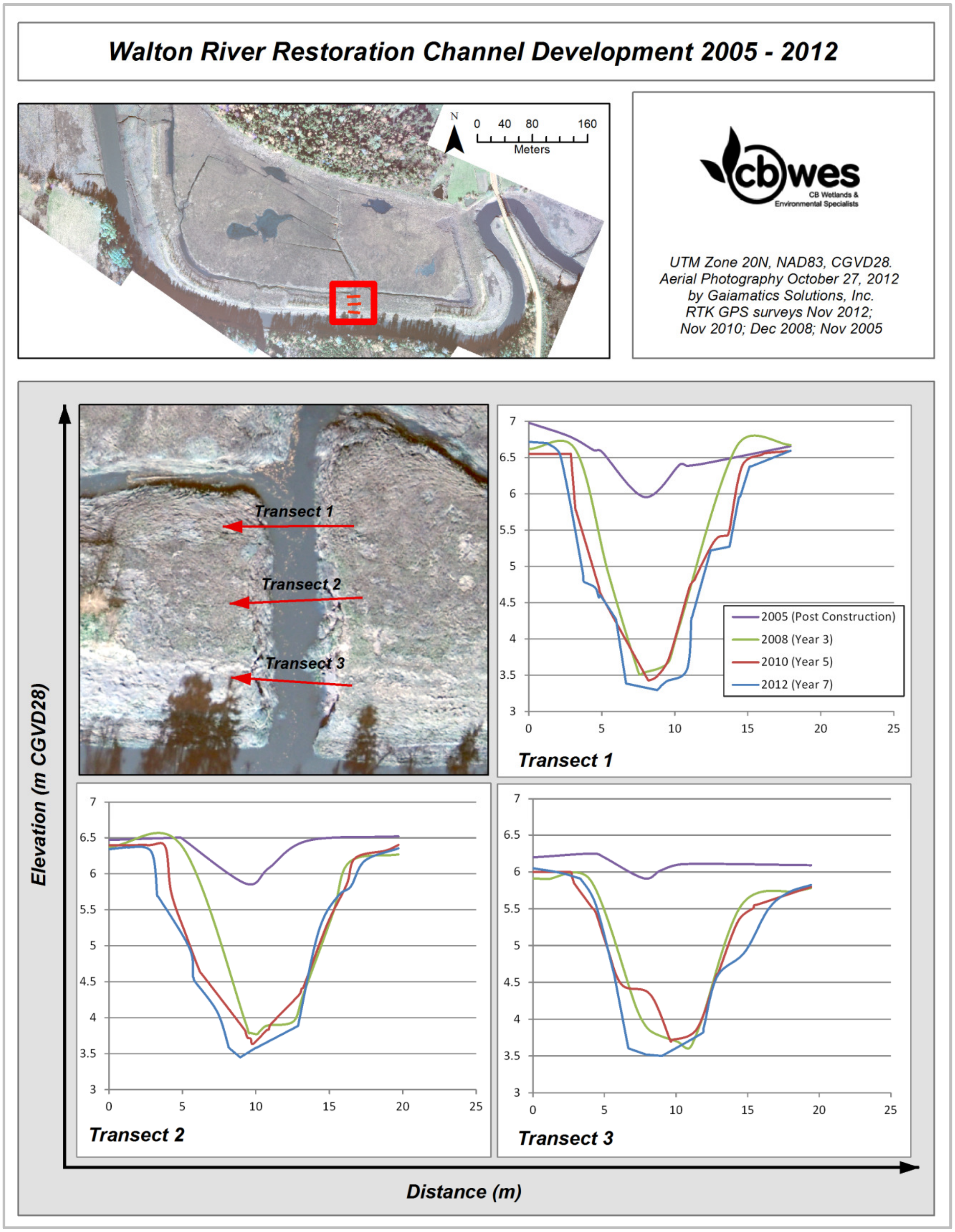


Figure 40: Excavated main channel development at WAL showing width and depth in 2012 and comparing erosion/slumping occurrence from 2005 (immediate post-restoration) to 2012 (seven years post-restoration).

Depth to Water Table

The conditions in 2005 were unsuitable at WAL for ground water sampling (super saturation of soils due to impoundment), therefore, there were no comparisons completed for pre- versus post-restoration. In 2010, data from 2006 and 2010 were analyzed and no significant differences were found for tests completed between sites or between years (Neatt et al. 2011). Five years post-restoration the number of shallow values at WAL had decreased and there was an increase in the number of deep values, although not significantly in either case. By five years post-restoration, WAL depth to water table values appeared to be closer to those at WAL-R, although WAL still had more values on the shallow end and a greater range (Neatt et al. 2011). There are many influences on depth to water table including tide height (inundation), rainfall amounts, and sediment types.

Depth to ground water was highly variable at both WAL and WAL-R; however, trends followed the same patterns and were in the same range for most sampling events. For 2012, the mean at WAL was 2.85 cm with a range of -1 to 10 cm and at WAL-R the mean was 3.36 cm with a range of 0 to 13 cm (Table 5). In 2010, the mean at WAL was 6.64 cm with a range of -8 to 32 cm and at WAL-R the mean was 8.47 cm with a range of 9.50 to 23 cm (Neatt et al. 2011). T-tests completed for the 2012 data showed no significant differences between WAL and WAL-R (t = -0.53; p = 0.59), which agreed with temporal trends (Figure 42). When compared to 2010 data, WAL showed no significant difference (t = 1.67; p = 0.11), while WAL-R showed a significant difference (albeit marginally) between years (t = -2.16; p = 0.046). When all post-restoration data was analyzed (2006 – 2012), there was a significant difference at both WAL and WAL-R (WAL t = 3.19; p = 0.0024; WAL-R t = 3.61; p = 0.0013). ANOVA showed significant differences between years at both sites (WAL F = 6.96; p = 5.53E-06; WAL-R F = 2.79; p = 0.021). Therefore, overall the changes between 2010 and 2012 are reflective of the system and not necessarily the restoration project. WAL is in line with the reference site conditions (Figure 42).

Figure 41 shows the frequency of depth to ground water values for WAL and WAL-R. It is shown here that the 2012 percent frequency values for WAL and WAL-R were found in the categories -0.5 to 7.2 and 7.3 to 14.8. WAL-R also had readings in the lowest category -8 to -0.4. Prior to 2010 WAL-R did not have any readings this low. Figure 41 and Table 5 illustrate the decrease range of values at WAL and WAL-R in 2012.

Table 5: 2012 descriptive statistics for depth to ground water wells at WAL and WAL-R for A) each station and B) overall.

A)

Station	Sample Number	Minimum	Maximum	Mean	Standard Deviation
WALR L1S3	8	-1.00	4.00	1.75	1.91
WALR L3S4	4	0.00	8.00	3.75	3.30
WALR L3S7	4	0.00	7.00	2.25	3.30
WALR L4S4	4	2.00	10.00	4.75	3.77
WAL L1S1	4	0.00	4.00	1.25	1.89
WAL L1S2	4	0.00	3.00	1.00	1.41
WAL L1S3	4	4.00	12.00	8.50	3.70
WAL L3S1	4	0.00	13.00	4.00	6.06

Station	Sample Number	Minimum	Maximum	Mean	Standard Deviation
WAL L3S2	4	0.00	2.00	1.00	1.15
WAL L3S4	4	2.00	7.00	4.75	2.22
WAL L5S1	4	0.00	13.00	3.75	6.24
WAL L5S3	5	0.00	11.00	4.80	4.32
WAL L5S5	3	0.00	0.00	0.00	0.00
Grand Total	56	-1.00	13.00	3.18	3.73

B)

Site	Sample Number	Minimum	Maximum	Mean	Standard Deviation
WAL-R	20	-1.00	10.00	2.85	2.92
WAL	36	0.00	13.00	3.36	4.14
Grand Total	56	-1.00	13.00	3.18	3.73

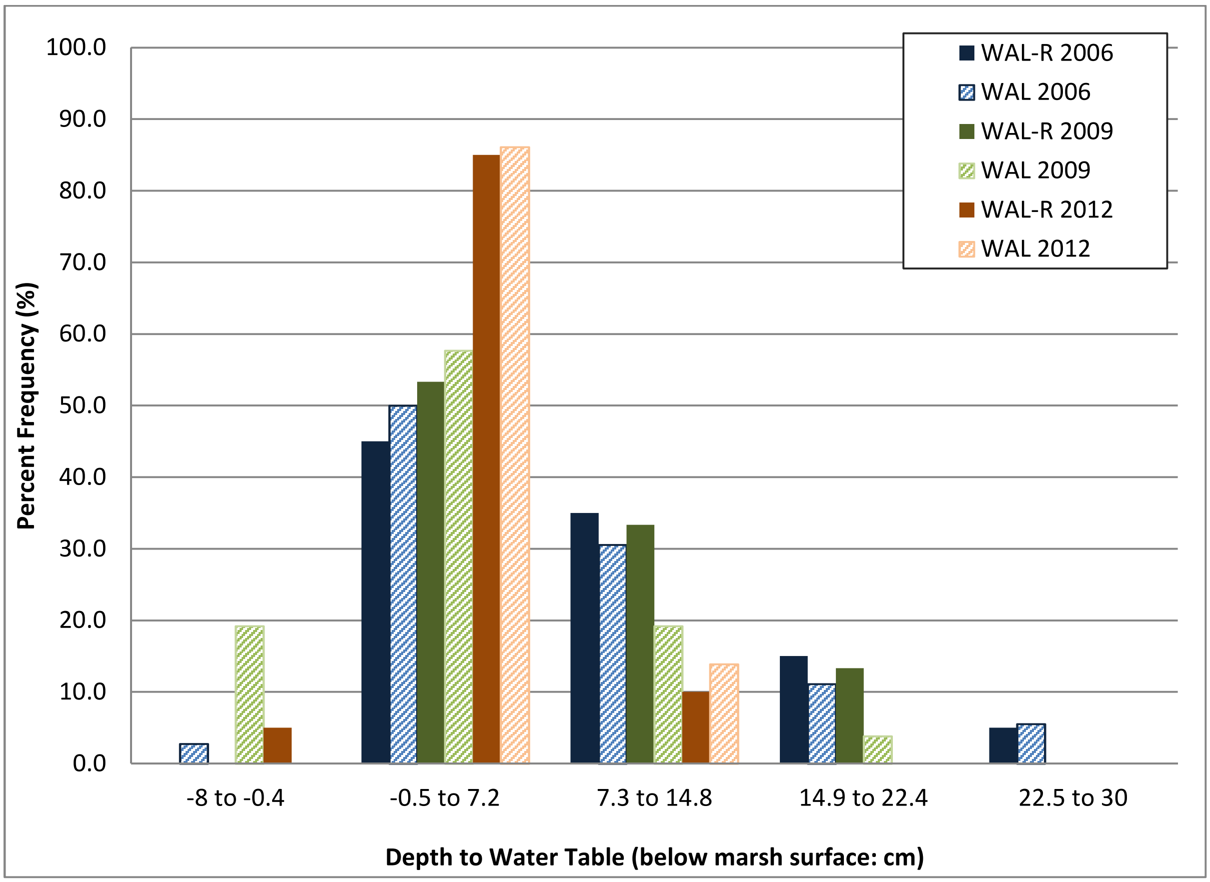


Figure 41: Frequency of depth to ground water values for wells at WAL-R and WAL for Years 1 (2006), 4 (2009) and 7 (2012) post-restoration.

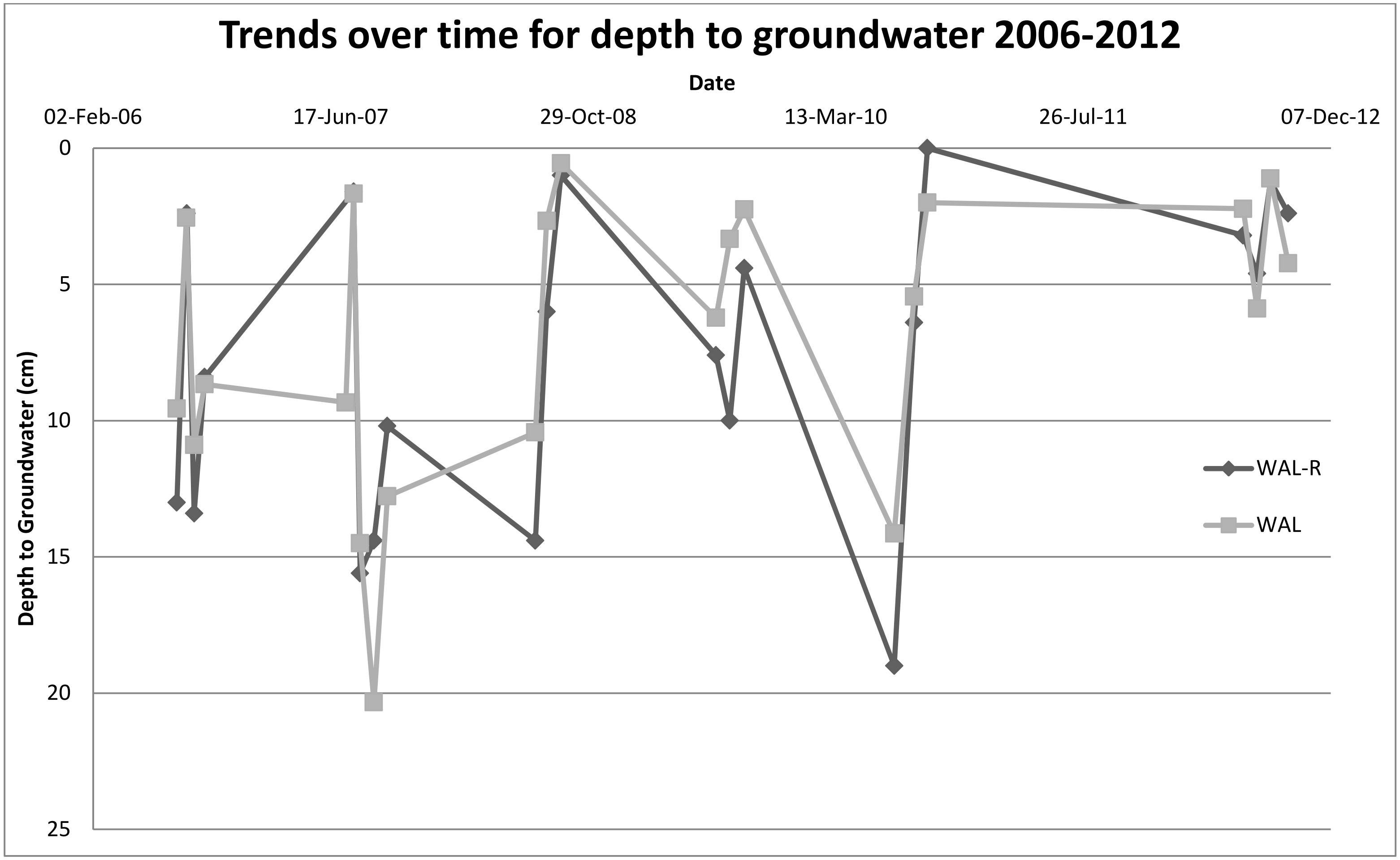


Figure 42: Trend over time for depth to groundwater at WAL and WAL-R for all years post-restoration.

Water Quality

Water quality sampling of the surface floodwaters was conducted concurrently with nekton sampling. Table 6 shows the water quality parameters during the nekton surveys at WAL and WAL-R for all years. Given the close proximity of the two sites the data has been pooled for each month the fish surveys were conducted. Similar to previous data collected, as the water temperature decreased into the fall, the DO and pH increased. Salinity has fluctuated over the years with a range of 16.5 ppt to 31.3 ppt, with most readings greater than 28 ppt. This is expected for salinity in the Bay of Fundy waters. The means for the water quality parameters for the 2012 sampling season were: Temperature = 15.7 ˚C; Salinity = 27.9 ppt; Dissolved Oxygen = 9.1 mg/L; and pH = 7.9.

Table 6: Average monthly water quality parameters for Walton River taken during fish surveys for all years.

Sample Date	Temp (°C)	Sal (ppt)	DO (mg/L)	pH
Sept-05	18.1	30.8	5.6	7.8
Jul-06	20.0	26.2	8.0	8.3
Sep-06	18.1	29.0	9.1	7.6
Oct-06	14.4	30.3	9.9	7.9
Aug-07	20.8	29.3	8.3	7.8
Sept-07	17.7	29.9	6.9	7.9
Oct-07	11.9	29.3	9.9	7.6
Sept-08	17.9	28.2	8.1	6.6
Oct-08	13.5	28.7	8.6	7.8
Jun-09	16.3	24.7	5.2	7.8
Sept-09	17.2	29.0	8.3	7.2
Oct-09	9.8	16.5	10.7	6.9
Sept-10	21.1	28.9	8.1	7.5
Oct-10	15.6	31.2	10.4	8.1
Sept-12	17.9	27.2	8.4	7.8
Oct-12	13.5	28.6	9.8	7.9

4.3 Soils and Sediments

Pore Water Salinity

Similar to depth to ground water sampling (*4.2 Hydroperiod and Tidal Signal*), conditions in 2005 were unsuitable at WAL for pore water salinity sampling (super saturation of soils due to impoundment). Therefore, there was no comparison completed between pre- and post-restoration at WAL. 2012 descriptive statistics for pore water salinity at each sampling station for WAL and WAL-R, as well as for each site overall, are found in Table 7. For all readings, WAL had a mean of 7.58 ppt with a range of 1.84 to 14.26 ppt and a standard deviation of 3.44 ppt (Table 7). WAL-R had a mean of 9.08 ppt with a range of 1.04 to 14.69 ppt and a standard deviation of 3.28 ppt (Table 7). Salinity values at WAL increase from Line 1 to Line 5 (Table 7).

T-tests (95% CI) were not completed between years 2011 and 2010 due to the change in methodology used to collect the salinity data (Sipper to EC Probe). T-tests (95% CI) were completed between 2012 shallow and deep readings and revealed a significant difference for both WAL ($t = -3.33$; $p = 0.0021$) and WAL-R ($t = -3.98$; $p = 0.00068$). Finally, t-tests (95% CI) completed between WAL-R and WAL sites in 2012 showed no significant differences when deep salinity readings were tested alone ($t = 1.02$; $p = 0.32$); however, when shallow readings ($t = 2.47$; $p = 0.017$) and all readings ($t = 2.31$; $p = 0.023$) were tested, both showed a significant difference.

Histograms, which illustrate temporal change, for shallow and deep readings showed some shift in immediate post-restoration (2006) and year seven post-restoration (2012) conditions. For 2006 shallow readings, salinities were higher with nearly 70% of the readings having occurred in the 16-20 ppt class (as compared to 5% or less for WAL-R and other years). The 2009 distribution matches WAL-R conditions for moderate salinity values, but lacked readings within the low-end salinity values (0-8 ppt). For 2012, salinity values were moderately lower than previous years. For deep readings, 2006 (Year 1) salinity values showed an expected number of high salinity readings and resembled the reference condition. 2012 deep salinity readings, similar to shallow readings, appeared to be moderately lower than the reference condition with the greatest percent frequency occurring in 6-9 ppt range (~40%) as compared to 12-15 ppt for WAL-R (~62%).

In 2008, the mean salinity was higher at WAL, similar to each year prior; however, there was no significant difference between sites or between years (Bowron et al. 2009). Since 2009, WAL-R had a higher mean salinity than WAL. This would be due to the change in WAL from a hypersaline environment to one closer to WAL-R with the colonization of vegetation on the site and the subsequent decrease in bare ground and associated evapotranspiration. The lower mean salinity at WAL over the past three years could be attributed to the number of salinity stations at WAL (3) that are close to the upland compared to WAL-R (1). In addition, with the change in methodology, stations near the upland edge that were difficult to obtain a sample from prior to 2012, could be easily obtained with the EC Probe, and this would explain the lack of lower values in previous years and their presence seven years post-restoration. This could also explain the significant difference between WAL and WAL-R when comparing the 2012 shallow salinity readings.

There has been no significant difference detected between WAL and WAL-R for any of the previous years post-restoration. However, at WAL in 2009, there was a significant difference (decrease) detected in the mean salinity for the years 2006 versus 2009 and 2008 versus 2009. This was the case in 2010 as well with a significant difference found at WAL when looking at years 2006 versus 2010 and 2009 versus 2010.

The mean salinity levels found at WAL and WAL-R (Table 7) are in a range similar to other restoration and reference sites being monitored along the Bay of Fundy such as Cheverie Creek (16 ppt/13 ppt; Bowron et al. 2013a) and Cogmagun River (9 ppt/9 ppt; Bowron et al. 2013c).

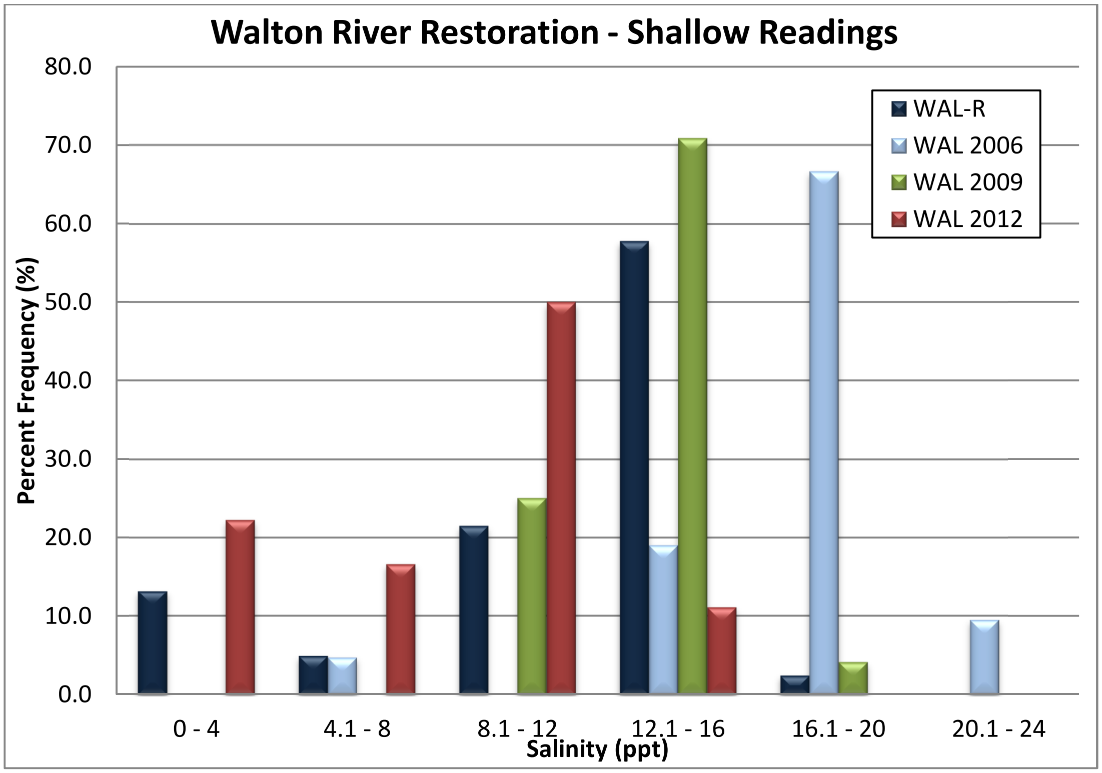


Figure 43: Frequency of pore water salinity values for shallow sample readings at WAL-R (all post-restoration years combined) and WAL (showing post-restoration Years 1, 3 and 5).

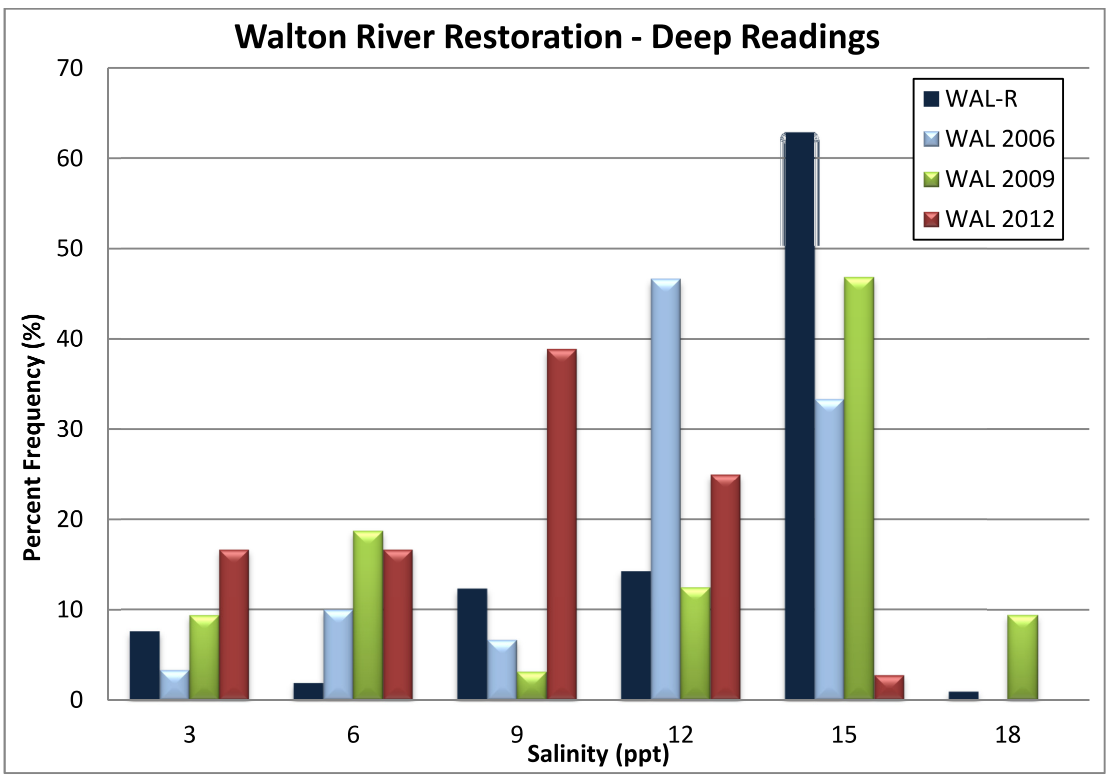


Figure 44: Frequency of pore water salinity values for deep sample readings at WAL-R (all post-restoration years combined) and WAL (showing post-restoration Years 1, 3 and 5).

Table 7: Descriptive statistics for pore water salinity at WAL and WAL-R for a) sampling stations and b) overall for 2012.

A)	Shallow					Deep					All Readings				
Station	**n=x**	**Min**	**Max**	**Mean**	**Std Dev.**	**n=x**	**Min**	**Max**	**Mean**	**Std Dev.**	**n=x**	**Min**	**Max**	**Mean**	**Std Dev.**
WALR L1S3	4	9.59	12.42	11.35	1.23	4	11.17	14.69	12.65	1.52	8	9.59	14.69	12.00	1.46
WALR L3S1	4	2.61	8.65	5.39	2.59	4	1.04	1.28	1.14	0.12	8	1.04	8.65	3.26	2.84
WALR L3S3	1	11.00	11.00	11.00		1	7.81	7.81	7.81		2	7.81	11.00	9.41	2.25
WALR L3S4	4	10.64	13.76	12.39	1.44	4	8.04	11.63	9.11	1.69	8	8.04	13.76	10.75	2.27
WALR L3S6	2	9.81	11.13	10.47	0.94	2	7.86	8.52	8.19	0.47	4	7.86	11.13	9.33	1.45
WALR L3S7	3	9.38	10.31	10.00	0.54	3	7.36	11.99	8.93	2.65	6	7.36	11.99	9.46	1.81
WALR L4S4	4	10.39	11.22	10.79	0.40	4	8.77	8.96	8.85	0.08	8	8.77	11.22	9.82	1.07
WAL L1S1	4	3.13	4.53	3.98	0.65	4	1.99	2.96	2.45	0.49	8	1.99	4.53	3.22	0.97
WAL L1S2	4	7.70	10.05	9.12	1.11	4	8.33	9.27	8.66	0.42	8	7.70	10.05	8.89	0.81
WAL L1S3	4	6.62	10.38	8.97	1.65	4	7.51	11.02	9.06	1.54	8	6.62	11.02	9.02	1.48
WAL L3S1	4	3.28	4.54	3.79	0.55	4	2.99	3.79	3.40	0.34	8	2.99	4.54	3.60	0.47
WAL L3S2	4	8.27	10.99	9.68	1.11	4	9.17	10.65	9.86	0.61	8	8.27	10.99	9.77	0.84
WAL L3S4	4	8.17	11.19	9.83	1.42	4	8.33	8.91	8.69	0.25	8	8.17	11.19	9.26	1.12
WAL L5S1	4	2.15	9.91	4.75	3.51	4	3.31	7.80	4.81	2.03	8	2.15	9.91	4.78	2.65
WAL L5S3	5	9.56	13.47	11.50	1.63	4	8.52	9.30	8.84	0.35	9	8.52	13.47	10.32	1.83
WAL L5S5	3	4.92	14.26	10.80	5.12	4	1.84	12.28	8.15	4.54	7	1.84	14.26	9.28	4.59
Grand Total	58	2.15	14.26	8.83	3.31	58	1.04	14.69	7.48	3.40	116	1.04	14.69	8.15	3.41

B)

WAL-R	22	2.61	13.76	10.07	2.69	22	1.04	14.69	8.09	3.87	44	1.04	14.69	9.08	3.44
WAL	36	2.15	14.26	8.07	3.46	36	1.84	12.28	7.10	3.06	72	1.84	14.26	7.58	3.28

Sediment Accretion and Elevation

Changes in surface elevation and sediment accretion have been measured at WAL and WAL-R using a benchmark and RSET device as well as marker horizons established in 2005 (Figure 22). These measurements provide crucial insight into how the marsh system is evolving and ultimately how well it will support halophytic vegetation. Changes in surface elevation measured by the RSET incorporate both below ground organic matter root production and sediment deposition whereas sediment accretion measured by the marker horizon cores incorporates primarily the deposition of suspended inorganic and organic matter. It was anticipated that the majority of changes in surface elevation following the initial breach at WAL would be due to inorganic sediment deposition.

Table 8: Surveyed elevations of RSET stations relative to geodetic datum at WAL and WAL-R.

Station ID	Zone	Line	Easting	Northing	Elevation (m)
WAL – RSET-01	LM	1	422420.6	5007906.9	6.39
WAL – RSET-02	HM	5			6.18
WAL- RSET-03	LM	5			6.21
WAL-R–RSET-01	MM	3	421853.9	5008133.2	6.72
WAL-R –RSET-02	HM	1			6.51

Overall, there was no significant difference between years at WAL (repeated measures ANOVA: $F_{1,5} = 0.198$, $p = 0.700$) nor were there any statistically significant differences by 2010 between WAL and WAL-R (repeated measures ANOVA; $F_{1,5} = 0.868$; $p = 0.508$). In the year immediately following the breach (2006), the surface of the marsh at WAL was unconsolidated and rates of change in surface elevation ranged from -0.7 (±0.1) to 1.7 (±0.2) $cm \cdot yr^{-1}$ (±1SE) at RSET-01 and 02 respectively (Table 9). This was compared to 0.9 (±0.3) $cm \cdot yr^{-1}$ (±1SE) at WAL-R in the same year (2005-06) (Table 10). This rate of surface elevation accretion change was supported by the marker horizon data from WAL-R (0.83 $cm \cdot yr^{-1}$), which suggested that the majority of change was likely attributed to sediment accretion. In 2006-07 at WAL, the surface at RSET-01 was firmer and recorded the highest rates of surface elevation change (Table 9). By 2008, the rate of surface elevation change decreased to a more moderate 0.5 (±0.1) $cm \cdot yr^{-1}$ with the marker horizons recording accretion rates of 1.11 $cm \cdot yr^{-1}$ (Table 11). A similar rate of accretion was recorded in 2009 (0.8 ± 0.1 $cm \cdot yr^{-1}$). This rate of surface elevation change doubled by 2010 (1.8 (± 0.1) $cm \cdot yr^{-1}$ (±1SE)) with half associated with sediment accretion and the remainder by subsurface processes (Table 9, Table 11 and Figure 45). From 2010-11, RSET-01 recorded a change in surface elevation of 2.1 (± 0.0) $cm \cdot yr^{-1}$ (±1SE) (Table 9), mostly associated with subsurface processes (Table 11). The rate of change decreased by 0.6 $cm \cdot yr^{-1}$ in 2012 despite a high rate of accretion (1.98 $cm \cdot yr^{-1}$) measured by the marker horizons (Table 11).

RSET-02 has been dewatering and consolidating, therefore, experiencing a negative rate of surface elevation change (-0.4 (±0.1) $cm \cdot yr^{-1}$) and was sparsely vegetated (Figure 47a). Vegetation density increased in 2008, yet there was still evidence of surface compaction (Table 9 and Figure 47b). However, the RSET base was completely ripped out of the ground by ice during the 2008 winter season (Figure 47c).

At WAL RSET-03, installed in 2006 in the vegetated low marsh (Line 5: Figure 22), the mean rate of surface elevation change was 0.40 (±0.1) $cm \cdot yr^{-1}$ (±1SE) in the first year, increasing to 0.7 (±0.1) $cm \cdot yr^{-1}$ (±1SE) in 2008 and remaining unchanged in 2009 and slightly lower (0.60 (±0.1) $cm \cdot yr^{-1}$ (±1SE)) in 2010. The surface was fully vegetated by year 3 (Table 13b). This was supported by a rate of 0.42 $cm \cdot yr^{-1}$ to 0.23 $cm \cdot yr^{-1}$ recorded by the marker horizon cores from 2007 to 2010. The highest rate of surface elevation change in all years was recorded in 2011 (1.0 (±0.1) $cm \cdot yr^{-1}$ (±1SE)) with the majority of change associated with 1.56 cm of sediment accretion (Table 11). In 2012, changes in surface elevation returned to previous levels (Table 9) (Figure 45). Subsurface processes here were minimal.

Although RSET-02 was located at the back of the former impoundment, it was at a lower elevation than RSET-01 (Table 9 and Table 10); therefore, it was not surprising that initially it would have higher rates of sediment accretion. A negative value, such as the one recorded at RSET-01 in 2005-2006 and at RSET-02 in 2007-2009 could have arisen because the surface of the marsh had dewatered and consolidated. The higher rates of accretion measured at the marker horizons, yet negative RSET values indicate that subsurface compaction processes dominate. This process, however, was spatially variable and was a function of the microtopography of the marsh surface (surface algae and sediment composition; Figure 45). In addition, the processes of sediment deposition and sediment accretion were inherently spatially variable across the marsh surface (van Proosdij et al. 2006). In general higher rates of accretion will be recorded initially in low lying areas and within vegetated areas as the vegetation assists in the sedimentation process (Figure 45b and Figure 48b).

Overall, RSET-01 recorded the highest net change in surface elevation (8.78 cm) with the highest amount of net accretion (Table 13) and positive changes in subsurface processes. The lowest net change in surface elevation was recorded at RSET-02 situated the lowest within the tidal frame (6.18 m CGVD28) mostly associated with -2.2 cm of subsurface subsidence (Table 13). The independent marker horizons all recorded net sediment accretion over the 5 year period ranging between 2.96 cm at the highest elevation to 4.78 cm at the second lowest elevation (Table 13).

At WAL-R, the rate of surface elevation change was relatively consistent between RSET-02 and the marker horizons (Table 10 and Table 12); however, RSET-01 revealed a significant change in surface elevation between 2006 and 2007. This was likely associated with a large ice block that melted *insitu* and deposited a mound of sediment. This deposit was redistributed in the surrounding area by 2009 and 2010 (Figure 49). In 2010, the rate of change in surface elevation decreased to 0.1 (±0.1) $cm \cdot yr^{-1}$ (±SE) and -0.20 (±0.08) $cm \cdot yr^{-1}$ (±SE) in the mid and high marsh respectively (Table 10). However, marked increases in RSET measurements were recorded in 2011 similar to WAL, with most associated with subsurface processes. This may reflect surface expansion due to water level conditions rather than true below ground production (Paquette et al. 2004). Comparable and slightly higher rates of accretion were recorded at both WAL-R RSET stations in 2012 indicative of ice or storm deposits (Figure 49b).

Table 9: Change in surface elevation at WAL from 2005 to 2012 measured by the RSET device. (stdev = standard deviation; SE = standard error).

WALTON Restoration Site				**Net change in elevation between sampling period (cm)**								
RSET-01 Line 1		**Position**	**Bearing**	**Pin 1**	**Pin 2**	**Pin 3**	**Pin 4**	**Pin 5**	**Pin 6**	**Pin 7**	**Pin 8**	**Pin 9**
2005-06		1	347	-4.5	0.4	-0.3	-0.2	-0.7	-0.9	-0.4	-0.6	-0.6
mean	**-0.7**	3	80	-0.5	-1	-1.1	-0.8	-0.9	-0.8	-0.7	-1	-1
stdev	0.7	5	165	-0.7	-1.2	-0.7	-0.3	-0.5	-0.6	-0.6	-0.6	-0.7
SE	0.1	7	260	-0.1	0	0	-0.3	0	-0.6	-0.7	-0.7	-0.5
2006-07		1	347	7.2	2.1	2.9	3.1	3.2	3.1	3	2.9	2.7
mean	**3.5**	3	80	3.5	3.3	3.3	3.2	3.2	3	3.3	3.2	3.2
stdev	0.8	5	165	2.7	3.9	4.2	3.9	3.7	3.6	3.9	4	4.2
SE	0.1	7	260	2.7	3	3.6	3.7	3.6	3.7	3.8	4	3.6
2007-08		1	347	7.2	2.1	2.9	3.1	3.2	3.1	3	2.9	2.7
mean	**0.5**	3	80	3.5	3.3	3.3	3.2	3.2	3	3.3	3.2	3.2
stdev	0.3	5	165	2.7	3.9	4.2	3.9	3.7	3.6	3.9	4	4.2
SE	0.1	7	260	2.7	3	3.6	3.7	3.6	3.7	3.8	4	3.6
2008-09		1	347	0.5	0.7	1.1	0.9	0.7	0.9	0.8	1.1	0.7
mean	**0.8**	3	80	1.2	1.2	0.8	1	0.9	1.1	0.7	0.6	0.6
stdev	0.5	5	165	1.9	0.7	0.7	1.1	0.7	0.7	-1.5	1	1
SE	0.1	7	260	0.9	1	1.1	1.1	1	1	0.6	1.2	0.8
2009-10		1	347	2.4	1.8	1.2	1.7	1.7	1.9	1.8	1.5	1.8
mean	**1.8**	3	80	1.6	1.3	1.9	1.8	1.7	1.9	1.6	2.3	2.3
stdev	0.4	5	165	1	2.6	2.4	1.4	1.7	1.6	2.6	1.6	1.6
SE	0.1	7	260	1.8	1.6	1.8	2.2	1.8	1.9	2	1.9	2.1
2010-11		1	347	2.2	2.1	2.4	2	2.3	2.1	2.4	2.1	2
mean	**2.1**	3	80	1.7	2.3	2.3	1.4	2.5	1.9	1.7	2.6	1.9
stdev	0.3	5	165	2.4	1.8	2.1	2.4	2.2	1.9	1.7	2.3	2.3
SE	0.0	7	260	2.3	2.1	2	2.1	2.3	2.1	2.6	1.4	1.8
2011-12		1	347	0	0.6	0.3	0.4	0.4	1.1	0.5	0.7	0.8
mean	**0.7**	3	80	0.8	0.2	0.6	1.2	1.3	0.7	1.1	0.6	0.9
stdev	0.3	5	165	0.1	0.8	0.6	0.8	1.2	1.1	1.1	0.8	0.5
SE	0.1	7	260	0.7	1	0.9	0.7	0.5	0.6	0.6	1.2	0.2
RSET -02 Line 5		**Position**	**Bearing**	**Pin 1**	**Pin 2**	**Pin 3**	**Pin 4**	**Pin 5**	**Pin 6**	**Pin 7**	**Pin 8**	**Pin 9**
2005-06		1	303	0.9	0.7	1.8	3.3	4.1	3	3.2	4.1	2.6
mean	**1.7**	3	27	2	2	2.3	3	1.8	1.3	2.8	1.7	1.8
stdev	1.1	5	119	1	0.8	-0.4	0.9	0.7	1.2	1.1	2.1	1.9
SE	0.2	7	209	1.4	0.1	0	2.4	1.5	1.4	0.6	1	1.3
2006-07		1	303	-0.7	-0.5	-0.4	-1.1	-0.6	-1	-0.5	-0.9	-0.9
mean	**-0.4**	3	27	-0.9	-1.1	-0.8	-0.8	-0.8	-0.1	-0.7	-0.7	-0.8
stdev	0.6	5	119	-0.1	-0.5	-0.4	-0.9	-0.6	-1	-1	-1	-1.4
SE	0.1	7	209	1.3	-0.2	-0.4	0.5	0.8	0.3	0.5	0.8	0.7
2007-08		1	303	0.3	0.1	-0.1	0.3	0.6	0.4	0.5	0.2	0.1
mean	**-0.2**	3	27	0.1	0.2	0.4	0.3	0.7	0.5	0.4	0.3	0.5
stdev	0.9	5	119	0.5	0.2	0.2	0.2	0.1	0.5	0.2	0.1	0.1
SE	0.1	7	209	-1.6	-0.3	-0.4	-1.7	-2	-2.2	-1.9	-2.2	-1.7
2008-09		**Destroyed by ice**										

RSET -03 Line 5		Position	Bearing	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8	Pin 9
2006-2007		1	335	-0.2	-0.4	-0.2	0	0.3	0.3	0.3	0.1	0.3
mean	**0.4**	3	68	0.2	0.4	0.4	0.3	0.3	0.4	0.6	0.3	0.3
stdev	0.4	5	154	0.3	0.3	0.5	0.5	0.6	0.7	0.7	0.7	0.6
SE	0.1	7	244	2.4	0	0.3	0.2	0.3	0.3	0.3	0.4	0.3
2007-08		1	335	0.7	0.5	0.6	1	0.4	0.6	1.1	0.8	0.7
mean	**0.7**	3	68	0.8	0.4	0.4	0.3	0.5	0.5	0.4	0.5	0.5
stdev	0.6	5	154	0.3	0.4	0.2	0.3	0.5	0.3	0.5	0.6	0.8
SE	0.1	7	244	-0.3	0.6	0.5	1	0.8	2.4	2.1	1.9	2.6
2008-09		1	335	1.3	1.3	1.4	0.3	0.8	0.3	-0.3	0.2	0.2
mean	**0.8**	3	68	0	0.1	1	1	0.1	0.9	0.9	1	0.9
stdev	0.5	5	154	1.6	1.3	0.8	1	1.3	1.2	1.8	1	0.7
SE	0.1	7	244	0.7	0.8	0.9	0.7	0.9	0.7	0.5	0.4	0.1
2009-10		1	335	-0.5	-0.4	-0.3	1.2	0.4	1.3	1.5	1.3	1.2
mean	**0.6**	3	68	1.6	1.2	0.8	0.7	1.2	0.1	0.4	0.5	0.7
stdev	0.6	5	154	-0.2	0	0.6	1.2	0.1	0.5	-0.2	0.4	0.4
SE	0.1	7	244	0.6	0.8	0.5	0.3	0.3	0.4	0.3	1.2	0.4
2010-11		1	335	1.4	1	0.7	1.2	1.2	0.9	0.9	1.1	1
mean	**1.0**	3	68	0.3	0.6	0.3	1.2	0.8	1.2	1	1.2	1
stdev	0.3	5	154	1.3	1.5	1.5	0.7	1.3	1.2	1.1	1.2	1
SE	0.1	7	244	0.7	1.1	1.7	1.3	1.3	0.6	1.1	0.7	0.8
2011-12		1	335	0.4	1	2	0.9	0.9	0.6	0.7	0.5	0.4
mean	**0.6**	3	68	1.3	1.3	0.7	0	1	1.3	1.1	0.6	0.8
stdev	0.5	5	154	0.6	0.2	0.4	0.7	0.2	0.2	0.1	0	0.3
SE	0.1	7	244	0.5	0.3	-0.1	0.5	0.4	0.3	0.1	0.3	0.1

Table 10: Change in surface elevation at WAL-R from 2005 to 2012 measured by the RSET device. (stdev = standard deviation; SE = standard error)

WALTON Reference Site				**Net change in elevation between sampling period (cm)**								
RSET-01 Line 3		**Position**	**Bearing**	**Pin 1**	**Pin 2**	**Pin 3**	**Pin 4**	**Pin 5**	**Pin 6**	**Pin 7**	**Pin 8**	**Pin 9**
2005-06		1	162	0.3	0	0.5	0	0.3	0.8	-0.2	0.9	1.1
mean	**0.9**	3	252	1.6	0.9	0.1	0.1	1.1	0.8	1.1	3.5	-0.2
stdev	1.6	5	342	-0.8	-3.7	3.2	3.5	3.1	2.3	1	6.7	0.4
SE	0.3	7	74	1.1	1.3	0	-0.1	0	0.5	0.7	0.8	0.8
2006-07		1	162	14.5	15.9	15	14.7	14.5	16	15.5	13.7	13.4
mean	**13.9**	3	252	15.7	13.8	13.6	13.8	13.8	13.6	12.6	11.1	14.2
stdev	3.3	5	342	14.8	16.3	13.2	11.8	12.9	0	13.6	8	14.1
SE	0.6	7	74	14.8	14.8	14.1	24.5	14.8	14.7	14.2	14	14.2
2007-08		1	162	0.1	-0.2	-0.2	0.1	1	-0.2	0.1	0.3	0.9
mean	**0.1**	3	252	0.2	-0.3	-0.4	-0.3	-0.1	0.3	0	-0.2	0
stdev	2.7	5	342	0.1	0.6	-0.2	-0.5	-0.9	12.6	0.4	0	0.1
SE	0.5	7	74	-0.3	0	0.1	-9.8	0.1	0.3	0.3	-0.2	0.7
2008-09		1	162	0.7	0.3	1.4	0.5	0.1	0.4	0	0.3	0.7
mean	**0.3**	3	252	-0.3	0.2	0.2	0.6	-0.3	-0.5	0.1	0.1	0.1
stdev	0.4	5	342	0.4	0	0.2	1	0.6	0.8	1.3	0.5	0.8
SE	0.1	7	74	0.3	1.2	0.1	0.2	0.1	0.1	0.2	-0.2	0
2009-10		1	162	0.1	0.4	-0.1	0.6	0.4	0.8	0.4	-0.4	0.2
mean	0.1	3	252	0.2	0	0.2	-0.2	0.1	0	0.1	0.2	0
stdev	0.3	5	342	-0.3	-0.1	0	0.5	0.1	0.2	0	0.3	0.5
SE	0.1	7	74	0.2	-1.2	0	-0.3	0	0.5	0.1	0.5	0.2
2010-11		1	162	0.8	0.5	0.2	1.1	0.7	0.3	0.9	1.6	1.3
mean	1.2	3	252	1.1	1.3	1	1	0.8	0.5	1.1	0.8	0.7
stdev	1.3	5	342	0.9	0.7	0.4	0.7	1	0.4	0.4	1.1	0.3
SE	0.2	7	74	0.4	0.9	0.7	1.4	4.3	3.9	4.8	5.3	1.2
2011-12		1	162	0.4	0.3	0.6	0.2	0.7	0.7	0.2	0.3	0
mean	0.4	3	252	0.2	0.5	0.6	0.6	0.5	0.3	0.5	0.7	0.4
stdev	0.4	5	342	1.5	0.5	0.4	0.2	0.6	0.6	0.5	0.3	0.7
SE	0.1	7	74	0.6	0.7	0.6	0.4	-0.9	-0.7	-0.6	-0.5	0.4
RSET-02 line 1		Position	Bearing	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8	Pin 9
2006-07		1	260	0.4	-0.1	0.5	-0.2	1.5	-0.6	1.2	0.6	0.4
mean	**0.8**	3	350	0.5	0.9	0.7	2.1	3	4.7	0.4	1.9	2.1
stdev	1.7	5	80	1	-1.2	2.8	2.2	1.8	-0.7	0.7	0.8	0.6
SE	0.3	7	170	1.7	-6.8	1.4	0.7	0.7	0.9	-0.2	1.2	0.6
2007-08		1	260	0.4	0.2	0	0.2	-1.1	-0.6	0.3	0.5	0.8
mean	**0.3**	3	350	-0.1	0.7	0	-0.6	-1	-3.2	0.3	-1	0.9
stdev	1.4	5	80	1.5	0.4	0	0.7	0.6	0.6	0.6	0.7	0.7
SE	0.2	7	170	0.2	7	0	0.4	0.4	0.3	0.7	0.1	0.7
2008-09		1	260	0.2	0.1	0.4	1	0.3	0.8	0.1	-0.2	-0.5
mean	**0.0**	3	350	-0.1	-0.9	-0.3	-0.4	-0.3	-0.8	0.2	-0.7	-1.4
stdev	0.6	5	80	-0.9	-0.2	0	-0.3	-0.2	-0.8	0	0	-0.1
SE	0.1	7	170	0	0.3	1.2	0.8	0.2	-0.1	0.3	0.5	0.6
2009-10		1	260	-0.4	-1.2	-0.1	0	-0.6	-1	-0.2	-0.2	-0.1
mean	**-0.20**	3	350	0.1	0	-0.4	0.1	-0.2	-0.3	-1	1.2	-0.8
stdev	0.47	5	80	0.8	-0.2	-0.4	-0.1	-0.1	0.4	-0.3	-0.2	-0.4
SE	0.08	7	170	-0.2	-0.2	-0.6	0.4	-0.5	0	-0.5	0.3	-0.2
2010-11		1	260	2.6	3.6	2.7	2.4	2.9	3.8	2.2	2.6	2.5
mean	**2.65**	3	350	2.2	2.5	3.4	2.4	2.5	3.8	3.5	1.8	3.5
stdev	0.73	5	80	2.1	3.7	2.6	2.4	3	2.3	3.9	3.4	3.3
SE	0.12	7	170	1.3	2.6	1.5	0.8	2.4	2.5	2.2	1.8	2.6
2011-12		1	260	-1	-1	-1	-0.1	-0.4	-0.9	-0.9	-1.7	-0.3
mean	**-0.90**	3	350	-2	-1.6	-1.7	-0.3	-0.7	-1.9	-2	-1.3	-1.4
stdev	0.58	5	80	-0.7	-1.6	-0.7	-0.1	-1	0.3	-1.1	-0.9	-0.6
SE	0.10	7	170	-0.8	-1.2	-0.4	-0.2	-0.5	-1.1	-0.5	-0.6	-0.4

Table 11: Sediment accretion measured by marker horizon cores at WAL.

WAL- Marker Horizons measurement 2011-12				Net Accretion (cm/yr)						
RSET-01 line 1 (LM)	**mean (cm)**	**# cores**	**quality**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
core 1a	6.15	1	Great	0.93						
core 1b	6.25	1	Great	1.08						
core 1c	5.60	1	Great	1.25						
mean	**6.00**			**1.08**	**0.54**	**1.11**	**0.62**	**0.61**	**0.06**	**1.98**
RSET-02 - Line 5 (HM)	**mean (cm)**	**# cores**	**quality**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
core 2a					1.88					
core 2b	destroyed by ice in 2009				2.08					
core 2c					1.93					
mean				**n/a**	**1.96**	**0.13**	**1.20**		**no data**	
RSET-03 Line 5 (LM)	**mean (cm)**	**# cores**	**quality**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
core 3a	4.15	2	Great		0.3					
core 3b	4.65	1	Good		0.45					
core 3c	4.98	1	Great		0.50					
mean	**4.59**			**n/a**	**0.42**	**0.87**	**1.01**	**0.23**	**1.56**	**0.51**

Table 12: Sediment accretion measured by marker horizon cores at WAL-R.

WAL-R- Marker Horizons measurement 2011-12				Net Accretion (cm/yr)						
RSET-01 line 3 (MM)	**mean (cm)**	**# cores**	**quality**	**2005-06**	**2006-07***	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
core 1a	2.60	3	Ok	0.40						
core 1b	2.20	1	Good	1.48						
core 1c	3.00	1	Ok	0.63						
mean	**2.60**			**0.83**	**17.92**	**0.69**	**0.25**	**0.33**	**0.86**	**1.77**
RSET-02 line 1 (HM)	**mean (cm)**	**# cores**	**quality**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
core 2a	3.33	1	Great		0.80					
core 2b	3.55	2	Good		0.63					
core 2c	4.40	1	Good		0.30					
mean	**3.76**			**n/a**	**0.00**	**1.65**	**1.96**	**-0.65**	**0.64**	**2.18**

Table 13: Net change in surface elevation, sediment accretion and net change due to subsurface processes from 2005-2012 at a) WAL and b) WAL-R.

a) WAL	**Elevation**	**net change in marsh surface elevation**	**net accretion**	**net change due to sub surface processes**
Station	**(m CGVD28)**	**(cm)**	**(cm)**	**(cm)**
RSET 2	6.18	1.09	3.29	-2.20
RSET 3	6.21	4.04	4.59	-0.56
RSET 1	6.39	8.78	6.00	2.78
L1_S2,L6_S3*	6.12		4.35	
L1_S4*	6.19		4.78	
L1_S3,L6_S4*	6.28		2.96	
b) WAL-R				
RSET2	6.51	2.64	6.36	-3.71
RSET1	6.72	17.00	22.44	-5.44

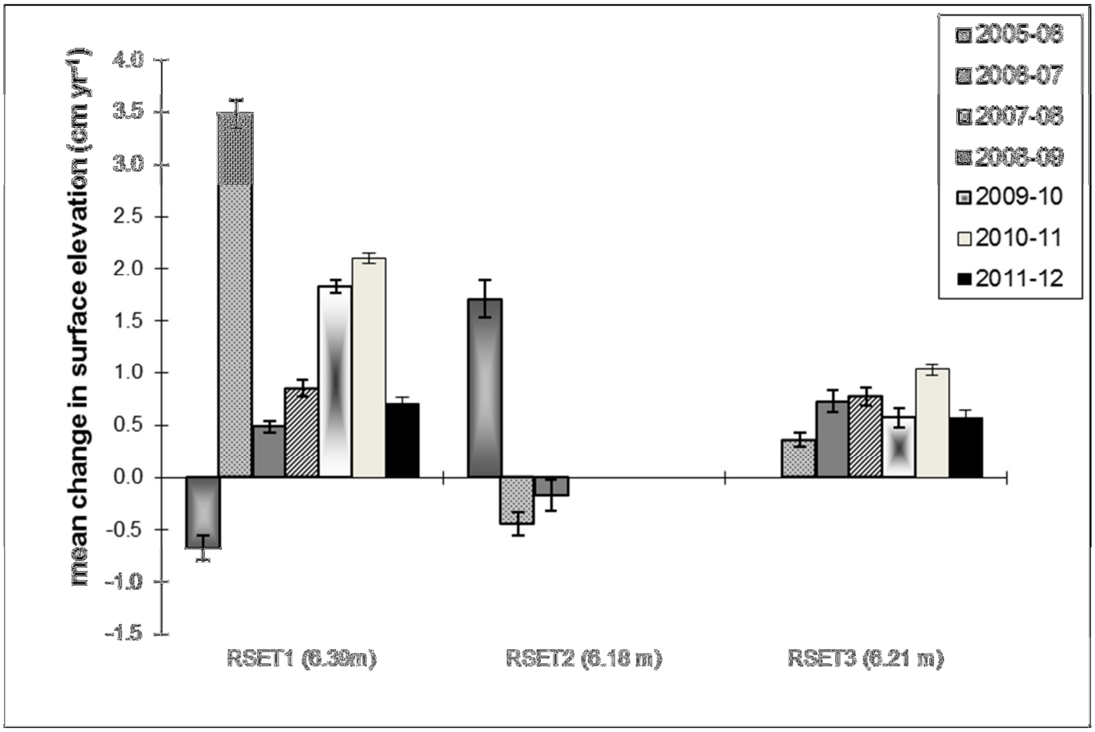


Figure 45: Mean change in surface elevation (± standard error) measured by the RSET devices at WAL from 2005 to 2012.

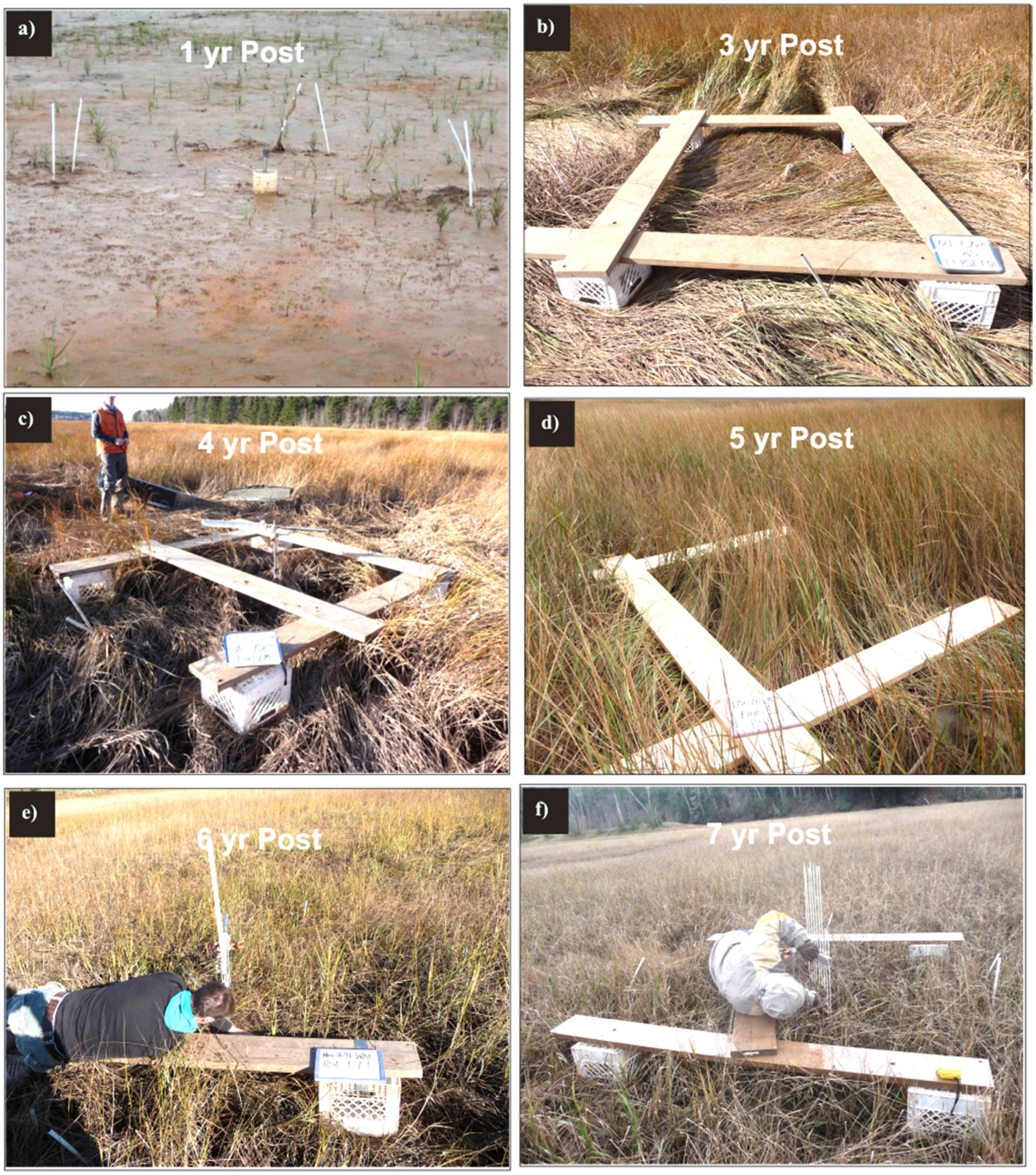


Figure 46: WAL RSET-01 Line 1 a) the end of July 2006; b) 7 October 2008; c) 11 December 2009; d) 1 October 2010; e) 16 November 2011; and f) 11 November 2012. Photographs by CBWES Inc.

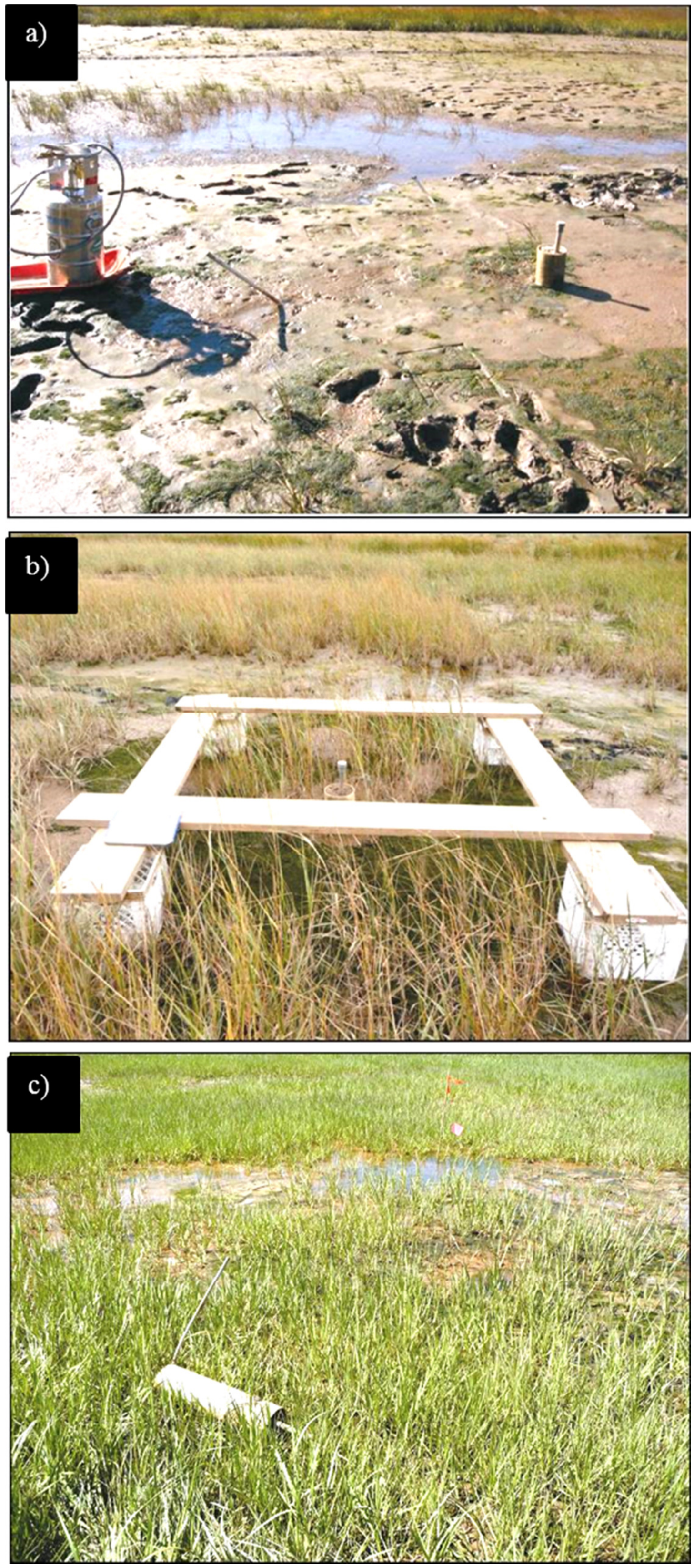


Figure 47: WAL RSET-02 and marker horizons on Line 5 HM on a) 17 October 2007; b) 10 July 2008; and c) after removal of RSET by ice, 15 June 2009. Photographs by CBWES Inc.

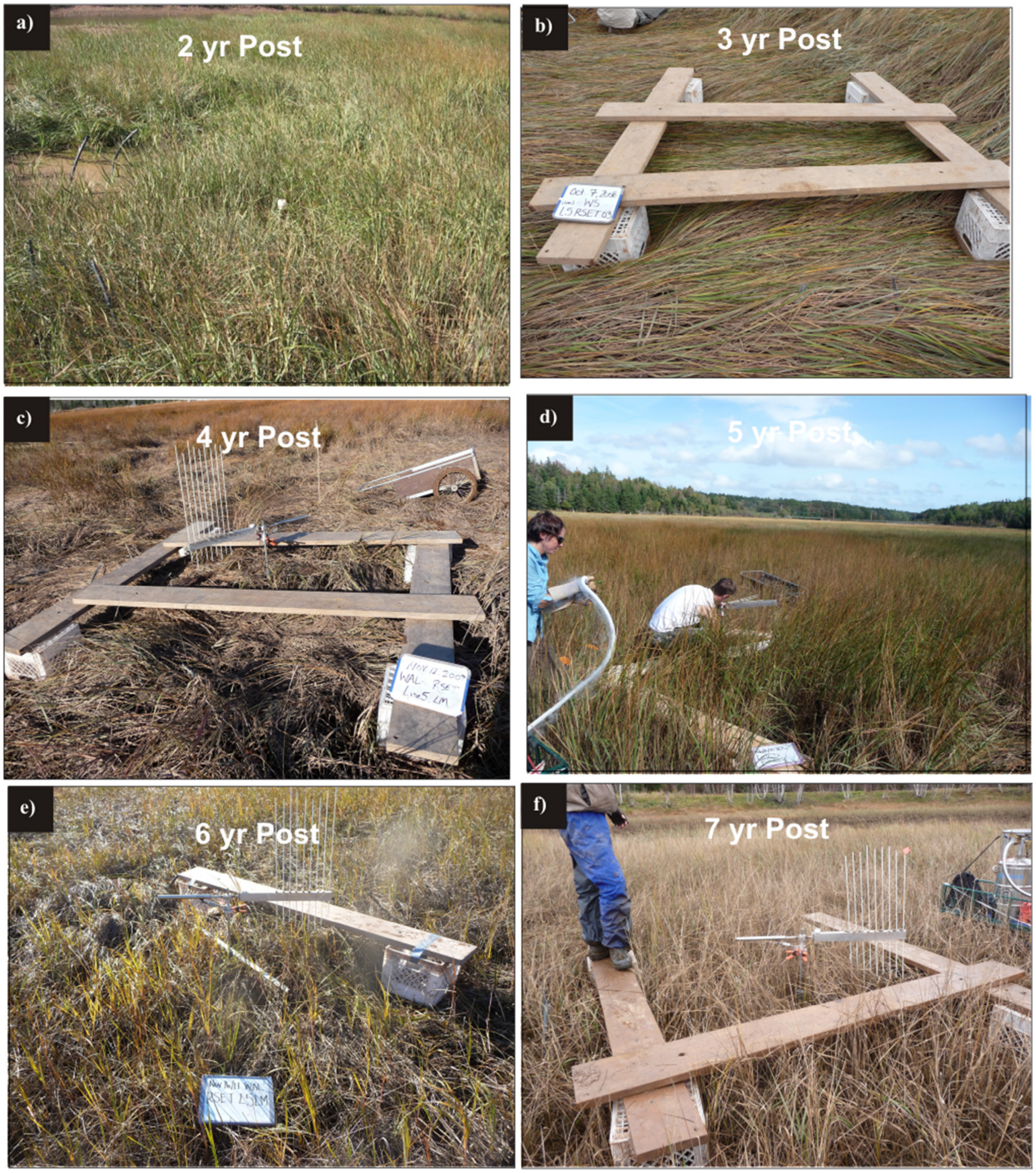


Figure 48: WAL RSET-03 and marker horizons on Line 5 LM on a) 17 October 2007; b) 10 July 2008; c) 12 November 2009; d) 1 October 2010; e) 16 November 2011; and f) 11 November 2012. Photographs by CBWES Inc.

Figure 49: WAL-R RSET-01 in a) 2009 showing minimal evidence of ice deposit from 2006-07 and b) 16 November 2012 with new potential ice or storm deposit. Photographs by CBWES Inc.

Table 13 illustrates the importance of sediment supply in maintaining a rate of change in surface elevation that can keep pace with the rate of sea level rise. Shaw et al. (1998) report a measured rate of sea level rise of 0.55 $cm \cdot yr^{-1}$ and Webster et al. (2012) suggests a range of 1.20 to 1.93 m by 2100 according the reports of Richards and Daigle (2011) and Greenberg et al. (2012). At the present time, neither WAL nor WAL-R can keep pace with sea level rise by below ground production alone. In fact, only WAL RSET-01 and WAL-R RSET-01, both at the highest elevations relative to datum in their respective sites, can keep pace with current rates of sea level rise. At WAL-R, this is solely attributed to the significant ice deposit in 2007. Overall however, WAL does appear to be behaving similarly to WAL-R seven years post-breach and as long vegetative health and adequate sediment flux are maintained, WAL should continue to develop along a positive trajectory.

Soil Characteristics

Soil characteristics at each sample location are highly influenced by the source material, the site's elevation within the tidal frame, distance from the mouth of the estuary, distance from the creek bank and flow velocity. Bulk density, water content and organic matter content are influenced primarily by the sediment characteristics of the underlying substrate and presence or absence of vegetation. Grain size spectra are controlled by the source material and current velocity (Krank and Milligan 1985).

A series of sediment cores were collected at WAL and WAL-R and analyzed for organic matter content, water content and bulk density and results are summarized in Table 14. All cores were processed at the In_CoaST for bulk density, water and organic matter content and grain size analyses performed at Mount Allison University using a Coulter Laser instrument in 2007 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 med 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.

Table 14: Sediment characteristics of homogenized cores collected by SMU in 2007 and 2008 as well as the top 5 cm and bottom 5 cm of cores collected in 2005, 2010 and 2012 by CBWES at: a) WAL and b) WAL-R. Elevations are in meters above geodetic datum CGVD28.

a) WAL			Organic matter content (%)					Water content (%)			
Station ID	**Elev (m)**	**Zone**	**2005***	**2007**	**2008**	**2010**	**2012**	**2007**	**2008**	**2010**	**2012**
WAL L1 S2	6.11	HM	9.50	8.23	10.75	13.32	10.66	51.19	58.39	59.98	51.73
WAL L1 S3	6.28	MM	9.59	7.16	10.62	10.26	9.81	46.85	51.48	43.86	52.00
WAL L1 S4	6.19	LM	10.48	10.09	11.26	7.33	9.99	62.57	60.21	47.62	61.62
WAL L5 S2	5.94	HM	7.80	10.48	10.38	7.19	8.52	65.12	57.05	51.97	53.80
WAL L5 S3	6.14	MM	9.91	8.00	9.54	9.93	11.36	50.13	55.05	50.67	57.73
WAL L5 S5	6.13	LM	25.84	8.74	10.22	9.19	10.55	54.07	50.97	47.11	61.04

			Dry Bulk Density ($g \cdot cm^{-3}$)				Mean grain size (µm)		
Station ID	**Elev (m)**	**Zone**	**2007**	**2008**	**2010**	**2012**	**2007**	**2010**	**2012**
WAL L1 S2	6.11	HM	0.66	0.42	0.63	0.60	28.07	11.39	9.93
WAL L1 S3	6.28	MM	0.75	0.61	0.81	0.51	28.60	10.47	9.88
WAL L1 S4	6.19	LM	0.48	0.26	0.70	0.51	35.86	9.13	10.23
WAL L5 S2	5.94	HM	0.45	0.36	0.72	0.41	25.40	9.74	12.17
WAL L5 S3	6.14	MM	0.67	0.47	0.79	0.36	24.56	11.04	11.67
WAL L5 S5	6.13	LM	0.58	0.55	0.75	0.30	31.54	9.23	9.67

*mean of top and bottom 5 cm sections of core

b) WAL-R Station ID	Elev (m)		Organic matter content (%) 2005*	2007	2008	2010	2012	Water content (%) 2007	2008	2010	2012
WAL-R L1 S1	6.58	HM	n/a	15.26	15.50	21.70	17.13	63.95	62.70	63.10	58.63
WAL-R L1 S2	6.12	MM	9.14	8.01	12.03	9.51	14.97	56.09	62.27	57.91	64.76
WAL-R L1 S3	6.22	LM	n/a	6.54	9.95	11.93	9.05	47.36	61.85	54.21	57.70
WAL-R L3S2	6.68	HM	12.06	19.31	21.41	12.15	12.46	69.90	69.57	57.47	55.87
WAL-R L3 S5	6.37	MM	9.41	11.26	10.88	9.60	17.78	59.36	56.59	55.66	57.24
WAL-R L3 S8	6.10	LM	6.71	9.87	6.96	7.33	14.94	54.98	48.99	41.47	53.47

Station ID	Elev (m)		Dry bulk density ($g \cdot cm^{-3}$) 2007	2008	2010	2012	Mean grain size (µm) 2007	2010	2012
WAL-R L1 S1	6.58	HM	0.48	0.30	0.44	0.32	12.14	10.56	9.06
WAL-R L1 S2	6.12	MM	0.65	0.27**	0.51	0.44	27.43	10.93	8.60
WAL-R L1 S3	6.22	LM	0.72	0.28**	0.69	0.37	26.97	10.45	8.89
WAL-R L3S2	6.68	HM	0.38	0.22	0.38	0.43	31.77	10.86	11.32
WAL-R L3 S5	6.37	MM	0.58	0.39	0.59	0.35	29.83	11.59	10.32
WAL-R L3 S8	6.10	LM	0.57	0.37**	0.84	0.58	62.05	9.25	12.90

*mean of top and bottom 5 cm sections of core **derived from 10 cm cores.

Organic matter content ranged from 8 to 26% at both sites, which was within the range reported elsewhere in the region (e.g., Daborn et al. 2003). This organic material forms a critical food source for grazing benthic invertebrates. At WAL, there was minimal variation in the overall range of organic matter values for most stations within the exception of WAL L5S5 (25.85%) pre-restoration (Table 14a). This was likely associated with decaying algae within the drained impoundment. The highest mean value post-restoration was located at station WAL L1S2 (10.74 ±2.08%) and lowest at WAL L5S2 (9.14 ±1.48%). No clear pattern in relation to elevation emerged (Figure 50a). In contrast, a clear pattern of increasing organic matter content within increasing elevation emerged at WAL-R (Figure 50b). The values were also generally higher at WAL-R and more variable between years. The highest values were recorded at WAL-R L1S1 (17.40 ±2.99) and WAL-R L3S2 (15.48 ±4.52) and lowest at WAL-R L3S8 (9.16 ±3.47) (Table 14b).

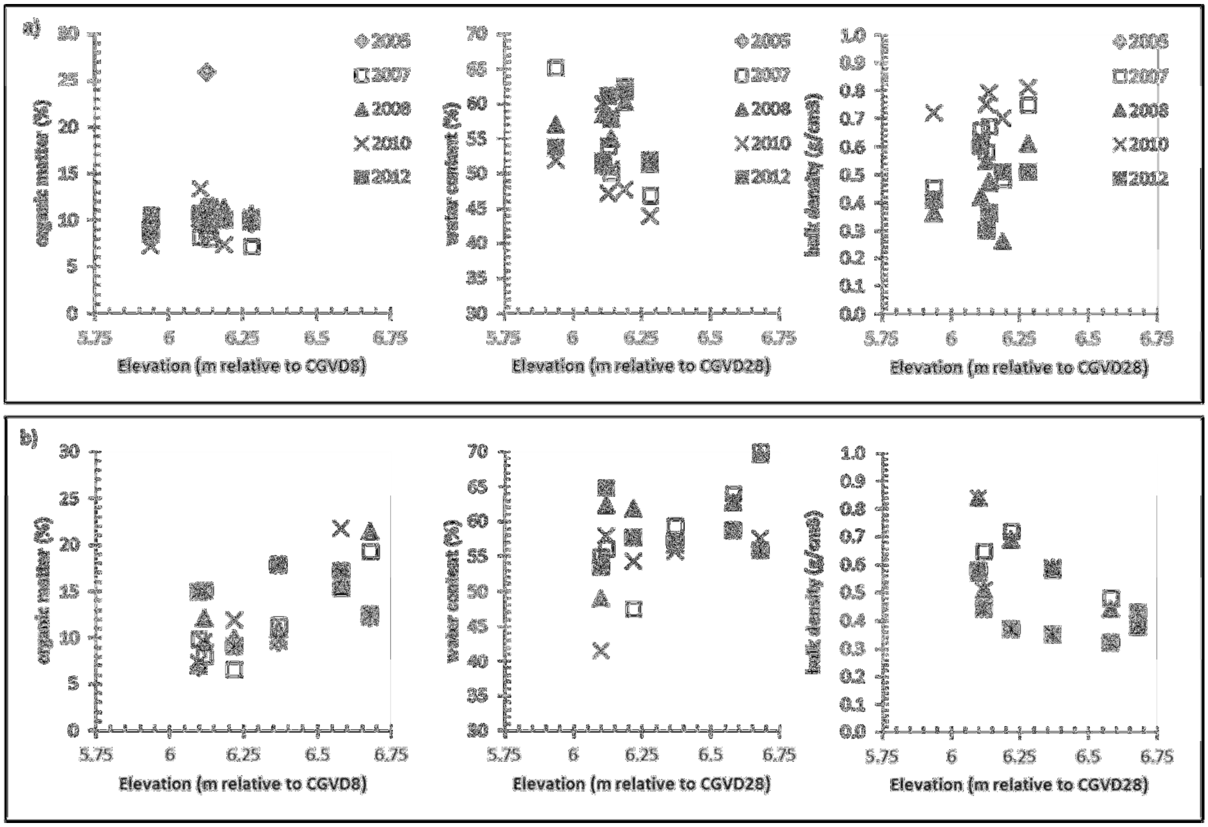


Figure 50: Influence of elevation relative to datum on organic matter, water content and bulk density at a) WAL and b) WAL-R.

The water content within the core sample ranged from 50 to approximately 65-70% at both WAL and WAL-R with increases observed over time in the high marsh and decreases in the low marsh (Table 14). This was similar to values recorded at the Windsor salt marsh downstream of the Windsor causeway (Daborn et al. 2003), but was higher than values reported in other studies in the region (see Daborn et al. 2003 for detailed list). Although water content is seasonably variable, cores at both WAL and WAL-R were taken at the same time, therefore, can be compared and suggest that the surfaces of both marshes are now at similar states of consolidation. Interestingly, water content decreases with elevation at WAL which is expected; however, at WAL-R, water content in some years increases with elevation (Figure 50). This may be associated with upland drainage into the high marsh area. The most notable spatial and temporal variability in sediment properties was observed in the dry bulk density values (Table 14 and Figure 50). Dry bulk density values decreased between 2007 and 2008 at both WAL and WAL-R; however, increased at all stations in 2010 and decreased in 2012. The highest mean bulk density post-restoration was found at station WAL L1S3 (0.67 ±0.14 $g \cdot cm^{-3}$) and lowest at both WAL L1S4 and L5S2 (0.49 ±0.16 $g \cdot cm^{-3}$). WAL L5S2 is found at the lowest elevation within the site (Table 14). At WAL-R, the highest mean value was recorded at WAL-R L3S8 (0.59 ±0.19 $g \cdot cm^{-3}$) also at the lowest elevation. The lowest value was recorded at WAL-R L3S2 (0.35 ±0.09 $g \cdot cm^{-3}$) at the highest elevation (Table 14b and Figure 50b). In general, increases in bulk density reflect increased soil strength and decreased porosity. Once again this reflects the increased compaction of the soil and the likely development of a comprehensive *Spartina* root matrix.

Comparison of grain size statistics between 2007 and 2010 was not directly possible due to the different instruments (and principles) that were used in their analysis. The 2007 samples were coarser, which could simply reflect being analyzed with a laser particle size analyzer (McCave et al. 1996), when compared to the 2010 samples. However, spatial variations in grain size parameters within a site and between restoration and reference site within a year are still possible. In 2007 sediments at both sites fell into the coarse silt to very coarse silt size class with the exception of WAL-R L1S1 which was classified at fine silt (Table 15; Figure 53). All samples were poorly sorted and coarse skewed. In 2010, once again there was little difference between WAL and WAL-R in terms of grain size. Samples at WAL ranged from 9.23 to 11.39 µm (med silt) and WAL-R ranged from 9.25 to 10.93 µm (med silt) (Table 15). Sediments were still poorly sorted, however, less so than in 2007 and remain coarse skewed. In 2012, there was a notable decrease in grain size at WAL L1S2 and L1S3 and increase at L1S4 and L5S2 (Table 15); however, the grain size classification remained medium silt. There was also much less variability in grain size in 2012 (Table 14b). The range of grain sizes (9.67 to 12.17 µm) was comparable to those found at WAL-R (8.6 to 12.90 µm). Grain size has an influence on bulk density with increasing grain size contributing to low bulk density values which is reflected at both WAL and WAL-R.

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 52). 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 reduced 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). 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 ($\hat{d}$) that is the roll-off diameter and represents the size of the largest grain in suspension (Curran et al. 2004).

Table 15: Grain size characteristics of homogenized cores collected in 2007, 2010 and 2012 at a) WAL and b) WAL-R. (Stdev = standard deviation). Sediment characterization determined using Folk and Ward method in GRADISTAT (Blott and Pye 2001).

a) WAL	**2007** Mean (µm)	Stdev (µm)	Skewness	**2010** Mean (µm)	Stdev (µm)	Skewness	**2012** Mean (µm)	Stdev (µm)	Skewness
WAL L1 S2	28.07 Coarse silt	21.19	0.60 coarse skewed	11.39 Med silt	13.73	1.46 Coarse skewed	9.93 Med silt	2.73	0.21 Coarse skewed
WAL L1 S3	28.60 Coarse silt	22.60	0.83 coarse skewed	10.47 Med silt	12.50	1.45 Coarse skewed	9.88 Med silt	2.77	0.19 Coarse skewed
WAL L1 S4	35.86 Very Coarse silt	26.25	0.58 coarse skewed	9.13 Med silt	11.00	1.48 Coarse skewed	10.23 Med silt	2.86	0.19 Coarse skewed
WAL L5 S2	25.40 Coarse silt	21.81	0.96 coarse skewed	9.74 Med silt	11.66	1.46 Coarse skewed	12.17 Med silt	2.95	0.23 Coarse skewed
WAL L5 S3	24.56 Coarse silt	18.42	0.57 coarse skewed	11.04 Med silt	13.24	1.45 Coarse skewed	11.67 Med silt	2.95	0.18 Coarse skewed
WAL L5 S5	31.54 Very Coarse silt	23.5	0.59 coarse skewed	9.23 Med silt	11.12	1.49 Coarse skewed	9.67 Med silt	2.99	0.19 Coarse skewed

b) WAL_R	**2007** Mean (µm)	Stdev (µm)	Skewness	**2010** Mean (µm)	Stdev (µm)	Skewness	**2012** Mean (µm)	Stdev (µm)	Skewness
WAL-R L1 S1	12.14 Med silt	8.57	0.544 Coarse skewed	10.56 Med silt	12.85	1.51 Coarse skewed	9.06 Med silt	2.92	0.08 Coarse skewed
WAL-R L1 S2	27.43 Coarse silt	21.64	0.738 Coarse skewed	10.93 Med silt	13.07	1.45 Coarse skewed	8.60 Med silt	2.92	0.09 Coarse skewed
WAL-R L1 S3	26.97 Coarse silt	24.64	1.314 Coarse skewed	10.45 Med silt	2.87	1.53 Coarse skewed	8.89 Med silt	2.97	0.09 Coarse skewed
WAL-R L3S2	31.77 Very coarse silt	24.68	0.769 Coarse skewed	10.86 Med silt	13.32	1.52 Coarse skewed	11.32 Med silt	3.05	0.14 Coarse skewed
WAL-R L3 S5	29.83 Coarse silt	28.59	1.632 Coarse skewed	11.59 Med silt	14.25	1.48 Coarse skewed	10.32 Med silt	3.20	0.12 Coarse skewed
WAL-R L3 S8	62.05 Very coarse silt	71.86	4.082 Coarse skewed	9.25 Med silt	11.10	1.48 Coarse skewed	12.90 Med silt	3.60	0.12 Coarse skewed

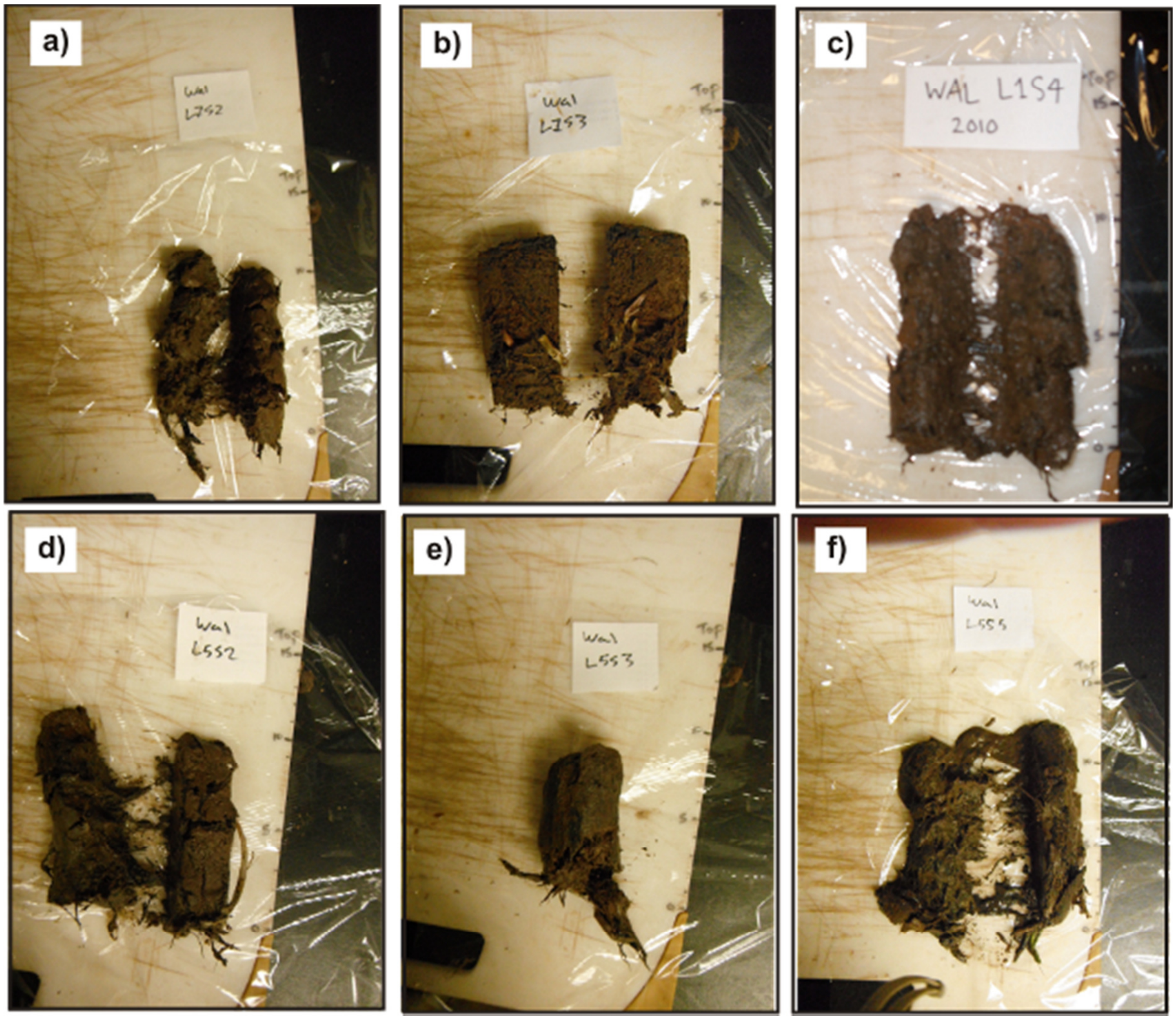


Figure 51: Split core photos from WAL for cores collected in 2012 a) WAL_L1S2, b) WAL_L1S3; c) WAL_L1S4; d) WAL_L5S2; e) WAL_L5S3 and f) WAL_L5S5.

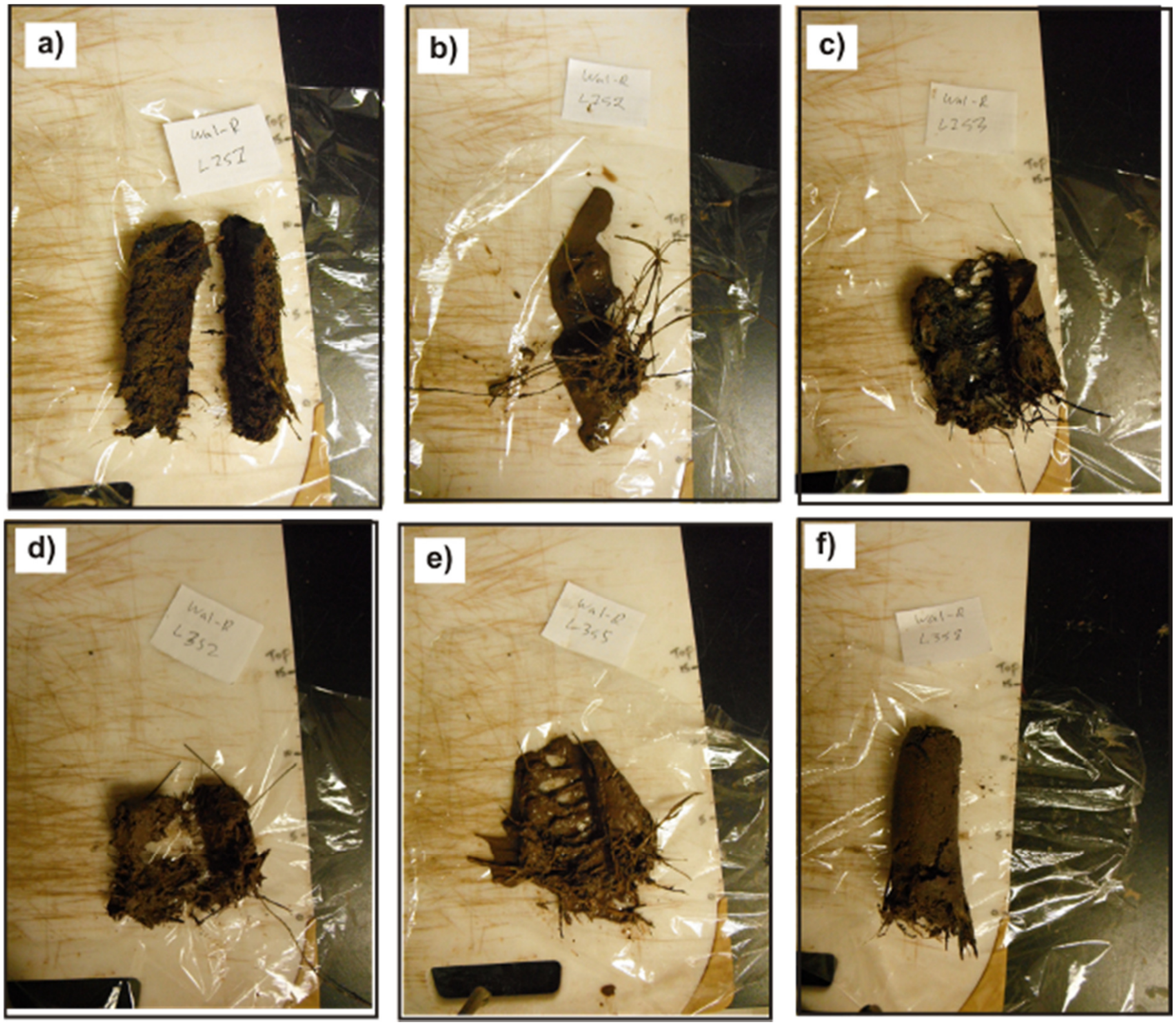


Figure 52: Split core photos from WAL-R cores collected in 2012 a) WAL-R_L1S1; b) WAL-R_L1S2; c) WAL-R_L1S3; d) WAL-R_L3S2; e) WAL-R_L3S5 and f) WAL-R_L3S8.

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

Figure 53: Modified size scale adopted in the GRADISTAT program (Blot and Pye 2001).

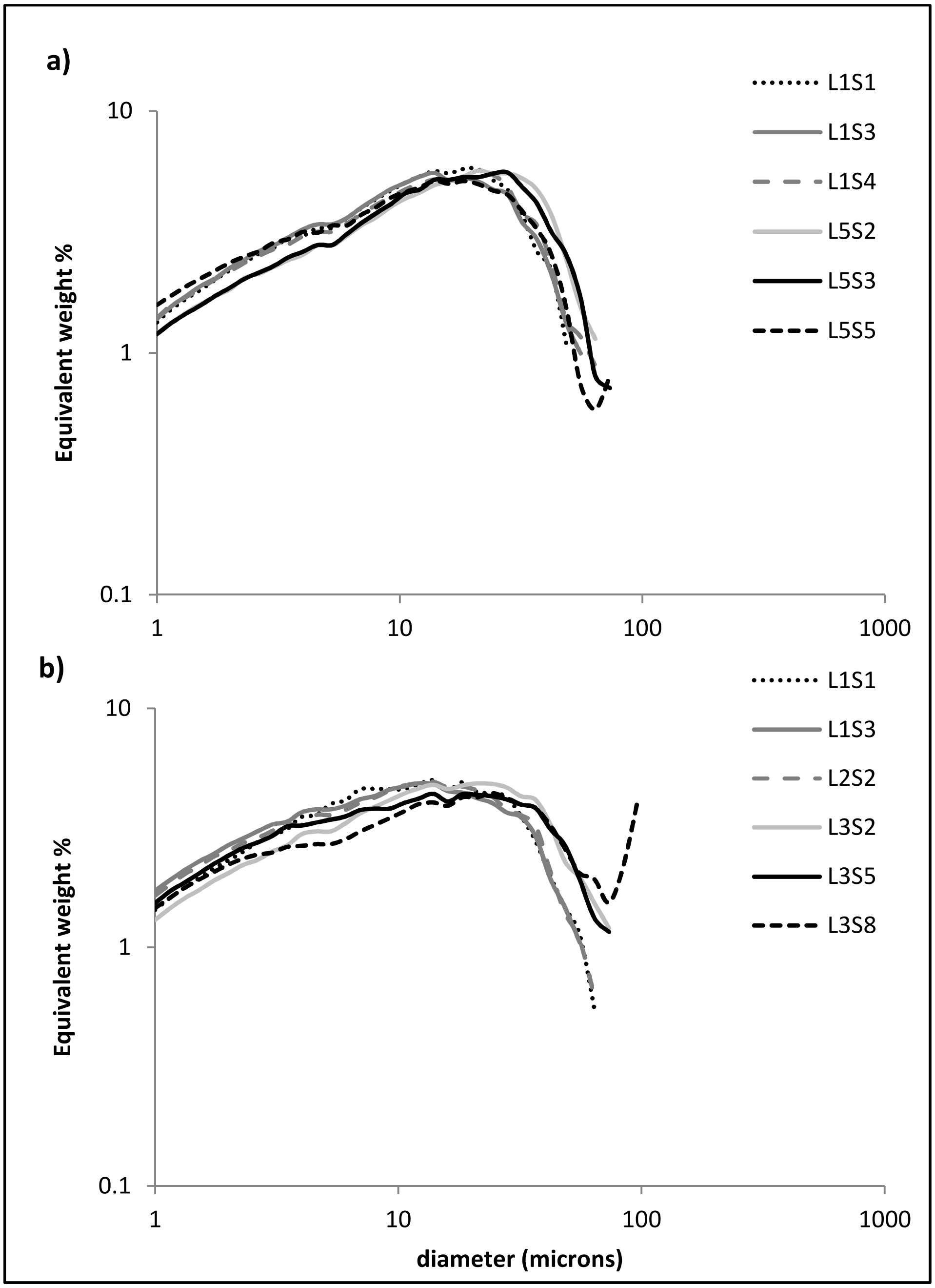


Figure 54: Comparison of the detailed grain size spectra for top 2 cm of core samples collected in 2012 processed with the Coulter Multisizer 3 at a) WAL and b) WAL-R.

There appears to be minimal difference in the grain size spectra (Figure 54) within a site; however, subtle differences do appear between sites. In general, source material and transport mechanisms at all stations at WAL were similar. The most variable station relative to the mean slope was WAL L5S5, which also had the smallest grain size and second highest water content (Table 15 and Table 16). Approximately 55 to 66% of the deposited sediments at WAL fell as flocs, which is similar to WAL-R, particularly in 2012 (Table 16). The cut-off diameter and roll-off diameter are almost entirely equal (Table 16).

Table 16: Inverse floc model statistics for a) WAL and b) WAL-R in 2010 and 2012. Model run by C. Skinner (2012).

a) WAL			**2010**				**2012**			
Station ID	**Elev (m)**	**Zone**	**Floc Fraction (*K_f*)**	**Floc Limit (*d_f*)**	**Source Slope (m)**	**Rolloff Diameter (*dhat*)**	**Floc Fraction (*K_f*)**	**Floc Limit (*d_f*)**	**Source Slope (m)**	**Rolloff Diameter (*dhat*)**
WAL L1 S2	6.11	HM	0.55	9	0.54	11	0.65	16	0.52	18
WAL L1 S3	6.28	MM	0.63	12	0.53	13	0.65	16	0.53	17
WAL L1 S4	6.19	LM	0.66	12	0.43	13	0.63	16	0.47	18
WAL L5 S2	5.94	HM	0.66	12	0.51	12	0.58	16	0.48	20
WAL L5 S3	6.14	MM	0.63	12	0.36	15	0.58	16	0.50	20
WAL L5 S5	6.13	LM	0.66	12	0.44	12	0.64	16	0.41	19
b) WAL-R			**2010**				**2012**			
Station ID	**Elev (m)**	**Zone**	**Floc Fraction (*K_f*)**	**Floc Limit (*d_f*)**	**Source Slope (m)**	**Rolloff Diameter (*dhat*)**	**Floc Fraction (*K_f*)**	**Floc Limit (*d_f*)**	**Source Slope (m)**	**Rolloff Diameter (*dhat*)**
WAL-R L1 S1	6.58	HM	0.67	13	0.65	12	0.66	16	0.58	14
WAL-R L1 S2	6.12	MM	0.64	13	0.67	13	0.68	16	0.45	15
WAL-R L1 S3	6.22	LM	0.68	14	0.39	15	0.66	16	0.44	16
WAL-R L3S2	6.68	HM	0.68	14	0.53	14	0.60	16	0.50	17
WAL-R L3 S5	6.37	MM	0.70	13	0.38	13	0.62	16	0.43	15
WAL-R L3 S8	6.10	LM	0.67	12	0.44	13	0.63	21	0.33	24

The floc limit and roll-off diameter of WAL-R were nearly identical within the site and when compared to WAL, with the exception of WAL L3S8, indicated the presence of larger grains (Table 16). This was also reflected in the larger grain size within the site (Table 15). Over sixty percent of the sediments fell in flocculated form, slightly higher than at WAL and may be associated with higher amounts of organic matter (Table 14).

4.4 Vegetation

Species Abundance and Frequency Trends:

Salt marsh dominants form the main communities at WAL-R and, with the exception of annuals/ruderal species, have maintained consistent abundances and frequencies over the study period (Table 17). Study site fringe marsh plots have either *S. alterniflora* (Smooth cordgrass) or *S. patens* (Salt meadow hay) dominated communities and have experienced minimal change over the seven year post-restoration monitoring program (Figure 55) (not shown on Table 17).

Prior to restoration activities, the main halophyte at WAL was *Juncus gerardii* (Black grass), which existed at low abundances at a few locations. This species has doubled in abundance over the study period (now found at six plots versus three plots in 2005: Table 17). Several species have disappeared entirely at WAL, including algae and freshwater aquatic species. Most of the halophytes now found on WAL colonized in 2006, and most have increased in abundance since then. *Carex paleacea* (Marsh sedge) is now found at six plots, *Scirpus maritimus* (Salt marsh bulrush) is now at four plots, and *Limonium nashii* (Sea lavender) was first observed on the site in 2010 and is still present. *S. alterniflora* rapidly colonized the site in 2006 and has remained a dominant presence on the marsh to 2012. *S. patens* also colonized in 2006, but have increased in abundance and frequency slowly since then, reaching its highest abundance in 2012. Several other species appear to be increasing slowly, so it is not clear whether they will continue to increase. This emphasizes the importance of long-term monitoring to track the increases in species that are slower to colonize than *S. alterniflora*. The abundances and frequencies of early successional/colonizer species such as *Salicornea europaea* (Glasswort) and *Suaeda maritima* (Sea-blite) have fluctuated greatly over the years, but were not present prior to restoration activities. They have also reached their maximum frequencies recorded during the monitoring program in 2012. As the tidal wetland habitat continues to progress at WAL, it is expected that high marsh species will continue to increase in abundance, with a subsequent decline in *S. alterniflora*.

Community Patterns:
Large shifts in plant communities took place after 2005. Many plots at WAL were dominated by a freshwater submerged aquatic community (Figure 55, plots on right side), or largely upland or freshwater wetland species (Figure 55, plots on lower left) pre-restoration. WAL-R plots and fringe plots largely had low marsh (*S. alterniflora*) or high marsh (*S. patens*) communities in 2005. By 2012, WAL plots largely overlap with WAL-R plots, with a range of different communities from low marsh, to high marsh, to brackish, although there are more high marsh (*S. patens*) plots at WAL-R. WAL still differs significantly from WAL-R in overall community composition (non-parametric multivariate ANOVA: $F_{1,50}$=11.1, P < 0.0001, R^2 = 0.18), but this is due to the greater number plots containing high marsh species at WAL-R compared to WAL, which has extensive coverage of *S. alterniflora* on the marsh surface.

Other Site-level Trends:
Both species richness and halophytic species richness have increased over time at WAL, reaching their maximum in 2012 (Figure 56; Figure 57; Table 18; Table 19). Halophyte richness was high in 2012 due to the occurrence of *Suaeda* and *Salicornia* in many plots where they were not present in 2010, and this was likely driving the overall richness pattern as well. Both richness indices were statistically equivalent by 2006 or 2007. Abundance of halophytes rose greatly between 2006 and 2008, but the increase seems to have levelled off by 2012 (Figure 58). Unvegetated area increased dramatically in 2006, post-breach, but has declined since (Figure 59).

Individual Plots at Walton:
The most dramatic changes at WAL occurred in 2006 when more than 20 plots were colonized by *S. alterniflora* in great abundance. Most of these plots have remained dominated by *S. alterniflora*, with the addition of several other salt marsh species (e.g., *Limonium nashii*) in relatively low numbers. A few plots have transitioned into a *S. patens*-dominated community e.g. WAL L2S1. One plot, WAL L5S1 (Figure 60), started with high cover of *S. alterniflora* post-

restoration and shifted to a mixed *S. patens/S. alterniflora* plot by 2012 and WAL L6S1 started pre-restoration dominated by *Juncus gerardii*, but is now (2012) mostly *S. patens* and *C. paleacea*. Both species are likely to be poorer colonizers and better competitors compared with *J. gerardii*, and thus would be expected to take over later during succession.

One plot (WAL L4S4) showed an increase in *S. alterniflora* beginning in 2007, continuing to 2009, and then a complete crash in 2010. This plot has become panne habitat as shown in (Figure 31; Figure 62).

Overall, WAL may represent a best-case scenario for "low intervention" salt marsh vegetation restoration in the Bay of Fundy. WAL has been transformed from a freshwater impoundment, into a salt marsh completely dominated by halophytes. Halophyte species richness and abundance are equivalent to that at WAL-R. While WAL is still mostly a low marsh community, high marsh species have been slowly increasing in abundance at the site. Given that these species are known to be relatively poor colonizers, and since there was no human-aided seeding or transplanting done, this was what could be expected of a natural salt marsh undergoing primary succession. It is possible that the eventual relative abundance of high versus low marsh vegetation may differ from WAL-R due to inherent differences in elevation range between the sites. Given these results, if a more diverse halophyte community is desired, it is suggested that future projects similar to WAL may benefit from further interventions, such as transplanting or seeding high marsh species to appropriate locations, to accelerate succession and lead to greater diversity of species and community types earlier in the process.

Table 17: Mean plot abundances and frequencies ("f" after the year = # plots containing the species) from 2005-12 at WAL. WAL-R results only presented for 2005 and 2012.

Species	05	05f	06	06f	07	07f	08	08f	09	09f	10	10f	12	12f	R-05	R-05f	R-12	R-12f
Agrostis stolonifera	2.2	5	0.4	2	3.1	5	1.9	5	1.8	4	1.4	4	0.4	3				
Algae	1.7	7			2.4	5			0.3	1								
Atriplex glabriscula				1	0.2	4	0.1	3	0.2	4	0.0	2		1	0.2	7	0.0	3
Betula sp.		1				1			0.6	1								
Carex hormathodes				1			0.1	2			0.3	1						
Carex paleacea				2	0.1	2	0.6	3	0.7	3	1.8	4	2.2	6	0.4	4	3.8	4
Distichlis spicata		1	0.4	2											1.7	2	1.5	2
Eleocharis parvula			0.3	2														
Elymus virginiana																		
Festuca rubra					0.2	2	0.6	1	0.8	1	0.5	1						
Hierochloe odorata																	0.3	1
Hydrocotyle americana		1		1														
Juncus effusus	0.6	3																
Juncus gerardii	1.4	3	1.1	4	2.2	5	2.2	4	1.3	5	3.0	6	3.2	6				
Limonium nashii											0.1	2		1			0.1	3
Plantago maritima		1	0.1	1	0.2	4		1	0.1	2		1			0.0	2		
Puccinellia maritima		0		1	0.1	2	0.0	1										
Ranunculus cymbalaria					0.3	1	0.7	1	0.4	1	0.6	1	0.4	1				
Ruppia maritima		1	0.3	1					0.3	1								
Salicornea europaea			0.1	5	0.2	9	0.4	5	0.1	3	0.0	1	0.4	14	0.3	7	0.1	4
Scirpus acutus		1	0.2	4					0.1	1								

Species	**05**	**05f**	**06**	**06f**	**07**	**07f**	**08**	**08f**	**09**	**09f**	**10**	**10f**	**12**	**12f**	**R-05**	**R-05f**	**R-12**	**R-12f**
Scirpus maritimus				2	0.2	2	1.2	5	0.2	4	0.4	2	0.4	4				
Scirpus validus	0.5	1			0.7	1	0.4	2	0.9	1	0.4	1	0.3	3				
Solidago gigantea	0.2	4										1						
Solidago sempervirens															0.9	3	0.2	2
Spartina alterniflora			5.4	21	14.7	25	18.5	24	20.3	22	18.8	22	19.1	25	9.0	18	9.9	18
Spartina patens			2.5	5	3.0	7	1.7	5	4.3	8	4.1	6	5.6	8	14.7	19	18.2	20
Spartina pectinata					0.3	2	0.6	1	1.0	2	0.8	2	0.5	2	2.0	4	1.3	2
Submerged aquatics	10.3	15										8		1				
Suaeda maritima			0.1	4		1	0.2	1	0.2	1	0.0	1	0.2	12	0.2	4	0.2	2
Triglochin maritima						1			0.1	2	0.1	1			0.4	2	0.7	2
Unvegetated area	8.4	14	14.9	24	6.0	10	0.4	3			1.1	3			1.4	10	0.1	2

Table 18: Repeated measures ANOVA comparing mean plot species richness at WAL, WAL fringe, and WAL-R over time.

Between Plots	Df	Sum Sq	Mean Sq	F	P
Site	2	46.2	23.094	1.597	0.211
Year	4	17.8	4.452	0.308	0.872
Site X Year	2	20.1	10.049	0.695	0.503
Residuals	58	838.5	14.456		
Within Plots					
Year	6	15.77	2.629	3.408	0.00275
Site X Year	12	40.94	3.412	4.423	<0.0001
Residuals	376	290.02	0.771		

Table 19: Repeated measures ANOVA comparing mean plot halophytic species richness at Walton, WAL fringe, and WAL-R over time.

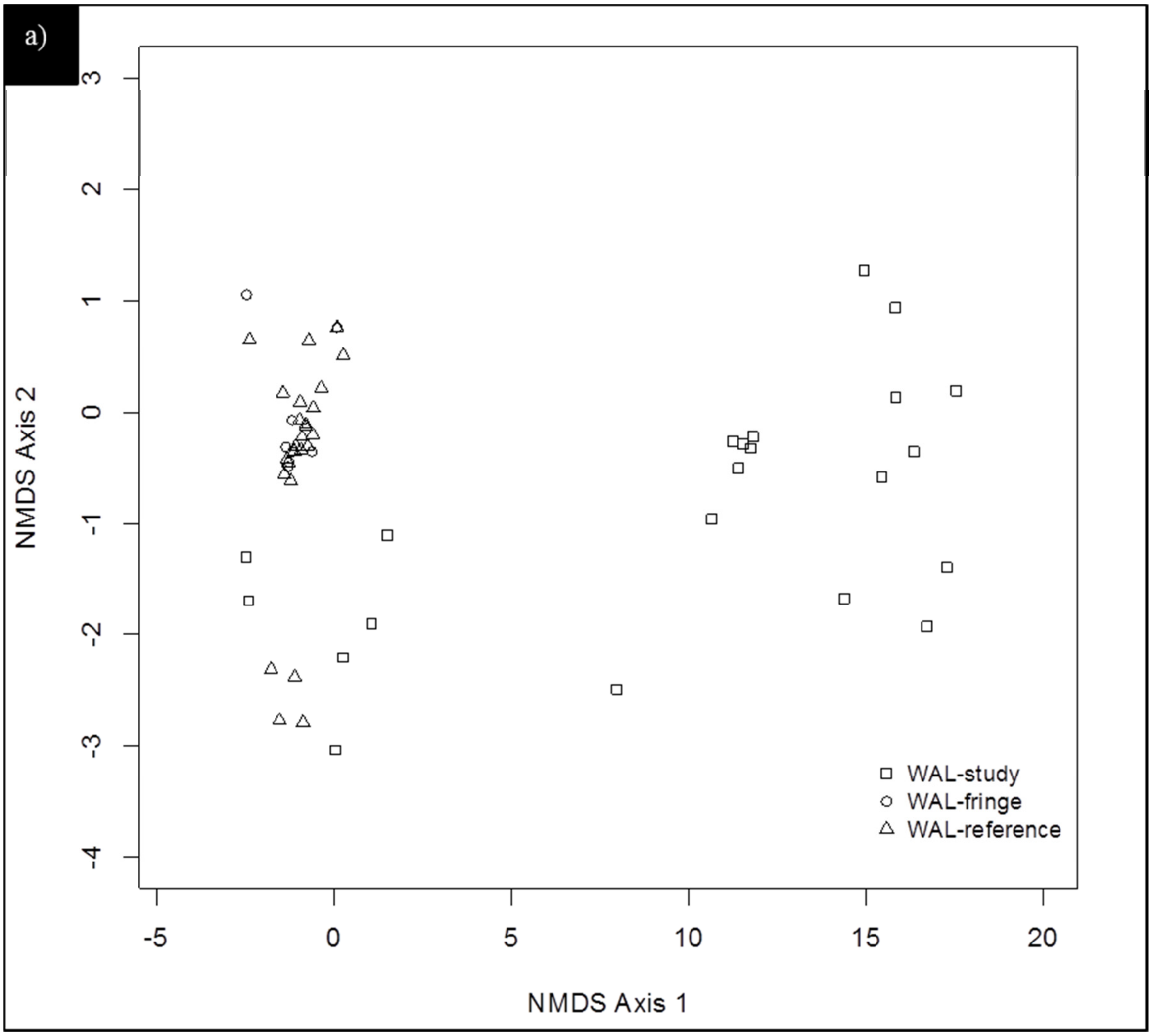
Between Plots	Df	Sum Sq	Mean Sq	F	P
Site	2	32.5	16.229	2.1	0.132
Year	4	8.9	2.228	0.288	0.884
Site X Year	2	10.8	5.406	0.699	0.501
Residuals	58	448.2	7.728		
Within Plots					
Year	6	38.51	6.419	9.871	<0.0001
Site X Year	12	92.03	7.669	11.794	<0.0001
Residuals	376	244.50	0.650		

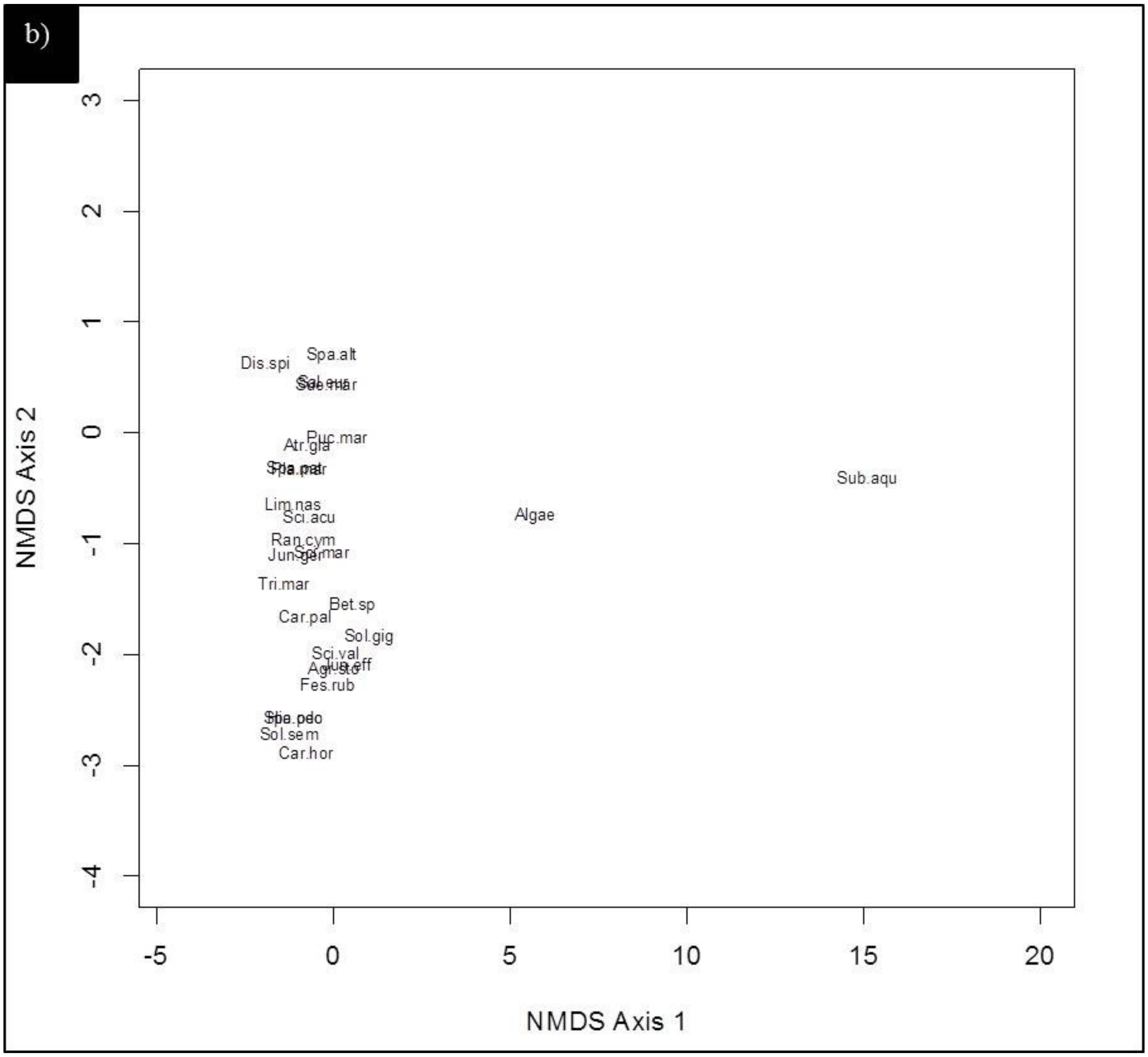
Table 20: Repeated measures ANOVA comparing mean plot halophytic species abundance at WAL, WAL fringe, and WAL over time.

Between Plots	Df	Sum Sq	Mean Sq	F	P
Site	2	14070	7035	17.989	<0.0001
Year	4	423	106	0.271	0.896
Site X Year	2	556	278	0.711	0.495
Residuals	58	22682	391		
Within Plots					
Year	6	11294	1882.3	36.40	<0.0001
Site X Year	12	10058	838.2	16.21	<0.0001
Residuals	376	19442	51.7		

Table 21: Repeated measures ANOVA comparing mean plot unvegetated area at WAL, WAL fringe, and WAL-R over time.

Between Plots	Df	Sum Sq	Mean Sq	F	P
Site	2	2010.4	1005.2	28.779	<0.0001
Year	4	0.9	0.2	0.006	1.00
Site X Year	2	0.7	0.3	0.010	0.99
Residuals	58	2025.8	34.9		
Within Plots					
Year	6	2298	383.1	20.96	<0.0001
Site X Year	12	2996	249.7	13.66	<0.0001
Residuals	376	6873	18.3		


a)
NMDS Axis 2
NMDS Axis 1
3
2
1
0
-1
-2
-3
-4
-5
0
5
10
15
20
WAL-study
WAL-fringe
WAL-reference


b)
NMDS Axis 1
NMDS Axis 2
-5
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5
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15
20
3
2
1
0
-1
-2
-3
-4
Spa.alt
Dis.spi
Puc.mar
Atr.gla
Lim.nas
Sci.acu
Ran.cym
Tri.mar
Bet.sp
Car.pal
Sol.gig
Sci.val
Fes.rub
Sol.sem
Car.hor
Algae
Sub.aqu

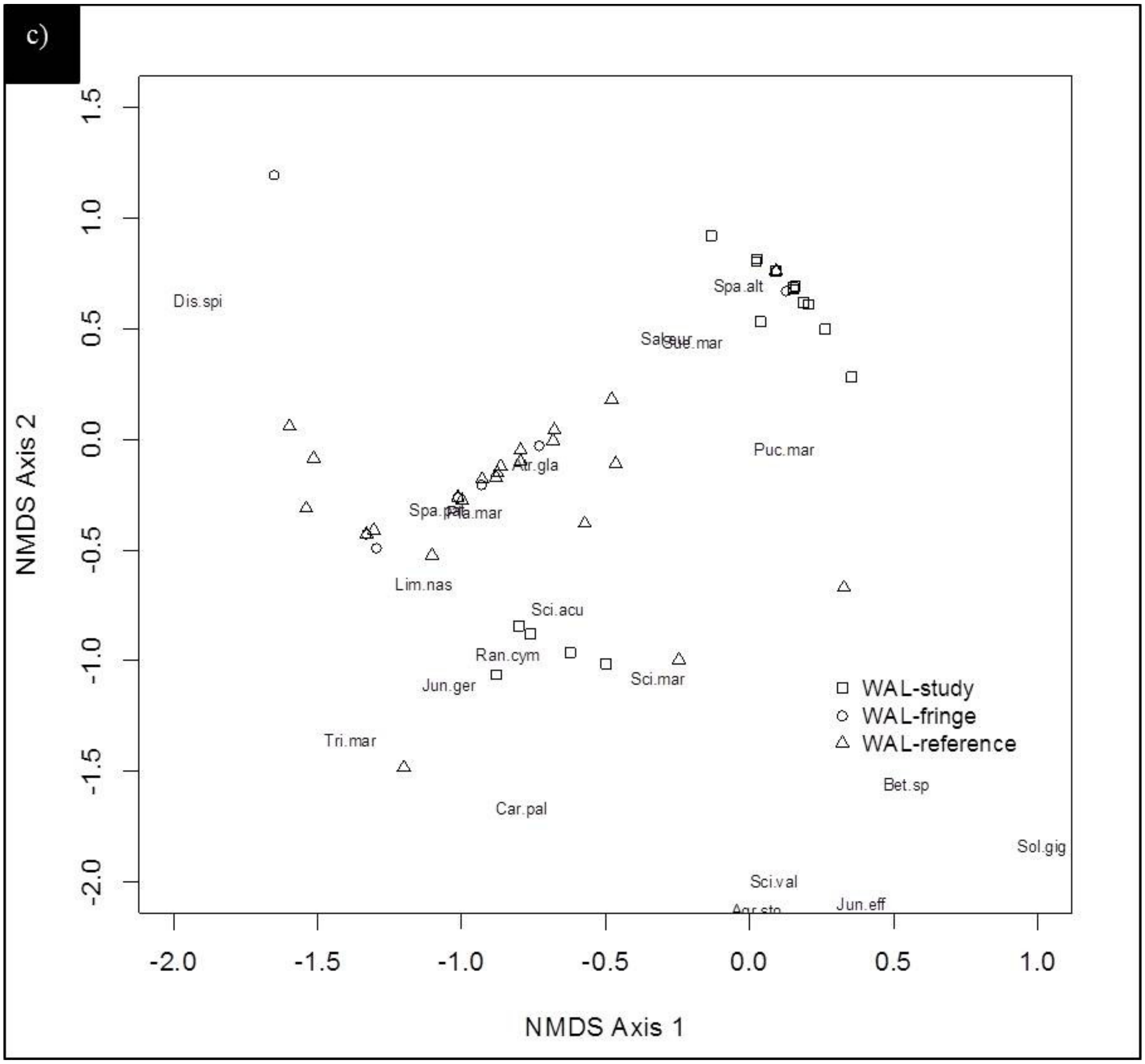


Figure 55: Non-metric multidimensional scaling of species abundances at WAL, WAL fringe, and WAL-R: a) is 2005 only; b) 2005 only showing species locations; and c) 2012 only (area enlarged, but from the same original ordination as previous).

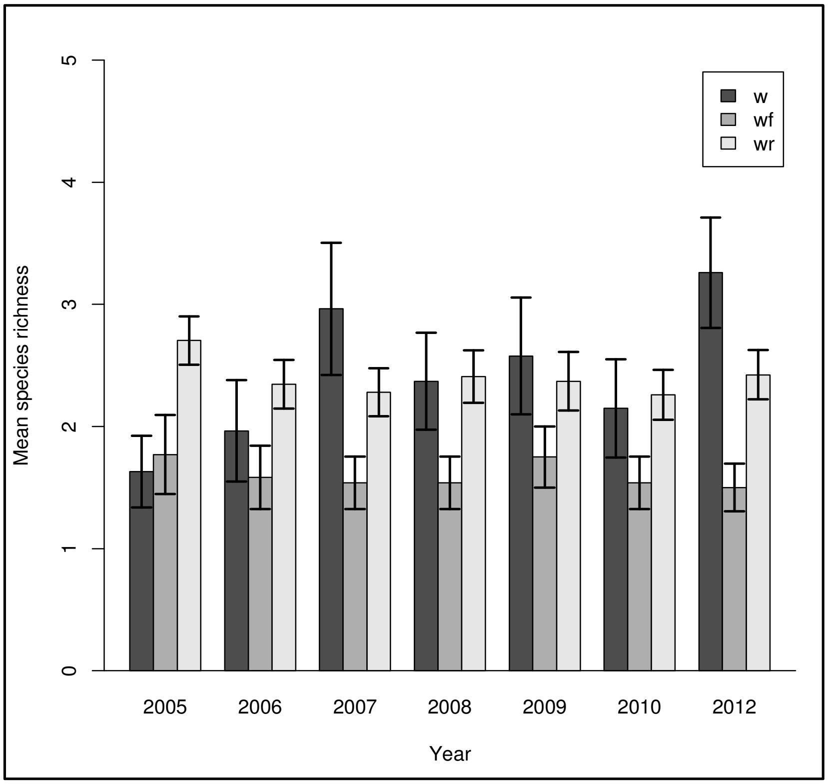


Figure 56: Mean plot species richness at WAL (w), WAL-R (wr) and WAL fringe marsh (wf) sites over time. 2005 is pre-restoration.

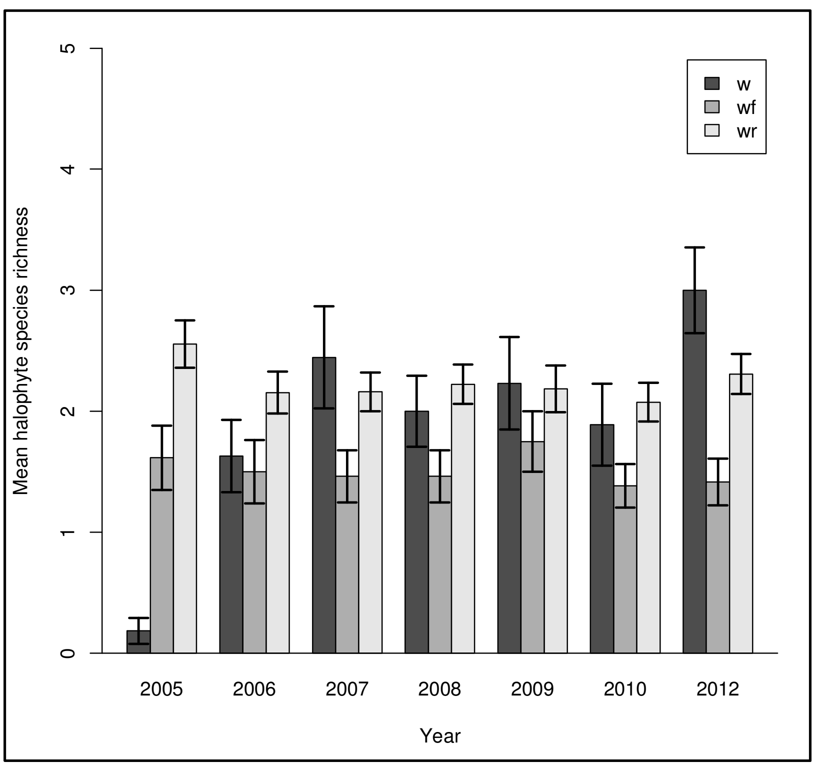


Figure 57: Mean plot halophytic species richness at WAL (w), WAL-R (wr) and WAL fringe marsh (wf) sites over time. 2005 is pre-restoration.

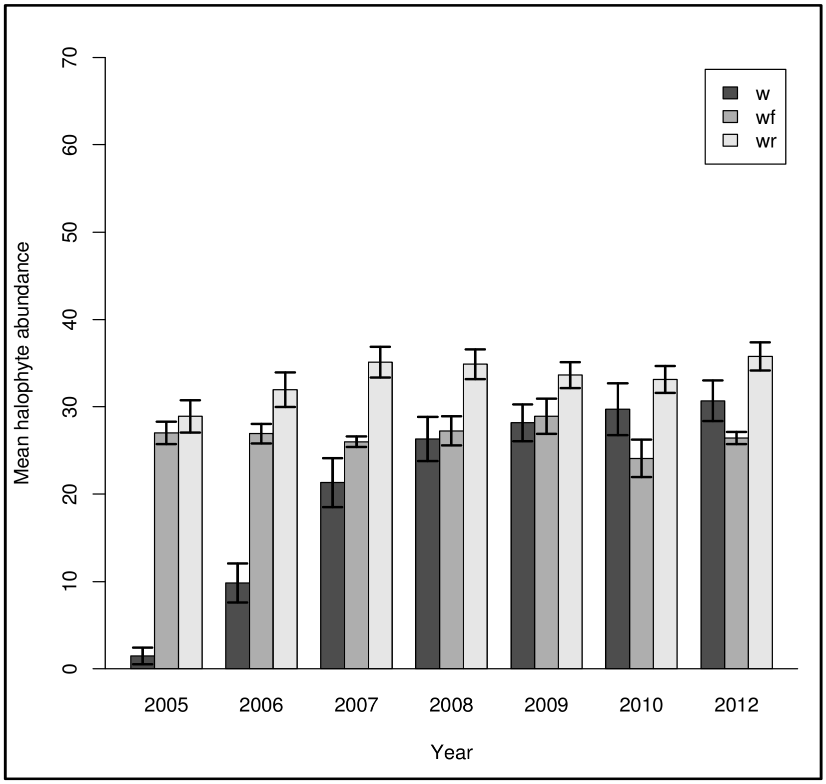


Figure 58: Mean plot halophytic species abundance at WAL (w), WAL-R (wr) and WAL fringe marsh (wf) sites over time. 2005 is pre-restoration.

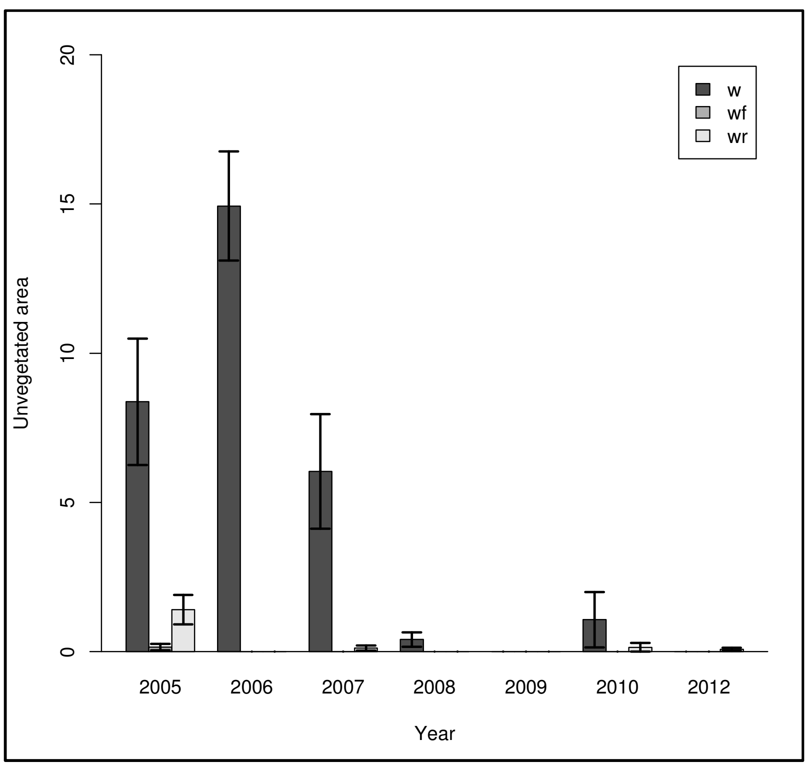


Figure 59: Mean plot unvegetated area at WAL (w), WAL-R (wr) and WAL fringe marsh (wf) sites over time. 2005 is pre-restoration.

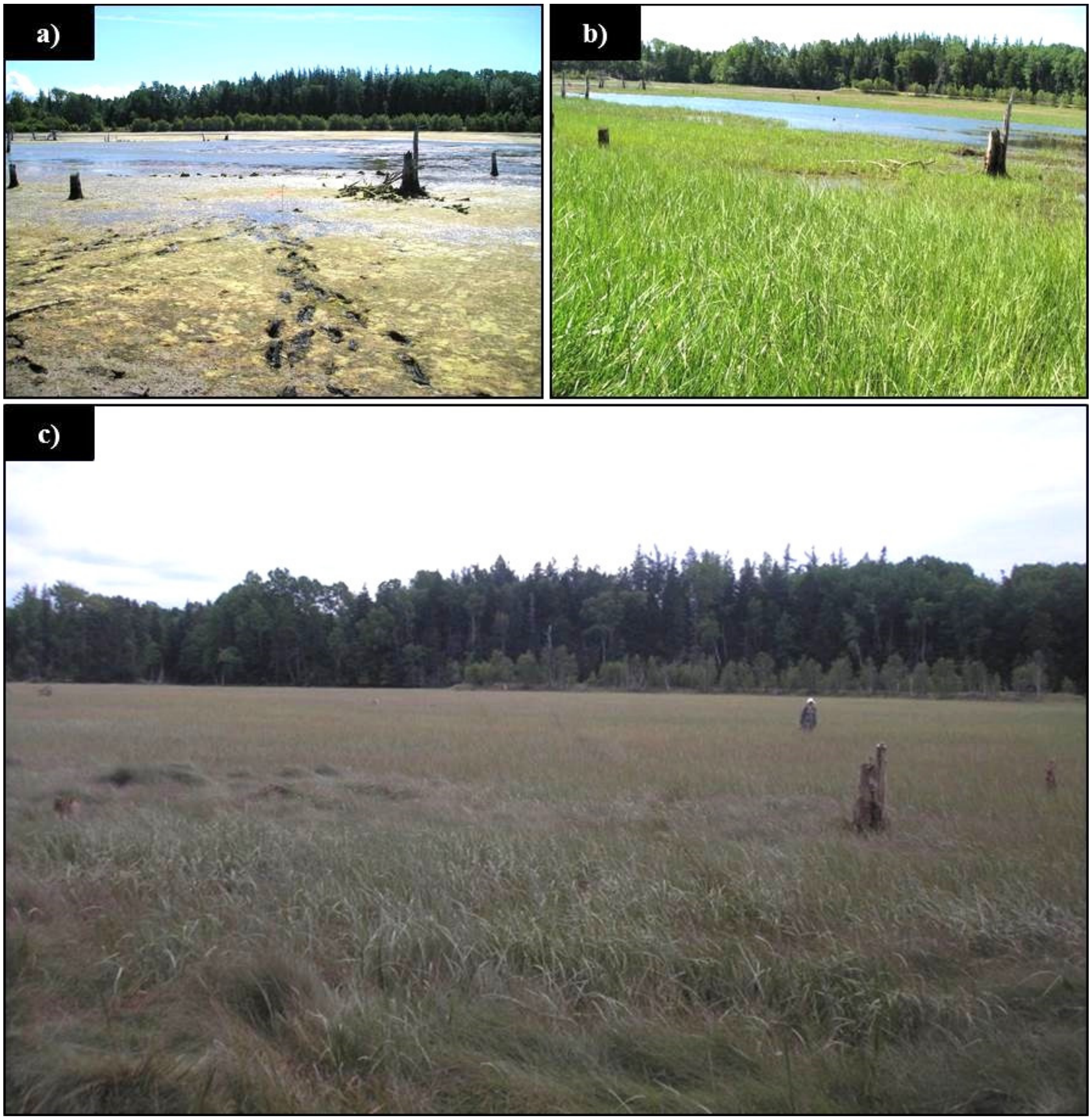


Figure 60: Vegetation survey (August) landscape photographs for Line 5 in a) 2005, b) 2006 and c) 2012 (the high marsh *S. patens* can be seen here at the bottom of the photo).

Figure 61: The dominant vegetation *S. alterniflora* at WAL.

Figure 62: WAL plot L4S4 that has changed from *S. alterniflora* dominated to panne habitat.

4.5 Nekton

Fish surveys were carried out on 19 September and 17 October 2012 at WAL and on 17 September and 17 October 2012 at WAL-R, using a combination of beach seine, minnow traps and fyke net (Figure 25). Individuals from sixteen species were observed and captured during the monitoring program (2005-2012) at WAL and WAL-R (Table 23). No new species were captured during the 2012 monitoring season at WAL, but Gaspereau (*Alosa pseudoharengus*) and juvenile rainbow smelt (*Osmerus mordax*) were captured for the first time at WAL-R. For pooled 2012 data (all methods), the mummichog (*Fundulus heteroclitus*) and Atlantic silverside (*Menidia menidia*) were the dominant species caught at WAL-R and the only two species caught at WAL (Table 23). At WAL the mummichog was 96.1% of the catch, while Atlantic silverside were 3.9% of the catch. At WAL-R these two species had a much different composition with the mummichog at 27% and Atlantic silverside at 67.1% of the catch (Table 23). The total catch for 2012 at WAL (77) was the lowest for all years and at WAL-R (614) it was one of the highest. The total catch at WAL-R was greater than at WAL for all three years post-restoration (Table 23).

When comparing the average relative abundance for each sampling method over the monitoring program, the minnow traps at WAL (24) and WAL-R (25) were fairly similar (Table 22). Both sites had the lowest relative abundance for the minnow traps in 2012. The average relative abundance for the seven years of monitoring for the beach seine (WAL 5x greater average) and fyke net (WAL-R 1.5x greater average) methods differed greatly between WAL and WAL-R (Table 22).

The standard length average for mummichog at WAL and WAL-R were similar for all years post-restoration (Table 24). For 2012 at WAL, no individuals from the small size class (1 – 39 mm) were present, and the majority of individuals were in the standard length range of 40 – 70 mm (Table 24). Atlantic silverside had the highest standard length average for the past three years post-restoration ranging from 50 - 75 mm at WAL and 40 - 75 mm at WAL-R. Mummichog have had similar numbers all years at both WAL and WAL-R.

The differences in relative abundance between WAL and WAL-R could be accounted for by a number of factors. Firstly, in 2005 and 2006 WAL was essentially a mudflat and catching fish was quite unproblematic as there was no vegetation to act as refuge and the net could slide along the surface of the mudflat allowing no escapees. In 2005, 500 mummichog were caught in the beach seine and 600 Atlantic silverside in 2006. The schooling behavior of Atlantic silverside was another factor, as it could result in very large numbers being captured, as was the case in 2006 and 2008 at WAL, in the beach seine and fyke net respectively, and 2012 in the fyke net at WAL-R. The other two factors were the environment and the survey method itself. The beach seine was very hard to use in vegetated areas, particularly where the vegetation, notably *S. alterniflora,* was tall. In addition, a spring tide was needed to use the beach seine; however, if the tide on the scheduled sampling day was significantly different (higher, lower) than predicted, the beach seine could not be used due to either insufficient water or safety reasons. A tide on one occasion was higher than predicted and produced velocities that exceeded the tolerance of the fyke net, which became displaced and did not properly fish.

Two species commonly found in salt marsh habitats are the mummichog and Atlantic silverside. The mummichog or salt water minnow is a resident of salt marshes and Atlantic silverside are known to swim into salt marshes at high tide searching for food, and both are prey for larger fish within the tidal rivers and salt marshes during high tide (Gibson 2003). Since mummichog are a resident of salt marshes, it was important to know if this species was using the restoration site for habitat, so minnow traps were set in the pannes at WAL and WAL-R. Layman and Smith (2001) found that this method of fish collection was beneficial when the objective was to collect a specific species. At WAL in Year 3 (2008), areas on the marsh surface developed to regularly hold water at low tide (pannes), connected by a series of secondary creeks to tidal waters, as shown in Figure 29. These pannes have become even more defined by Year 7 of the monitoring program. The mummichog was again the dominant species collected in 2012 in the pannes at both WAL and WAL-R. The standard length range for the mummichog and Atlantic silverside suggests that both sites are used for the entire life cycle of these species (Table 24).

In 2009 at WAL, American eel (*Anquilla rostrata*) and Tomcod (*Microgadus tomcod*) were captured during the fish survey in the minnow traps and fyke net respectively. Tomcod were again captured in 2012 at WAL-R in the fyke net. Rainbow smelt were caught at WAL in 2008 (beach seine) and juveniles of this species were captured at WAL-R (fyke net) in 2012. These survey methods are used to capture species using the pannes and marsh surface during a high tide. Therefore, the presence of these species shows that higher order predatory species are accessing the site during high tide. The standard length range of the Tomcod could suggest that the sites function as nursery habitat for this species (Table 24).

Table 22: Relative abundance for each sampling method at WAL and WAL-R for all post-restoration surveys. Sample size is the total number of samples over the seven years of sampling.

	WAL			WAL-R		
Year	**Minnow Trap**	**Seine**	**Fyke**	**Minnow Trap**	**Seine**	**Fyke**
2005	-	734.00	-	-	39.75	-
2006	34.83	150.63	-	26.42	52.71	-
2007	40.50	62.40	-	12.37	82.00	-
2008	15.75	49.00	174.50	33.62	22.67	65.00
2009	29.10	47.60	49.30	45.00	8.25	62.33
2010	12.75	2.20	34.00	27.25	5.80	55.00
2012	12.00	-	45.50	3.14	14.00	239.00
Total	**144.93**	**1045.83**	**303.30**	**147.80**	**225.18**	**421.33**
Average	**24.16**	**174.305**	**75.83**	**24.63**	**32.17**	**105.33**
	n=52	n=28	n=9	n=54	n=28	n=9

Table 23: Percent composition of total catch of fish species for WAL (W) and WAL-R (WR) immediately post-restoration (IP) and for the seven years of post-restoration sampling (2006 – 2012), all sampling methods (minnow trap, fyke and seine). *observed

		2005 (1P)		2006 (1)		2007 (2)		2008 (3)		2009 (4)		2010 (5)		2012 (7)	
Common Name	**Species Name**	**W**	**WR**	**W**	**WR**	**W**	**WR**	**W**	**WR**	**W**	**WR**	**W**	**WR**	**W**	**WR**
Atlantic silverside	*Menidia menidia*	14.6	19.0	51.7	42.4	12.3	4.9	58.0	12.4	37.5	9.7	15.5	7.8	3.9	67.1
Mummichog	*Fundulus heteroclitus*	68.1	79.0	45.4	54.4	86.6	93.0	41.2	83.5	59.7	85.0	82.3	90.0	96.1	27.0
Nine Spine stickleback	*Pungitius pungitius*	-	1.0	-	0.7	0.6	1.0	0.2	1.5	-	1.4	1.6	1.4	-	0.7
Three Spine stickleback	*Gasterosteus aculeatus*	-	-	0.4	0.2	0.3	-	-	2.4	1.6	1.3	-	-	-	-
Four Spine stickleback	*Apeltes quadracus*	-	-	-	-	-	-	0.2	-	-	1.9	-	-	-	-
Banded killifish	*Fundulus diaphanous*	16.3	1.0	0.1	-	-	-	0.2	-	-	-	-	-	-	-
Tomcod	*Microgadus tomcod*	-	-	-	-	-	-		-	0.9	0.7	-	-	-	0.3
Alewife (Gaspereau)	*Alosa pseudoharengus*	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2
Rainbow smelt	*Osmerus mordax*	-	-	-	-	-	-	0.2	-	-	-	-	-	-	3.1
Eel	*Anquilla rostrata*	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-
Glass eel	*Anquilla rostrata*	-	-	2.2	-	0.2	-	-	-		-	-	-	-	-
Green crab	*Carcinus maenas*	-	-	-	0.2	-	-	-	-	-	-	0.6	0.8	-	1.6
Mud shrimp	*Crangon septemspinosa*	-	-	0.2	2.1	-	1.1	-	0.2	-	-	-	-	-	-
WS Unknown A 05		1.0	-	-	-	-	-	-	-	-	-	-	-	-	-
Striped bass*	*Morone saxatilis*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TOTAL	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
	TOTAL CATCH	**734**	**159**	**1623**	**686**	**636**	**345**	**671**	**467**	**677**	**715**	**181**	**357**	**77**	**614**

Table 24: Standard length average (rounded to nearest 5 mm) and range for the most common fish species caught at WAL and WAL-R post-restoration (2006 - 2012) using the measurements of the first 15 individuals for each species caught using all survey methods.

		SL Average (mm)		SL Range (mm)	
Date	**Species**	**WAL**	**WAL-R**	**WAL**	**WAL-R**
2006	Mummichog	50	40	20 to 85	10 to 90
	Atlantic silversides	50	40	10 to 90	20 to 80
	Nine-spine stickleback	0	35	0	30 to 40
	Three-spine stickleback	30	30	10 to 50	30
2007	Mummichog	50	40	10 to 90	20 to 90
	Atlantic Silversides	60	20	35 to 85	20 to 30
	Nine-spine stickleback	40	40	30 to 45	40 to 45
	Three-spine stickleback	45	0	45 to 50	0
2008	Mummichog	55	50	30 to 90	10 to 100
	Atlantic Silversides	65	70	30 to 90	40 to 90
	Three-spine stickleback	0	35	0	35 to 40
2009	Mummichog	50	50	10 to 90	30 to 80
	Atlantic Silversides	65	70	50 to 90	30 to 120
	Nine-spine stickleback	0	35	0	15 to 50
	Four-spine stickleback	0	45	0	40 to 50
	Three-spine stickleback	50	25	25 to 70	15 to 40
	Tomcod	110	105	90 to 130	100 to 110
2010	Mummichog	45	55	25 to 90	30 to 90
	Atlantic Silversides	75	75	60 to 85	50 to 120
	Nine-spine stickleback	30	45	15 to 45	40 to 50
2012	Mummichog	60	60	40 to 70	25 to 90
	Atlantic Silversides	60	90	40 to 80	60 to 110
	Nine-spine stickleback	0	40	0	35 to 50
	Tomcod	0	145	0	140 to 150

4.6 Aquatic Invertebrates

For the pre-restoration data collection, IATs were only used for sampling at WAL-R. There was no similar habitat at WAL for IAT sampling to occur. In Year 1 post-restoration, panne development had still not occurred at WAL to allow for IAT sampling, therefore, no data was collected at either site. For Year 7, samples from two pannes each month (July and August) were pooled for WAL and WAL-R.

In 2012, 22 different species were collected with IATs at WAL and WAL-R, which were a mix of estuarine and freshwater animals. Seven years post-restoration the WAL and WAL-R samples were dominated by freshwater insects (water boatmen, family, Corixidae), and by the estuarine amphipod, *Gammarus mucronatus*. *Hydrobia totteni* and Copepods were also present in the samples (Figure 63 and Figure 64).

At WAL, the highest abundance was Year 2 post restoration, whereas the number of species per sample was highest in Years 4 and 5 post-restoration (Figure 65 and Figure 66). At WAL-R, both the abundance and number of species per sample were highest in Year 7 (Figure 65 and Figure 66).

Over the seven-year monitoring program, WAL had greater species richness (8) than WAL-R (7) in the IAT samples. This could be contributed to the changes that have occurred in the panne development at WAL over the monitoring period and the difference in panne habitat between WAL and WAL-R. Corixidae sp., *Gammerus mucronatus* and species from the sub-class Copepoda were the individuals that had been present most often at WAL. AT WAL-R, Corixidae sp. have had the greatest number of individuals during the monitoring program. However, there was no significant difference post-restoration between sites ($F = 0.346$; $p = 0.5636$), nor over time ($F = 1.401$; $p = 0.2614$) when ANOVA was completed.

Over the seven-year monitoring program, WAL had a larger number of *Gammarus mucronatus* each year compared to WAL-R, while WAL-R had a larger number of Corixidae sp. *Gammerus mucronatus* is expected to be found in a salt marsh environment, feeding on dead plants and animals, diatoms and other algae, as well as filtering detritus and small organisms from water (Gibson 2003). They are in turn preyed upon by larger animals such as crabs, fish, shorebirds and ducks (Gibson 2003). Corixidae sp. can tolerate a wide range of salinity from pure seawater to mildly brackish, so it was expected that these insects would be found in the salt marsh pannes.

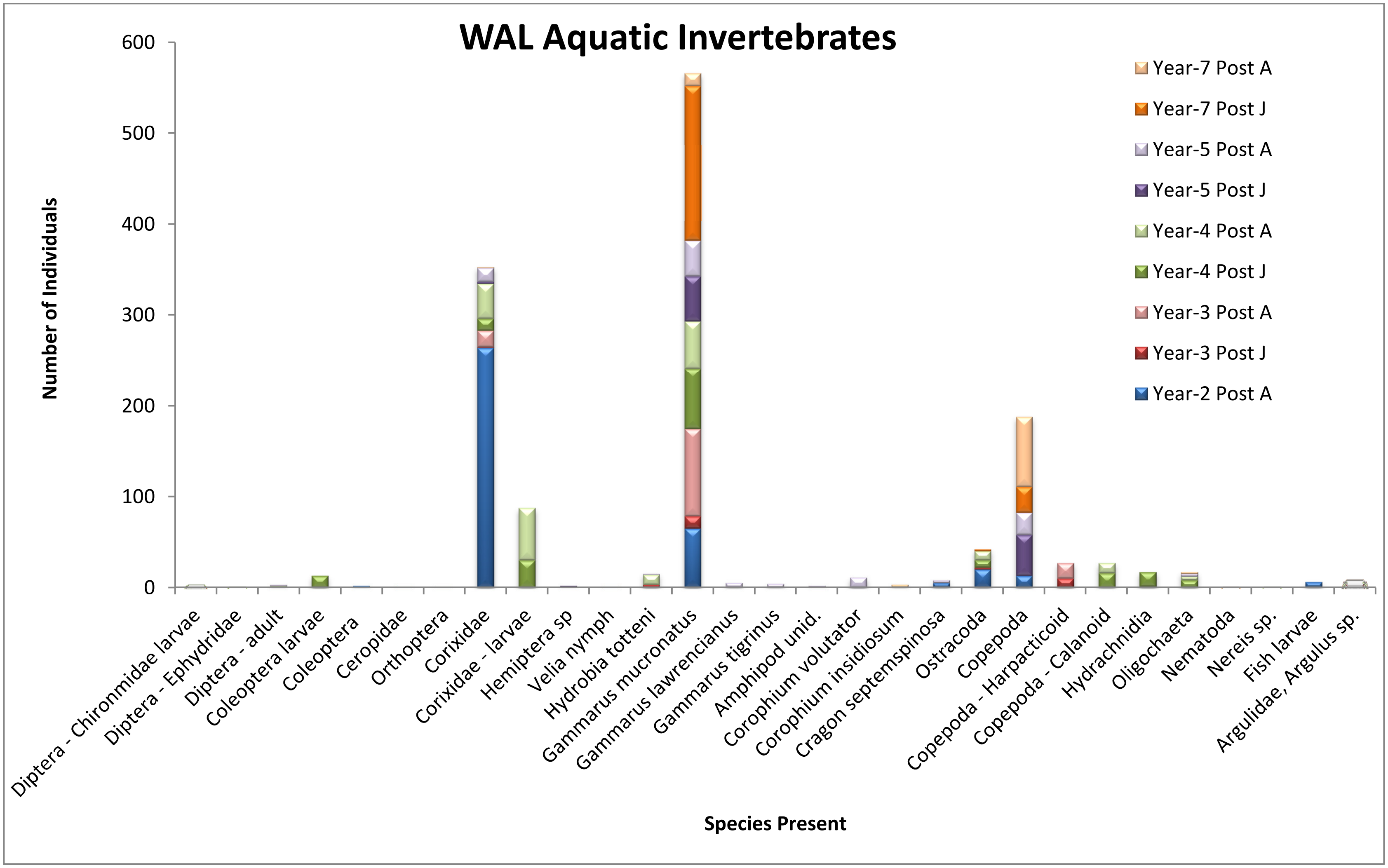


Figure 63: Number of individuals and species type collected in the IATs set at WAL from 2007 (Year 2 post-restoration) to 2012 (Year 7 post-restoration).

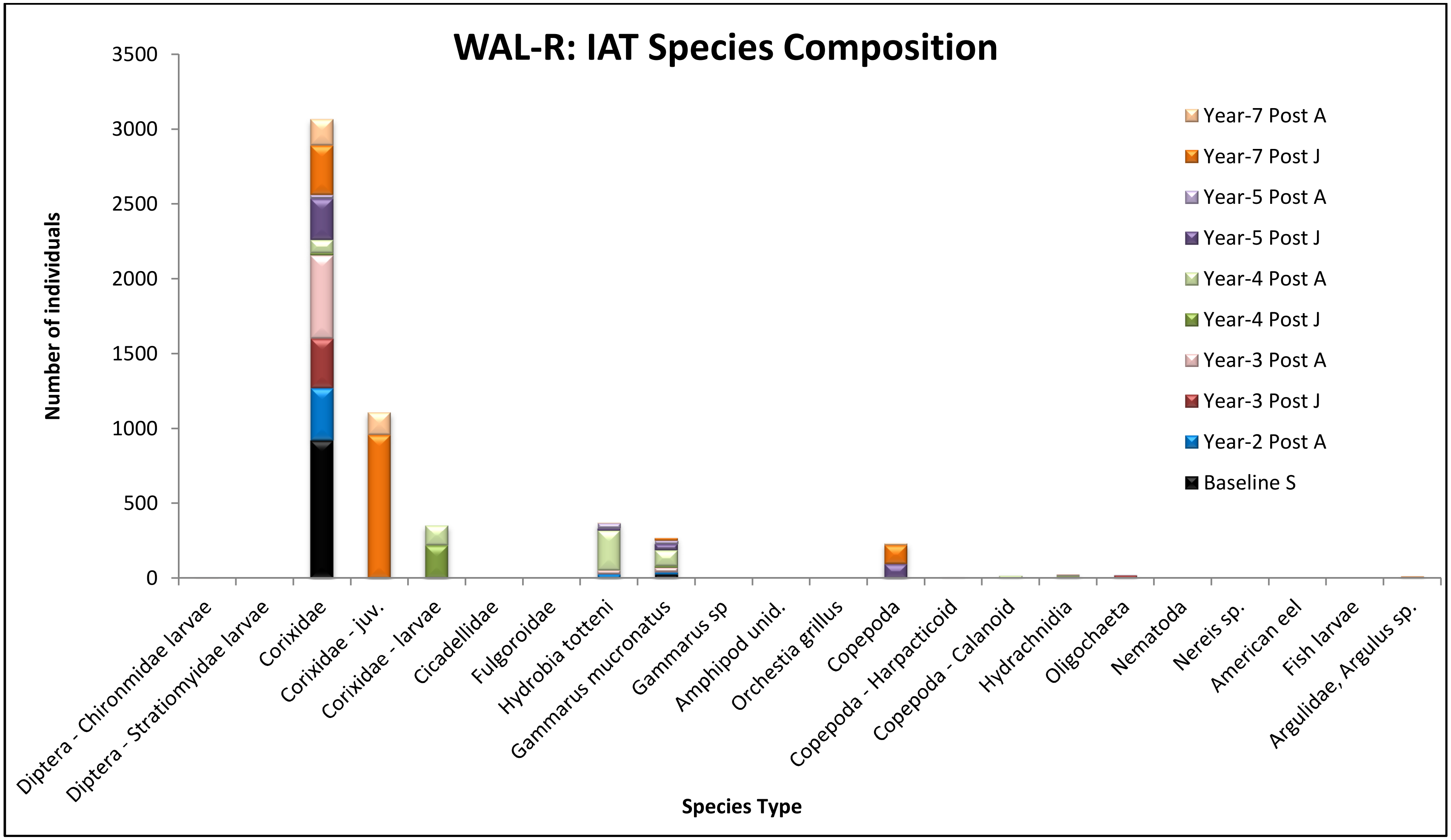


Figure 64: Number of individuals and species type collected in the IATs set at WAL-R from 2007 (Year 2 post-restoration) to 2012 (Year 7 post-restoration).

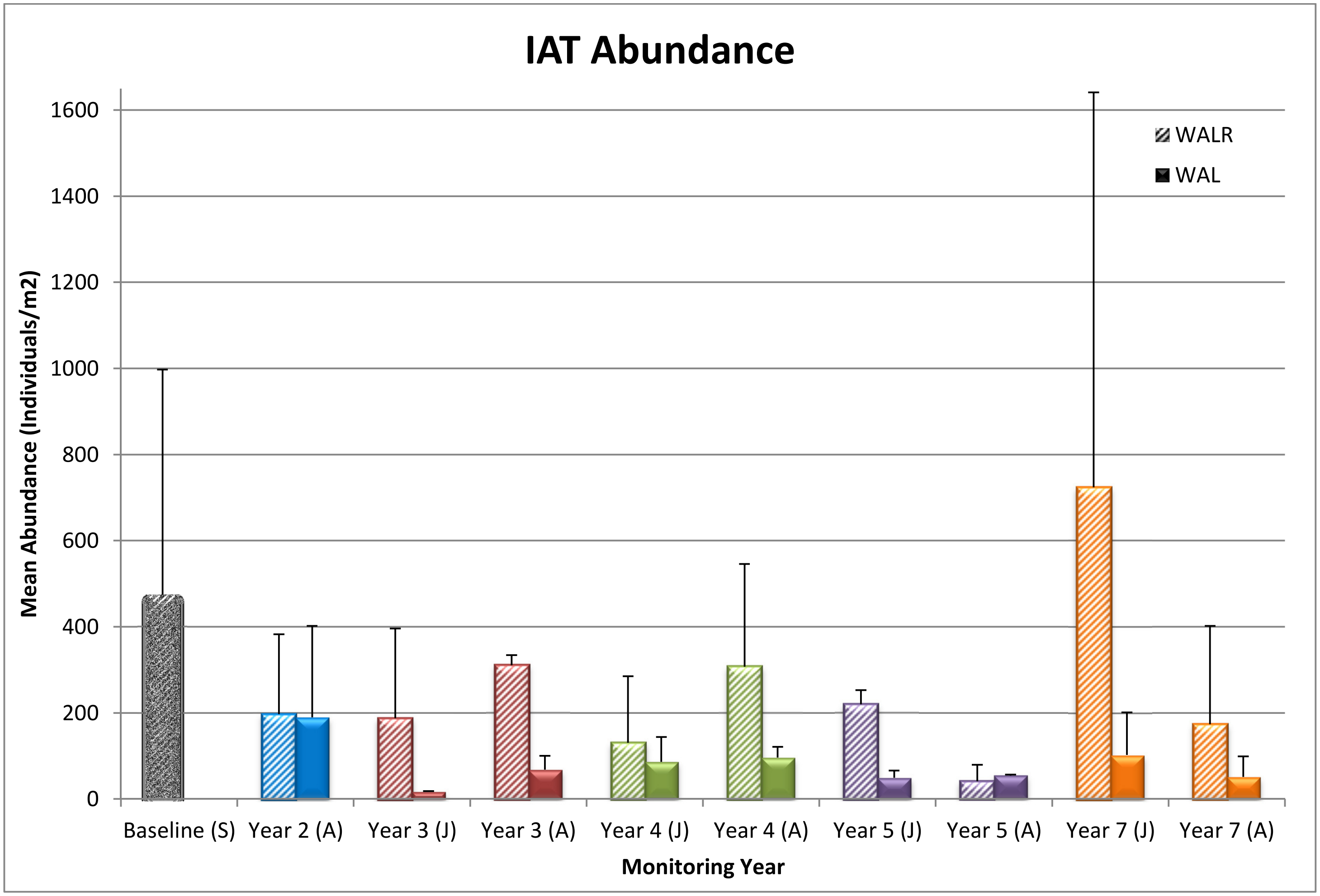


Figure 65: Species abundance for the IATs set at WAL-R and WAL for all years.

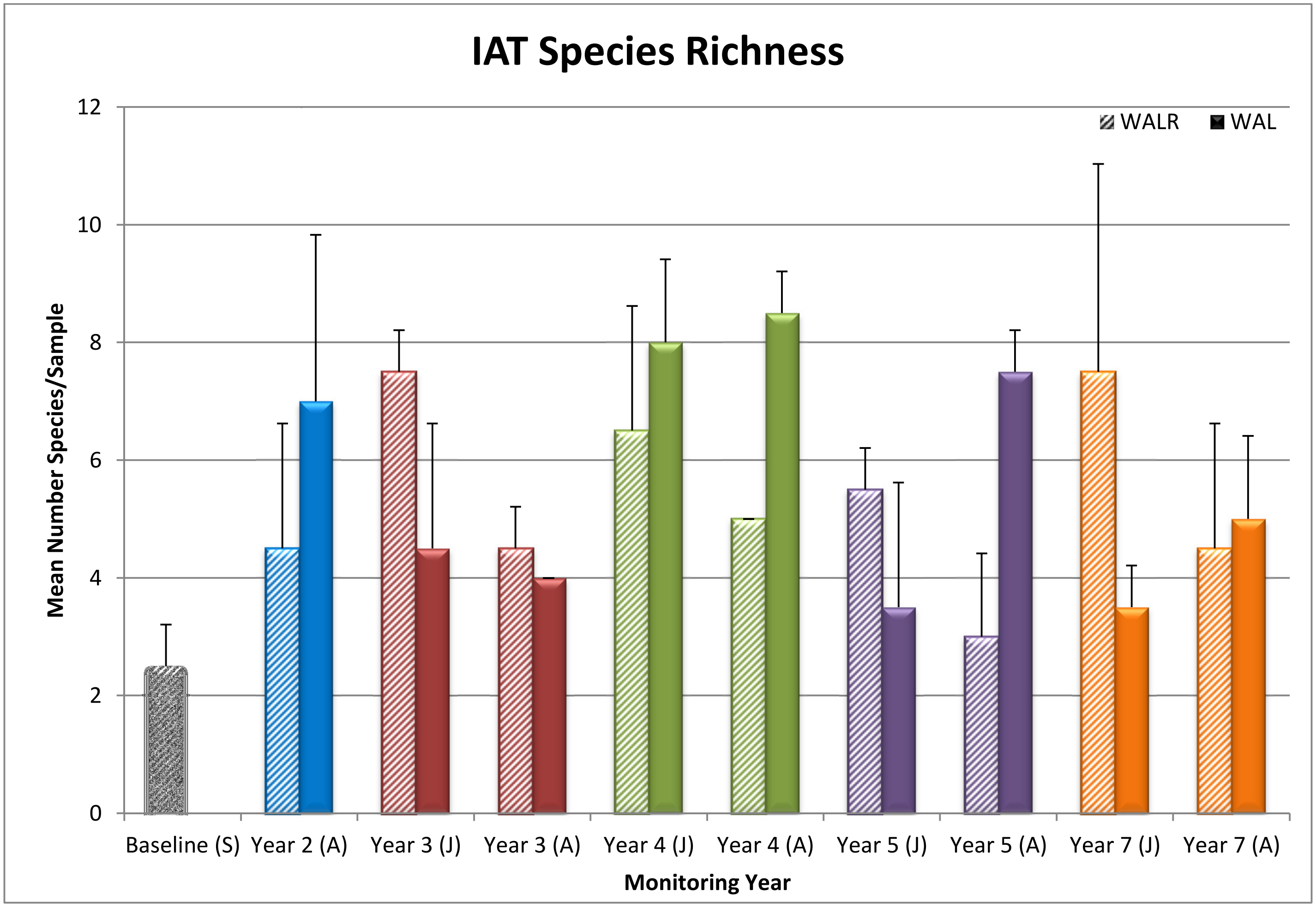


Figure 66: Species richness for the IATs set at WAL-R and WAL for all years.

4.7 Structured Winter Site Walk

There was a mix of heavy rain and heavy snow, with the rise and fall of temperatures during the winter of 2013. The beginning of March was another period of milder temperatures and rain; therefore, much of the snow and ice that had developed earlier in the winter has melted. However, WAL still had ice blocks remaining on the marsh surface (Figure 67a; Figure 67d) and material deposited on-site from melted ice blocks (Figure 67b). The main channel at WAL was not ice covered and it appeared that no additional erosion had occurred in this area (Figure 67c). At WAL-R there were also ice blocks on the marsh surface but the majority were clustered towards the western edge of the site (Figure 68). Appendix B has a selection of photographs from the 2013 winter walk.

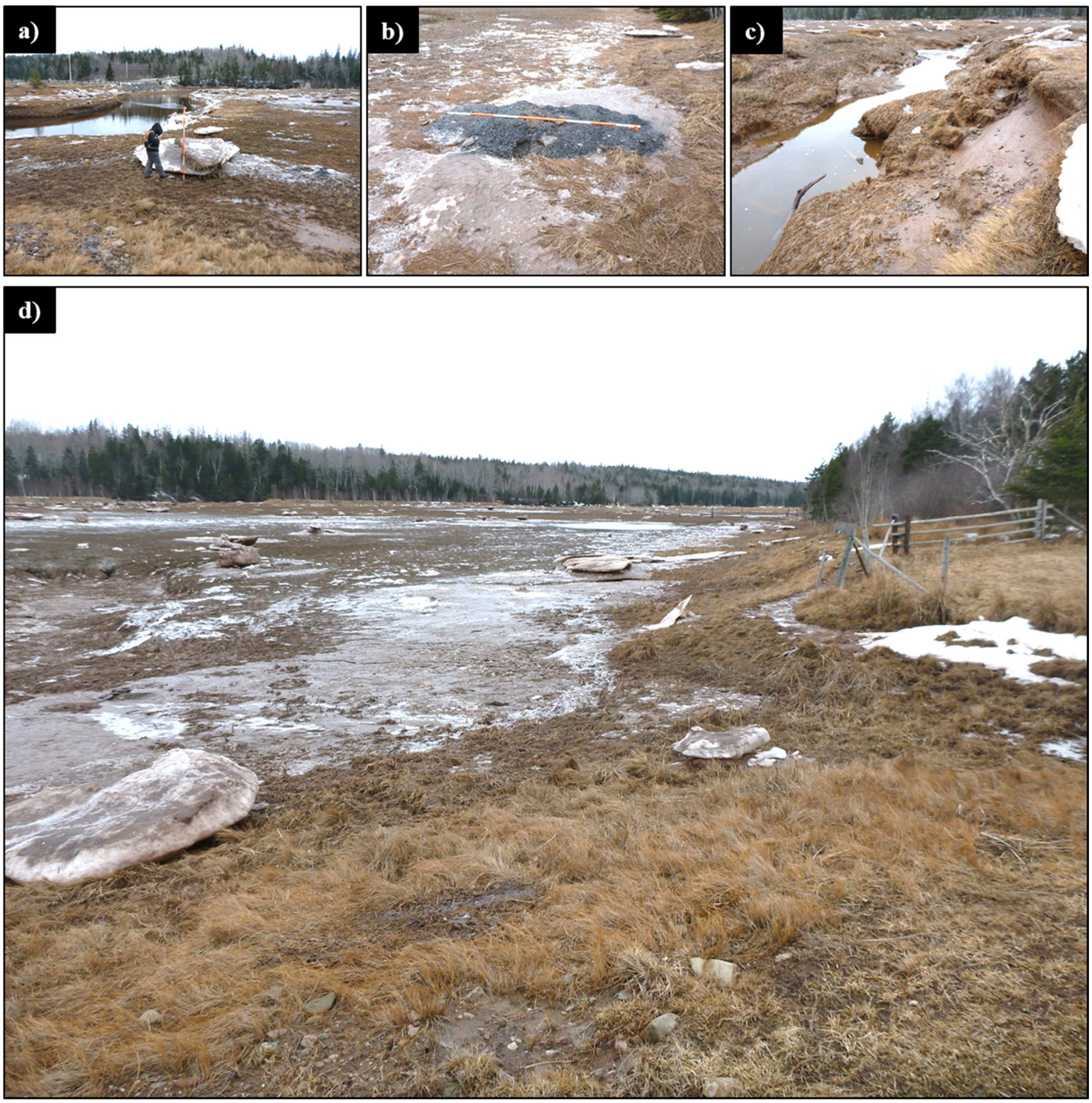


Figure 67: Winter site visit at WAL a) ice blocks; b) material deposit from melted ice blocks; c) main channel; and d) landscape towards downstream.

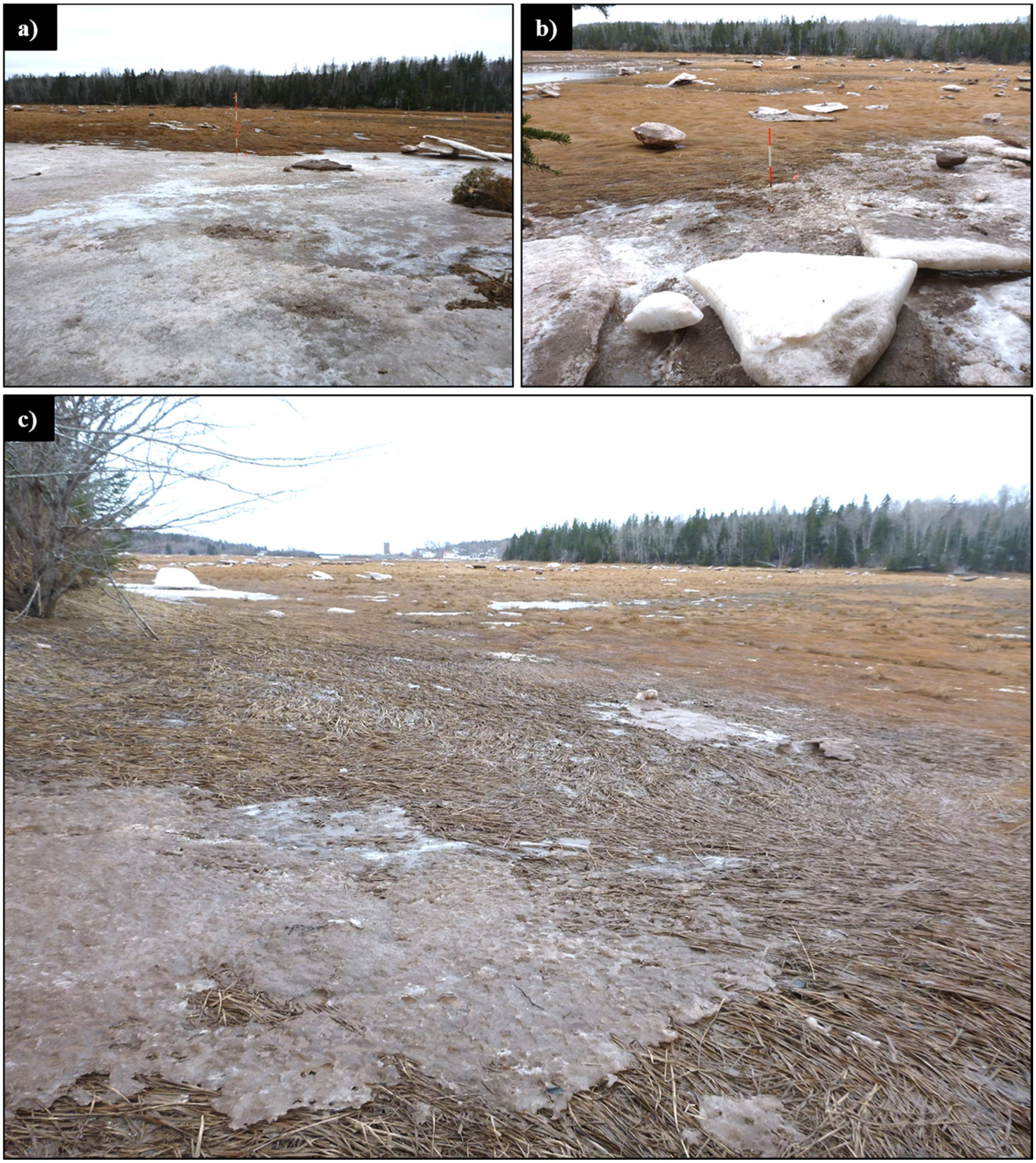


Figure 68: Winter site walk at WAL-R a) Line 1; b) Line 2; and c) landscape facing downstream.

5.0 Walton River Year 7 Project Summary

The seventh year of post-restoration monitoring has again shown that changes are still occurring at WAL although these changes have been subtle. Changes continue to be observed in the habitat structure (primary and secondary channel development, sediment and elevation) and the biological community structure (continued re-colonization by halophytic vegetation). No comparable changes have occurred at the reference marsh.

One of the major influences on the changes at WAL has been the formation of the main channel at the second breach/gap (Figure 39; *Section 4.2*). The formation of this main channel has connected the channel network (borrow pit, relict channel, drainage ditches) within the restoration site directly to the Walton River. This has resulted in the site experiencing tidal flooding across a wider range of tidal conditions, allowing for greater access to the site for fish and improved habitat quality of pannes within the site. There has been some slumping still occurring at the main channel and the channel bottom has been flattening and widening (Figure 40). According to van Proosdij et al. (2010), channel flow speeds recorded were greater than 0.5 $m \cdot s^{-1}$ in the main channel with no reported sediment plumes, which would indicate no bed erosion. Therefore, it is expected that any further erosion of the main channel would occur via slumping.

Portions of the original borrow pit have been infilling/channelizing, accelerated in part by the increased colonization of the banks and shallows by *S. alterniflora* (Figure 35; *Section 4.2*). This creates fish habitat on the lower high tides (5.18 m CGVD28) similar to the low marsh at WAL-R (Figure 34), whereas prior to restoration a tide level of 6.3 m was required to top the fringe marsh. On a spring tide (2012 maximum recorded 7.85 m: CGVD28) WAL is flooded, allowing fish to enter the site and use the marsh surface. During the monitoring program mummichog and Atlantic silverside have dominated the catch at WAL, but American eel, tomcod and rainbow smelt have also been captured at this site. The majority of mummichog were captured in the pannes during nekton sampling and a range of bird species (ducks, herons, egrets, kingfishers, geese, various shore birds) have been observed feeding in them. The long term stability of these features cannot be predicted, but indications over the course of the seven year monitoring program would seem to indicate that they are likely to persist on the landscape for an extend period of time.

The tides have also brought suspended sediment into WAL, which has promoted change within the site. Figure 27 (*Section 4.1*) shows the 2012 DEM for WAL and WAL-R. The mean elevation for WAL (2012) was 5.66 m (CGVD28) with a range of 3.36 m to 9.52 m and a standard deviation of 0.87 m. The mean elevation for WAL-R was 5.89 m (CGVD28) with a range of 3.53 m to 10.18 m and a standard deviation of 0.93 m (Table 2; *Section 4.1*). At WAL-R, the elevation means and ranges have remained stable over the seven years of the monitoring program and the elevation at this site has remained higher than WAL for all years. The mean elevation at WAL has shown a decrease each year new data has been collected and the range has increased. This change mostly reflects an increased ability to survey the borrow pit and other hydraulic features that were inaccessible in the first few years of monitoring; however, WAL and WAL-R both reported increases in RSET measurements in 2011. In 2012, the accretion rates at WAL decreased to 2010 levels and WAL-R increased slightly indicative of ice or a storm. The individual marker horizons at WAL, over the five years of sampling, showed accretion ranging from 2.96 cm to 4.78 cm. There has been no significant difference between the sites by 2010 and the rates of accretion at WAL continue to behave similar to WAL-R at seven years post-restoration.

Sediment characteristics at WAL have also been progressing towards that of WAL-R during the monitoring program. The water content at WAL and WAL-R showed a similar state of consolidation with organic matter values generally higher at WAL-R compared to WAL, although more variable between years. The grain size of WAL and WAL-R seven years post-restoration was still in the classification of medium silts with a range at WAL of 9.67 to 12.17 µm and at WAL-R 8.6 to 12.90 µm. Grain size has an influence on bulk density with increasing grain size contributing to low bulk density values which is reflected at both WAL and WAL-R.

Similarly, sediment pore water salinity has also been changing over the monitoring program, becoming closer to conditions at WAL-R. For 2006 (year 1) WAL shallow readings, salinities were higher with nearly 70% of the readings having occurred in the 16-20 ppt class (as compared to 5% or less for WAL-R and other years). The 2009 (Year 4) distribution matched WAL-R conditions for moderate salinity values, but lacked readings within the low-end salinity values (0-8 ppt). For 2012 (Year 7), salinity values were moderately lower than previous years. In 2008 (Year 3), the mean salinity was higher at WAL, similar to each year prior, and then in 2009 and 2010, WAL-R had a higher mean salinity than WAL. This switch could be due to the change in WAL from a hypersaline environment to one closer to WAL-R with the colonization of vegetation on the site and the subsequent decrease in bare ground. Therefore, seven years post-restoration the sites are similar, but have site specific and sampling differences (*Section 4.3*). As discussed in previous reports, the initial hypersaline environment of WAL was identified as one of the potential reasons for the amount of *S. alterniflora* found at this site (Neatt et al. 2011).

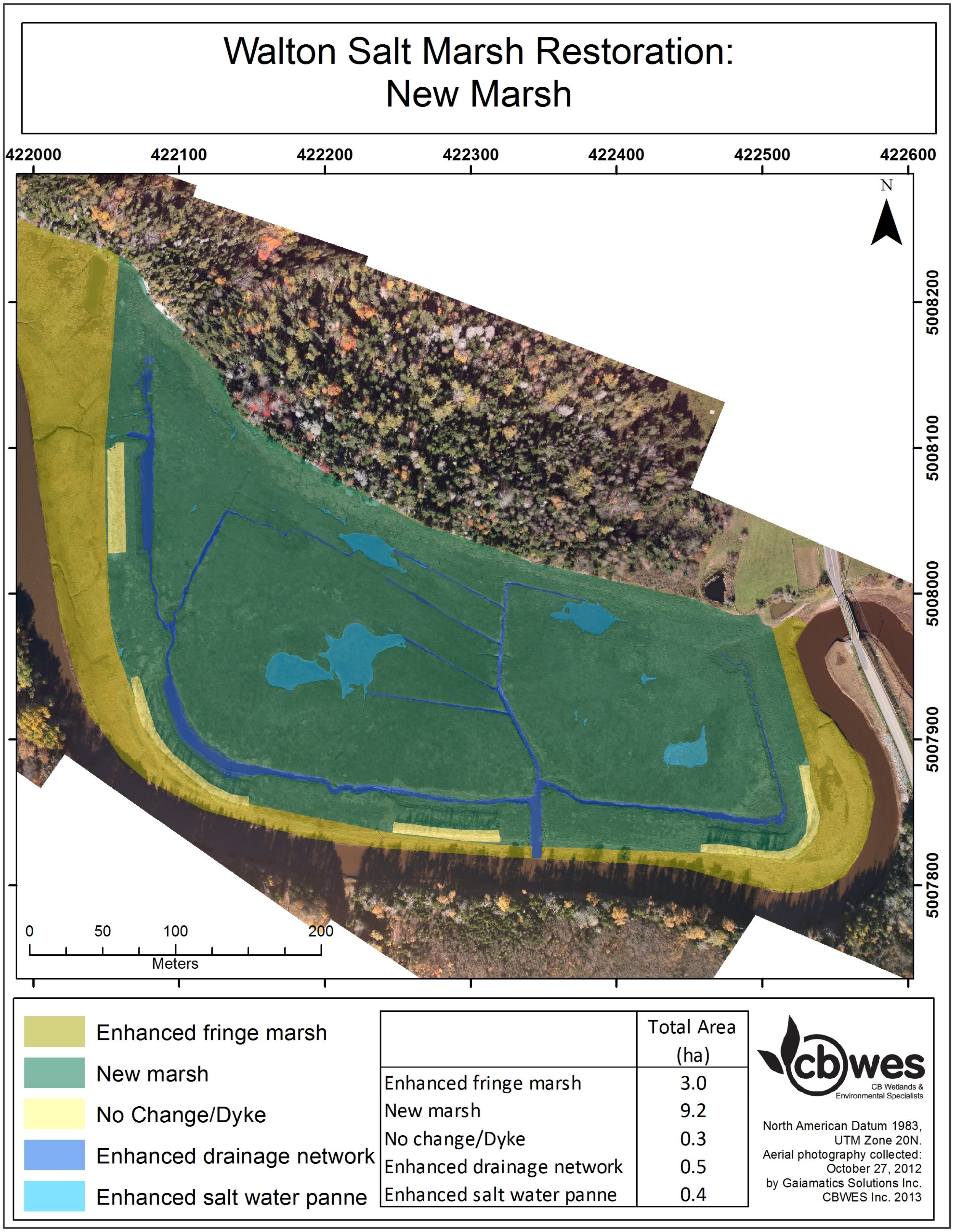
Pre-restoration WAL was dominated by freshwater submerged aquatic vegetation and upland/freshwater wetland species, changing to more than 20 plots (out of 27) colonized by *S. alterniflora* in great abundance by 2006 (Year 1). Whereas WAL-R was typical low and high salt marsh habitat. Most of the plots at WAL remained dominated by *S. alterniflora*, but several other species colonized in relatively low numbers and a few plots transitioned to *S. patens*. WAL still differs from WAL-R in overall community composition due to a greater number of plots at WAL-R with high marsh species and WAL with greater abundance of *S. alterniflora*. The relative abundance of high versus low marsh may differ between sites due to inherent differences such as elevation (WAL-R more stable and higher in elevation than WAL: *Section 4.1*). Halophytes started colonizing the site in 2006 (*Carex paleacea*, *Scirpus maritimus*, *S. patens, Salicornea europaea*, and *Suaeda maritima*) and have been slowly increasing in frequency and abundance during the monitoring program. Most likely as sediment pore water salinity, sediment characteristics and elevation changes have also been occurring.

In conclusion, the restoration site continues to change, although more subtly, from pre-restoration and immediate post-restoration conditions. With these changes in conditions at WAL, the site has progressed to one more similar to WAL-R, in certain indicators, over the time of the monitoring program. The quick and positive response to restoration at WAL was most likely due to the local source of colonists (*S. alterniflora*) present, high rates of sediment accretion in certain areas and the presence of a relict creek and drainage network. At seven years post-restoration sediment accretion is behaving similarly to WAL-R, as well as sediment characteristics, pore-water salinity distributions, and both sites have panne habitat for fish and invertebrates, while recording the same dominant species during nekton surveys. Where the two sites differ substantially is the dominant vegetation and a lack of zonation at WAL. *S. alterniflora* remains the dominant vegetation species at WAL, although *S. patens* have been increasing in frequency and abundance during the monitoring program. With the increasing similarities in sediment characteristics and pore water salinity, conditions at WAL could be progressing towards one more favourable for the high marsh species. It is difficult to predict how long it may take the system to establish itself as a mature salt marsh. Changes (positive or negative) could still occur in abiotic (soil) conditions; decline in vegetation abundance and/or abundance; or the development of a second channel within one of the breaches. Any of these scenarios could alter the hydrology, morphology and function of the site. However, it can be stated at this point that original project objectives have been meet and that the restoration activities have allowed a self-sustaining salt marsh system to develop at WAL, with positive changes still occurring seven years post-restoration.

5.1 Restored Area at Walton

Given the placement of WAL within the Walton River and the successful re-introduction of tidal waters to the site, the entire site is considered restored. A mean high tide of 6.37 m (CGVD28) covers the majority of the site (8.72 ha), with the higher high tides covering the upland areas (Figure 34: *Section 4.2*). None of these areas were tidally influenced prior to restoration activities; therefore, the restored area at WAL is considered to be 9.72 ha, the amount of area inside the remaining dyke structure (Figure 69).

While it is difficult to predict how successful this restoration will be in the long term, it is clear that the major objectives (reduce the tidal restriction caused by the dyke; 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 WAL and WAL-R, the restoration activities undertaken at WAL in 2005 have resulted in the restoration of a self-sustaining and resilient salt marsh and tidal wetland system.



	Total Area (ha)
Enhanced fringe marsh	3.0
New marsh	9.2
No change/Dyke	0.3
Enhanced drainage network	0.5
Enhanced salt water panne	0.4

Figure 69: Restored area (new marsh) at WAL.

6.0 Recommendations for Future Restoration Monitoring Activities

The monitoring program developed for the Walton River 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 Bay of Fundy macro-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 original length of the program was modified from a five consecutive year program to a seven year. A reduced monitoring program was still completed during the sixth year post-restoration (2009).

Annual monitoring during the first three years following restoration is critical because it is during these initial years that the greatest and most rapid change 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; Bowron et al. 2013a). .

The results of the seven 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, and that aside from the initially rapid erosion of the central tidal channel during the winter of 2006 immediately following restoration, no additional issues of concern emerged during the monitoring period. That the objectives for the project have been met and that the WAL site has begun the natural successional process of returned to a self-sustaining and resilient mature salt marsh system.

Additionally:

- The long term monitoring program associated with the WAL restoration project represents one of the most comprehensive salt marsh restoration monitoring programs for a dyke breach project. The resulting data set has provided new insights into the form and function of tidal wetland systems in NS and their response to restoration efforts. With this knowledge and experience comes the greater ability to design, construct, monitor and manage future restoration projects. One of the important lessons learned from this project 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; halophyte establishment; and channel network development/bank colonization) 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 (Cheverie, 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, Ben Lemieux, Danika van Proosdij, Tony Bowron, Nancy Neatt, Jennie Graham
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.

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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
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.

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Appendix B - Structured Winter Site Walk: Walton River Restoration Site and Reference Site

STRUCTURED WALK PHOTOGRAPHS WAL (select images):

Figure 1: WAL Line 2.

Figure 2: WAL Line 5.

Figure 3: WAL main channel.

STRUCTURED WALK PHOTOGRAPHS WAL-R (select images):

Figure 4: WAL-R Line 2.

Figure 5: WAL-R Line 3.

Appendix C – Waterfowl Monitoring Report by Ducks Unlimited Canada

Ducks Unlimited Canada
Conserving Canada's Wetlands

2006-2010 Post Tidal Restriction Removal Monitoring of Waterfowl at the Walton Salt Marsh

Background

Walton was a freshwater marsh constructed by Ducks Unlimited Canada in 1989. Overtime this project began to degrade and saltwater intrusion was becoming a maintenance issue. In July of 2005 salinity measurement revealed an elevated salt content which was causing excessive algal blooms and decreasing oxygen levels in the water. Due to the age and degraded status of the impoundment, DUC chose to naturalize the site by removing the surrounding dyke, thereby allowing full tidal exchange thus returning the area to its natural state. Since 2005, three bird surveys have been completed annually during key waterfowl life stages. Once in May during the pairing and breeding season, in mid-June to early July during brood rearing and in early October during fall migration or staging. Numbers of birds using the salt marsh were recorded at dusk and dawn. DUC has now completed the 5 year post monitoring, which provides opportunity to compare the data.

Results

Since 2005, there have been 12 species of water birds, including five species of waterfowl, observed at Walton during seasonal monitoring (see Table 1). Of these, the most prevalent was the American black duck, both prior to the project restoration and after completion. No broods were observed prior to the restoration and only one brood of black ducks was observed after restoration (2009). Additionally, 4 shorebird species were observed during monitoring.

Table 1 **–** Total birds counted during seasonal monitoring at Walton Marsh

Year	*Date*	*ABDU*	*CAGO*	*MALL*	*AGWT*	*NOPI*	*GBHE*	*GRYE*	*PEEPS†*	*SEPL*	*SESA*	*SPSA*	*BEKI*	*DCCO*
2005	July	24	9	0	0	0	0	0	0	0	0	0	5	0
	August	140	0	0	0	0	40	50	50	0	0	0	35	0
	September	15	0	0	0	0	22	2	15	0	0	1	6	16
	October	26	0	0	0	0	1	0	0	0	0	0	0	0
2006	May	2	0	0	0	0	0	0	0	0	0	0	0	0
	August	2	0	0	0	0	0	14	0	2	44	1	1	1
	October	8	0	0	0	0	0	0	0	0	0	0	0	3
2007	May	6	0	0	0	0	0	2	0	0	0	0	0	0
	July	1	0	0	0	0	2	2	0	0	0	4	0	0
	October	0	0	0	0	0	0	0	0	0	0	0	0	0
	November	5	0	0	0	12	0	0	0	0	0	0	0	0
2008	May	2	0	0	0	0	1	0	0	0	0	0	0	0
	June	1	0	0	0	0	1	0	0	0	0	0	0	0
	October	22	0	0	0	0	1	0	0	0	0	0	0	0
2009	May	3	0	0	0	0	0	0	0	0	0	0	0	0

	July	4	0	0	0	0	0	0	0	0	0	0	0	0
	October	12	0	0	2	0	1	0	0	0	0	0	0	0
2010	April *	0	0	0	0	0	0	0	0	0	0	0	0	0
	August *	0	0	0	0	0	0	0	0	0	0	0	0	0
	Totals	***275***	***9***	***1***	***2***	***12***	***69***	***70***	***65***	***2***	***44***	***6***	***47***	***20***

Each monitoring period (month) listed above includes both a dawn and dusk survey. Please see Table 2 for 4-letter species codes.

*Both of these monitoring periods only include 1 afternoon survey.

Discussion

Since these monitoring results only capture a small snapshot of time during each field season it is difficult to conduct meaningful statistical analyses. Thus the discussion must be based directly on the data collected as listed in Table 1.

Direct observations (Figure 1 and 2) suggest that Walton has successfully been reverted back to its historical salt marsh state. This is most evident by the re-establishment of salt marsh vegetation (*Spartina sp.*). When reviewing the data collected during this time there have been a few observations of interest. In 2005, there was an obvious spike in numbers for many bird species which is likely related to the lowered water levels and higher food availability. August 2006 was the last time larger numbers of the shorebirds were observed using the marsh which may be a result of the exposed mud and food availability. Additionally, surveys in subsequent years were mainly conducted outside the month of August when peak shorebird numbers would be expected. As well, visibility of the marsh has decreased since salt marsh vegetation has reestablished. Over the last couple of years a larger diversity of ducks has been observed as well as the marshes' use for brood rearing (ABDU brood in 2009).

Figure 1 – Walton May 14th, 2006 low tide.

Figure 2 – Walton August 2010, high tide

Table 2 - 4-letter codes for bird species

ABDU – American black duck
CAGO – Canada goose
GBHE – great blue heron
GRYE – greater yellowlegs
BEKI – belted kingfisher
DCCO – double crested cormorant
NOPI – northern pintail
AGWT – American green-winged teal
MALL – mallard
SESA – semi-palmated sandpiper
SEPL – semi-palmated plover
SPSA – spotted sandpiper
PEEPS – small shorebirds including semi-palmated sandpipers, semi-palmated plovers, least sandpiper, etc.