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

Post-Restoration Monitoring (Year 7) of the Cheverie Creek Salt Marsh Restoration Project

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Executive Summary

The monitoring of a range of physical and biological components of the Cheverie Creek Tidal River and Salt Marsh system has been underway since the summer of 2002. In December of 2005 the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR) replaced the existing culvert with a more appropriately sized and placed structure in order to restore a more natural hydrological regime to the system. The primary goals of Cheverie Creek Salt Marsh Restoration Project site were to:

- Significantly reduce the tidal restriction caused by causeway-culvert highway crossing;
- Improve hydrological conditions upstream of the causeway;
- Increase the extent and distribution of halophytic vegetation (tidal wetland area); and
- Improve fish passage to and within the wetland habitat upstream of the causeway.

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

- Replacing the existing undersized culvert with a 9.2 m by 5.5 m elliptical, aluminum culvert to restore a more natural tidal regime to the system and to improve fish passage; and
- Conduct a pre- and post-restoration monitoring program to ensure project success.

CBWES Inc. was commissioned to develop and implement a pre- and post-restoration monitoring program. Following the third year (2008) of post-restoration monitoring it was decided that an additional year of monitoring (Year 7) would be added to the program. The seventh (final) 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 Cheverie Creek 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 was collected for geospatial attributes, hydrology, soils and sediments, vegetation, nekton (fish) and benthic invertebrates at both the salt marsh restoration site (Cheverie Creek: CHV) and a nearby reference site (Bass Creek: CHV-R). The information collected provided insight into the changes to the site as a result of the restoration activities, and contributed to our collective understanding of salt marsh ecology, and the effectiveness of restoration efforts in the region.

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

Geospatial Attributes

Updated digital elevation models (DEM) for CHV and CHV-R were produced using a combination of the 2007 LiDAR data and the 2012 on-site elevation survey. The habitat maps were updated using the 2012 elevation/habitat survey, vegetation survey, and low-altitude photography. The two areas that continued to display the most notable difference were around the main river channel and along the upland, or terrestrial edge, of the marsh. Total marsh area at CHV-R was 5.4 ha. Total restored marsh area at CHV, as illustrated by the expansion of key halophytic vegetation species throughout the site, was 43 ha. The CHV-R marsh surface exhibited the general trend of increased elevation from the creek edge to the upland, and from downstream to upstream. In contrast, CHV experienced an increase in elevation with distance from the creek edge that peaked in the mid-high marsh zone, decreased over much of the remainder of the marsh platform, and then increased into the upland. A similar elevation profile extending from the causeway to the upstream end of the system was also present. This elevation pattern is typical of larger marshes and of tidally restricted systems. The formation of pannes throughout much of the high marsh at CHV and the absence of similar pannes at CHV-R are evidence of this. As is the flood pattern that has tidal waters reaching "breakout" elevations and flooding the back portion of the CHV marsh while remaining confined to the main river channel at the front of the marsh.

Hydrology

A comparison of recorded downstream and upstream tide signals indicated that the new culvert continued to have a limited restrictive influence on hydrological conditions at CHV. This restriction manifested only on tides in excess of 7.11 m (CGVD28), conditions which existed on only 15% of predicted high tides for the study period (2005-2012). The highest recorded tide during the 2012 sampling period was 7.25 m (downstream) and 7.13 m (upstream). This was sufficient to flood the 43 ha of recovering marsh at CHV. Recovering marsh area was determined through a flood analysis for unrestricted tides and mapping of the die-off boundary (new high marsh – upland boundary). Flood analysis was performed using recorded tide levels and a LiDAR DEM, while the die off boundary was identified through on-site vegetation survey and analysis of low-altitude aerial photography. The highest recorded tide at CHV-R was 7.30 m. A tide elevation of 7.2 m is needed to flood the 5.4 ha of marsh surface at CHV-R.

<u>Depth to Groundwater</u> – The fifth year post-restoration was the only year that no significant difference in depth to groundwater between CHV and CHV-R was detected. By year three a significant difference in depth to groundwater was detected between pre- and post-restoration measurements at CHV which continued for the remainder of monitoring years. Although depth to groundwater at CHV-R was variable, the overall trend was fairly consistent, with depth to groundwater neither increasing nor decreasing over time. Whereas at CHV depth to groundwater clearly decreased over time following restoration. Throughout the post-restoration monitoring program CHV-R exhibited a general trend of greater depth to groundwater than CHV. The smaller size and higher elevation of the CHV-R marsh platform, smaller hydroperiod and potentially greater influence of freshwater (precipitation and runoff) could account for this. The

relative stability of depth to groundwater levels at CHV-R over time would suggest that the changes that were observed at CHV were the result of restoration.

Water Quality - Water quality (salinity, temperature, DO, and pH) measurements for tidal floodwaters obtained for both sites showed little difference in the abiotic factors between the two sites over the seven years when looking at comparable sampling periods.

Soils and Sediments

Pore Water Salinity – Pore water salinity levels at CHV increased following restoration, a pattern that was quite uniform across all stations. A trend of decreasing salinities towards the back (upstream) of the marsh and from the low to high marsh was observed. Mean pore water salinity levels at CHV post-restoration were significantly higher than pre-restoration levels. The largest changes in salinity were observed at the high marsh sampling stations and those further upstream. Mean pore water salinities at CHV were also found to be significantly higher than those of CHV-R. No significant difference in salinity levels between shallow and deep samples were detected at CHV, however, a significant difference was detected at CHV-R. CHV-R readings were less saline relative to CHV, with greater variability between deep and shallow samples. The differences between sample depths and sites may be associated with the differences in the size and elevation of the marsh platform at the two sites, which directly influences the inundation period and degree of freshwater (precipitation; runoff) influence.

Sediment Accretion & Elevation – The greatest rate of elevation change (increase) at CHV was recorded over the first two years following restoration. Throughout the post-restoration period, both sites experienced positive rates of surface elevation change, however, the rates of change were lower at CHV-R over the first five years following restoration. By Year 7 (2012), there was no significant difference in the rate of elevation change between CHV and CHV-R. Changes in elevation at both sites were found to be due to changes (increase or decrease) in below ground biomass production and surface expansion (sediment deposition).

Soil Characteristics – In general, a trend of decreasing bulk density and increasing organic matter content with distance from the main creek at CHV was common to the first three years of data collection following restoration. Year 5, however, recorded lower organic matter content and higher bulk density values with similar trends observed in Year 7. There was a general increase in bulk density across the marsh in all years post-restoration and a decrease in organic matter when compared to pre-restoration conditions. The highest bulk density values 7 years post-restoration were recorded at stations closest to the creek reflecting sediment accumulation in those regions. By Year 5, the distribution pattern of water content, organic matter and bulk density at CHV began to resemble the pattern displayed at the reference site; however there remained more variability at the upper elevation values. Water content was highly variable in all years. Organic matter content decreased over time and demonstrated a smaller range of values. Over time, it appears as though the sediments at the restoration site are becoming more minerogenic. A comparison of soil type and grain size between the restoration and reference sites implies similar source material and transport mechanisms. Overall however, the characteristics of sediments at CHV are similar to those recorded at CHV-R seven years post-restoration.

Vegetation

By Year 7 post-restoration, vegetation community structure at both sites showed a range of communities from low marsh (*Spartina alterniflora*), high marsh (*S. patens*), to a variety of brackish communities along the upland edge. The main halophytic communities were present at the study site, and there was a shift in community structure from non-halophytic to halophytic dominant over time. Despite the similarity in vegetation community class structure, there continued to be differences between the two sites. The average number of halophytic species was consistently greater at the reference site. There was less diversity, on average, at CHV, even seven years post-culvert replacement. The presence of several non-salt marsh species at CHV-R compared with CHV resulted in the reference site continuing to exhibit greater species richness. At the sample plot level, many of the sampling stations at CHV showed a rapid transition from freshwater wetland or upland vegetation to halophytes over time. Shifts in species composition were also seen with some of the halophytic plots originally containing high marsh species yielding to low marsh species, and vice versa as the classic salt marsh successional processes re-established with the new hydrological regime. The changes at the study site were consistent with what we might expect given the increased tidal flow resulting from the installation of a properly sized and placed culvert: shift in communities from upland to salt marsh.

Nekton

Individuals from eight species were observed and captured over the course of the 2005-2012 field seasons at CHV and ten species at CHV-R. No new species were captured during the 2012 monitoring season. However, species richness was similar between the two sites, and although abundance varied, more individuals were caught at CHV. The mummichog, a resident fish of salt marshes, was dominant over all years at CHV, whereas the Atlantic silverside, a migratory species, occurred with the highest frequency at the reference site overall years except 2010. There was a marked increase in the relative abundance of fish at CHV post-restoration, most likely due to increased panne size, re-activated creek network and improved hydrological conditions. Although individuals of all size classes of mummichogs and silversides were captured, the dominant size class corresponded to sexual maturity. The presence of American eel, Tomcod, and several species of Salmonids at both sites (particularly CHV-R) throughout the post-restoration monitoring program is evidence that higher order predators are accessing these sites during high tide events.

Benthic and Aquatic Invertebrates

<u>Invertebrate Activity Traps</u> – Invertebrate samples from CHV and CHV-R contained a mix of estuarine and freshwater animals over all years. Over the course of the monitoring program, sixteen species in total were identified between the two sites: 13 species at CHV and 10 at CHV-R. Both sites had an average of six species per sample over all years. The 2008 (third year) and 2010 (fifth year) samples for CHV showed the greatest abundances and diversity of all years. Despite the variation between the two sites, which was likely due to the location, size and condition of the pannes sampled, they were not significantly different.

Issues of Concern – Causeway

It was first noted during the 2009 field season (Bowron et al. 2010) that erosion was starting to occur along the seaward side of the causeway, particularly along the exposed parkway. The erosion of the causeway has continued, with more of the parkway being eroded (land under the administration of the NS Department of Natural Resources). It was noted that armour stone around either end of the culvert was replaced by NSTIR staff between the period of 2010 and 2012. However, nothing was done to address the situation with the remainder of the causeway.

Summary

Following seven years of post-restoration monitoring of the CHV tidal river and salt marsh system, the key conclusion was that the changes in the physical and biological conditions at the restoration site following culvert replacement were proceeding along an acceptable restoration trajectory.

The installation of the larger culvert in 2005 was instrumental in altering the geomorphology of the site, facilitated the creation of new salt marsh pannes, improved and expanded existing pannes in the mid and high marsh zones and expanded the tidal creek network by incorporating relict agricultural ditches and remnant channels. The restored hydrological regime has increased the tidal marsh area at CHV to 43 ha while enhancing the habitat conditions of the previous 5 ha of tidal wetland. The increase in frequency and extent of tidal flooding has resulted in greater availability and accessibility of the marsh surface for fish, wildlife, invertebrates and plants. In addition to the improved hydrological conditions at CHV, the changes observed for depth to ground water, pore water salinity levels, accretion rates, soil characteristics and the vegetation community were all indicative of a positive response to the restoration activity.

While it is difficult to predict how successful this restoration will be in the long term, it is clear that the major project objectives (significantly reduce the tidal restriction caused by the Highway 215 crossing; re-establish a more natural hydrological regime to the site; improve fish passage; increase the extent, distribution and abundance of halophytic vegetation) were achieved. Despite the continued differences in habitat conditions observed at the restoration site compared to the reference site, attributable in large part to the natural variability between sites, the restoration activities undertaken at CHV in 2005 have resulted in the restoration of a self-sustaining and resilient salt marsh and tidal wetland system.

Acknowledgements

We are particularly indebted to Dr. Bob Pett (NSTIR), Dr. Danika van Proosdij and Dr. Jeremy Lundholm (Saint Mary's University - SMU) who have been and continue to be strong supporters of CBWES and partners on this project.

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This study was a collaborative effort spanning ten years and involving a large number of people and financial supporters. It needs to be emphasized that the driving force behind this project from the beginning was the Ecology Action Centre and the members of its Salt Marsh Team. A special thank you to Hazel Dill and the teachers and students at Dr. Arthur Hines Elementary School for their enthusiastic support and participation in the project; to Doris Haggman at the Avon Emporium for keeping the field crew well fed; and to the Cheverie Crossway Salt Marsh Society for their efforts to develop an interpretative hiking trail and community center adjacent to the marsh. Thank you to the property owners and people in Cheverie and all along the Hants Shore for allowing us to undertake this project in their community and for making us feel welcome.

Financial and in-kind supporters of this project include: NSTIR, Fisheries and Oceans Canada, Ecology Action Centre, Gulf of Maine Council on the Marine Environment, NS Department of Natural Resources Habitat Conservation Fund, Wildlife Habitat Canada, Science & Technology Youth Internship Program (DFO), Science Horizons Youth Internship Program (Environment Canada), Unilever-Evergreen, NS Museum of Natural History, Saint Mary's University (MP_SpARC and the Community-Based Environmental Monitoring Network), Dalhousie University, Ducks Unlimited Canada, BoFEP's SMaRTS Working Group, Natural Sciences and Engineering Research Council of Canada, and the North American Fund for Environmental Cooperation.

1.0 Introduction

During the fall of 2005, the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR) in partnership with Fisheries and Oceans Canada - Small Craft Harbours (DFO-SCH), the Ecology Action Centre (EAC), and Ducks Unlimited Canada (DUC), undertook construction activities to restore tidal flow and fish passage to the Cheverie Creek (CHV) Salt Marsh and Tidal River System in Cheverie, Hants County, Nova Scotia (NS). The restoration of tidal flow, and ultimately of salt marsh habitat, to this site has resulted in the establishment of marine habitat restoration compensation banks for both NSTIR and DFO-SCH based on the Memorandum of Understanding (MOU) among DFO-Habitat Protection and Sustainable Development, DFO-SCH and NSTIR for application against past and future HADDs[1] (DFO 2006). Restoration activities consisted of the replacement of the existing tidally restrictive culvert with a 9.2 m by 5.5 m elliptical, aluminum culvert. Installed by Dexter Construction Limited, the new culvert increased the tidal opening approximately seven fold from 4.7 m^2 to 32.6 m^2.

Between May 2002 and October 2004, an extensive baseline study of the restoration site (CHV) and nearby unrestricted river and salt marsh ecosystem (Bass Creek: CHV-R) was conducted by the EAC (under the supervision of T. Bowron and N. Neatt) in preparation for eventual culvert replacement. Prior to the installation of the new culvert in December 2005, CB Wetlands & Environmental Specialists (CBWES) collected additional baseline data during the summer and fall of that year. A detailed description of the restoration and reference sites, the monitoring program, and the results of the pre-restoration monitoring program were presented in Bowron and Chiasson (2006). The results of the first five years of post-restoration monitoring were presented in Bowron and Neatt (2007), Bowron et al. (2008), Bowron et al. (2009), Bowron et al. (2010), and Bowron et al. (2011a).

Long-term, post-restoration monitoring of the CHV and CHV-R systems, a key component of the MOU (DFO 2006), was originally scheduled to continue through to 2010 in order to quantify environmental changes and validate project benefits. The first three years of post-restoration monitoring indicated that the system was responding in a positive and acceptable manner to the original intervention, but the stabilization/maturation of the system was unlikely to be captured by the originally designed six year monitoring program (Bowron et al. 2009). Given the size of the site and that this project was the first intentional tidal wetland restoration project with a long-term monitoring program to be undertaken in Nova Scotia, it was decided that the schedule for the remainder of the monitoring program would be adjusted from a consecutive five-year post-restoration program to a Year 5 and 7. The reduction of the fourth year of monitoring in favour of the addition of monitoring activities seven years post-restoration (2012) was an attempt to document the longer-term changes in physical and biological components of the system as a result of culvert replacement.

[1] HADD refers to the Harmful Alteration Disruption or Destruction of fish or fish habitat under Section 35(2) of the Federal Fisheries Act (DFO 1985).

Between May 2012 and March 2013, the seventh year of post-restoration monitoring was conducted by CBWES. The monitoring program utilized for this project was adopted and adapted from a set of regional protocols developed for use as part of tidal wetland restoration projects in the Gulf of Maine and Bay of Fundy (Neckles and Dionne 2000; Neckles et al. 2002). Data was collected for geospatial attributes, hydrology, soils and sediments, vegetation, nekton, and aquatic invertebrates from the restoration site as well as the reference site.

All aspects of this project were conducted and supervised by CBWES staff and project partners, under contract to NSTIR. Field and laboratory work was carried out by: Tony M. Bowron, Nancy C. Neatt, Jennie M. Graham, Ben Lemieux, Christa Skinner, Michelle Whidden, Amy Lawrence with CBWES; Dr. Jeremy Lundholm and Dr. Danika van Proosdij, Carly Wrathall with SMU; and Patrick Stewart and Heather Levy (Envirosphere Consultants Ltd.).

1.1 CBWES Inc.

Since 2005, CBWES has been involved in the restoration and monitoring of nine salt marsh restoration projects in NS in collaboration with NSTIR[2]. These projects, in particular, the design and monitoring activities, have been presented by CBWES staff in poster and oral presentation formats at a number of regional, national and international scientific conferences[3]. Please contact CBWES for more information on these presentations. CBWES is committed to continuing to participate in important events such as these in order to share our experience and to stay abreast of current trends, techniques and science of restoration.

CBWES has a strong research partnership with SMU. Through this partnership, a number of undergraduate and graduate level research projects involving the restoration project sites have been supported. As a recognized Industrial Partner with the Natural Sciences and Engineering Research Council of Canada (NSERC), CBWES Inc. received NSERC grants for five of these projects (three undergraduate, 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.

In 2009, a peer-reviewed paper on the CHV Restoration Project titled "*Macro-Tidal Salt Marsh Ecosystem Response to Culvert Expansion*" was published in *Restoration Ecology* (Bowron et al.

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[2]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,b,c; Bowron et al. 2012; 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)

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

2011b). A paper on the Walton River Restoration Project titled *Ecological Re-engineering of a Freshwater Impoundment for Salt Marsh Restoration in a Hypertidal System* appeared in the journal *Ecological Engineering* (van Proosdij et al. 2010). A book chapter titled "Chapter 14 – Salt Marsh Tidal Restoration in Canada's Maritime Provinces" has been submitted for peer-reviewed publication in the book *Restoring Tidal Flow to Salt Marshes: A Synthesis of Science and Management* (Roman and Burdick 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).

1.2 Report Organization

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; Bowron et al. 2010; Bowron et al. 2011a). 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 CHV 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.

A series of appendices provide: (A) summary of CBWES supported student research; (B) comparison of the original and revised sampling station labeling system for Cheverie Creek; (C) select images from the CHV and CHV-R 2012 vegetation survey and 2013 structured winter walk; and (D) DUC's waterfowl monitoring report.

2.0 Study Sites and Monitoring Program

2.1 Cheverie Creek Restoration Site

CHV is a small tidal river centrally located in the coastal village of Cheverie, Hants County, NS (45^0 09' 31.44" N 64^0 10' 09.92" W) (Figure 1 and Figure 2). Route 215, the main road in the area, crosses the mouth of CHV as a two-lane, rock-filled causeway (Figure 3). Prior to restoration, limited tidal exchange was allowed through a 1.5 m x 1 m double wooden box culvert (Figure 3a) set deep in the road bed on the south end of the causeway. This culvert allowed a limited amount of tidal flow to approximately 4-5 ha of the marsh. The installation of the new culvert (Figure 3b) in the fall of 2005 has resulted, as anticipated, in improved fish access to the river and marsh surface, and a more regular flooding of the entire marsh surface. Figure 4 provides a series of photographs of the CHV system at both low and high tide.

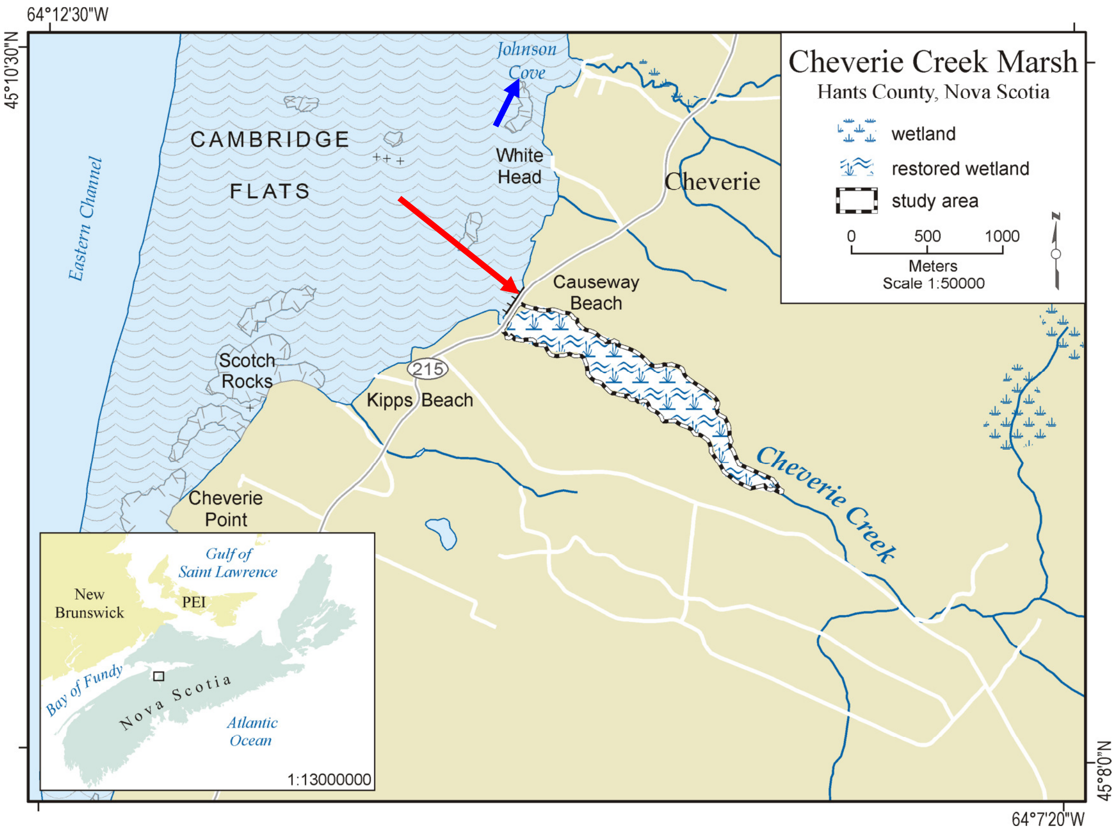

Figure 1 Location of the CHV restoration site (red arrow). CHV-R is located 5 km north along Highway 215 (blue arrow).

Figure 2 Low-altitude aerial photograph of CHV system as viewed from the front end of the marsh looking upstream. Photograph by CBWES, October 2010.

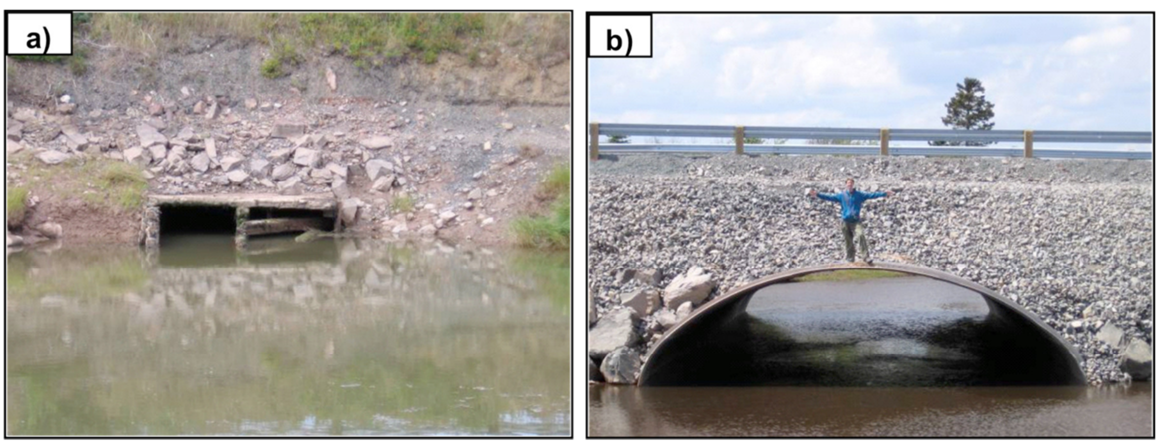

Figure 3 (a) Old box culvert at CHV in 2002 (photograph by T. Bowron, 2002); and (b) new culvert installed in December 2005 (Photograph by N. Neatt, 2006).

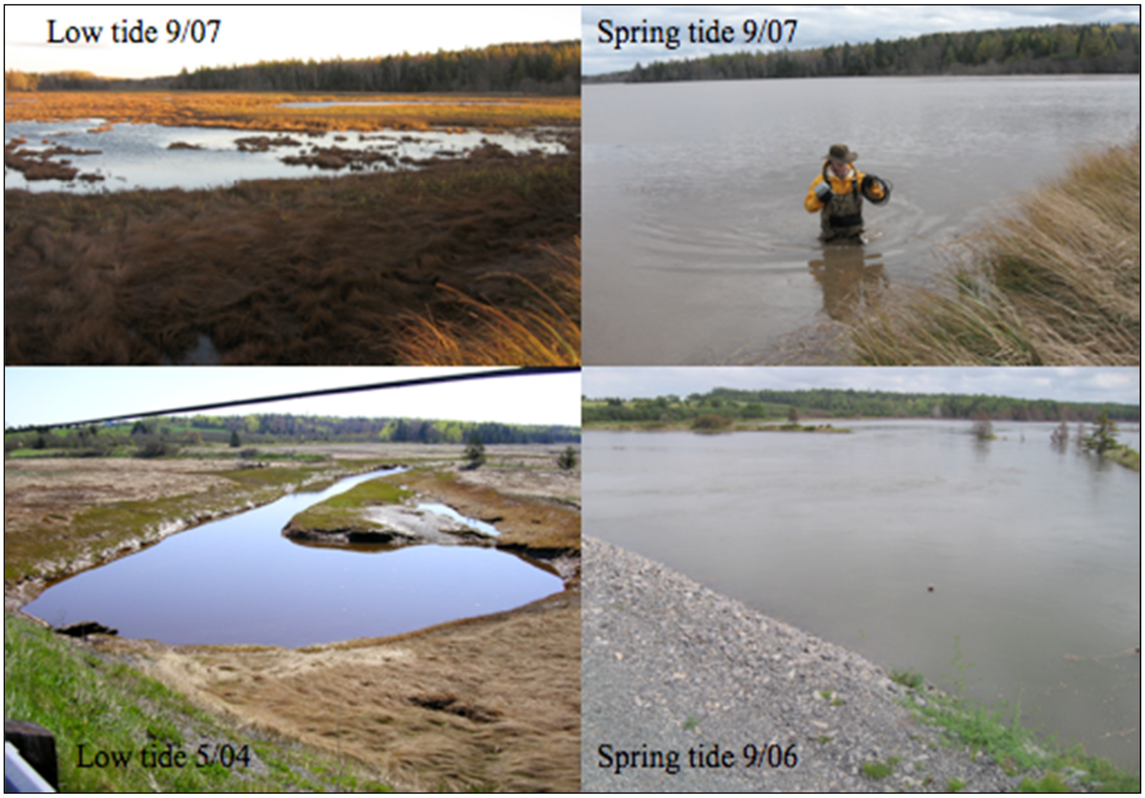

Figure 4 Time series of high (spring) and low tide conditions at CHV. The top two images are of the back portion of the marsh (Transects 3 through 8), taken from the top of the dyke. The lower images are of the front portion of the marsh (dyke is in the back ground), taken from the road surface above the culvert. Photographs by CBWES Inc..

2.2 Bass Creek Reference Site

CHV-R is an unrestricted tidal river and salt marsh system located in Bramber, approximately 5 km north of CHV along Highway 215 (45^0 11' 54.73" N 64^0 07' 57.79" W) (Figure 5). Similar to CHV, Highway 215 crosses the river near its mouth. However, unlike the crossing at CHV, the CHV-R crossing is a combination causeway-bridge structure, whereby the bridge section spans the width of the main river channel.

Figure 5 1992 aerial photograph of CHV-R causeway-bridge. (Modified from Department of Natural Resources, 2003). Inserted image is of the CHV-R bridge at low tide. Photograph by T. Bowron, 2001.

2.3 Monitoring Program

The monitoring program makes use of a suite of salt marsh indicators and data collection methods that have been tailored to this project, and which seek to characterize a broader range of salt marsh ecosystem components. These indicators (geospatial attributes, hydrology, soils and sediments, vegetation, fish and invertebrates) are measures of wetland structure and function, and when applied pre- and post-restoration, collectively provide information on ecosystem status and response to restoration. The physical and biological parameters within each of these indicator categories for which data was collected during the 2012/13 monitoring season are identified in Table 1.

Table 1 The CHV Salt Marsh Restoration monitoring program, including core and additional ecological indicators, methodologies, and sampling frequency (annual application indicated by X – all sites; C – CHV; B – CHV-R; Y – scheduled future sampling).

Category	**Parameters**	**Sampling Method**	**Annual Sampling Frequency**	**Monitoring Year**							
				Pre (2002-2005)	**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 interval) water level recorders (Solinst Levelogger (Model 3001)	Daily maximums: CHV: 18/9/03 to 2/10/03 CHV: 3/11/06 to 24/11/06 CHV: 19/11/07 to 19/12/07 CHV-R: 19/12/06 to 9/1/07 CHV-R: 17/11/08 – 16/12/08 CHV(-R): 6/7/10 – 16/8/10 CHV(-R): 25/5/12 – 3/10/12	C	X	C	B		X		X
	Depth to groundwater	Groundwater wells (0.02 m x 1m sampled at depth 0.9 m)	CHV & CHV-R: bi-weekly 7/03 to 11/03; 7/04 to 11/04; monthly from 7/06 to 9/06; 7/07 to 9/07; 7/08 to 10/08; 8/10 to 9/10; 5/12 to 9/12	X	X	X	X		X		X
Soils & Sediments	Marsh surface elevation	Digital elevation model (DEM). Total Station; Differential GPS; LiDAR	Once per sampling year.	C	B	C	B		X		X
	Pore water salinity	Sipper & refractometer (2002-2010)	CHV & CHV-R: bi-weekly 7/03 to 11/03; 7/04 to 11/04; monthly from 7/06 to 9/06; 7/07 to 9/07; 7/08 to 10/08; 8/10 to 9/10; 5/12 to 9/12	X	X	X	X		X		X
	Sediment elevation	Rod Sediment Elevation Tables (RSET)	CHV: 4 stations, installed 6/05, measured 9/05; 9/06; 9/07; 9/08; 10/09; 25/11/10; 2/11/11; 10/10/12 CHV-R: 2 stations installed 9/06, 1 station installed 10/06, measured 10/06; 10/07; 9/08; 10/09; 3/12/10; 2/11/11; 10/10/12	X	X	X	X	X	X	X	X
	Sediment accretion	Sediment plates*; marker horizons (3 per RSET) sampled using a cryogenic corer (Cahoon et al., 1996).	Sediment plates – CHV: 25 locations; monthly from 07/02 to 12/02; 7/03 to 10/03; 1/04 to 11/04; annually 7/05; 7/06; 7/07; 10/08; 10/09 Marker horizons – CHV: installed 6/05, measured 9/06, 9/07, 9/08, 10/09, 25/11/10; 2/11/11; 10/10/12 CHV-R: installed 10/06; measured 10/07, 9/08,	X	X	X	X	X	X	X	X

Category	Parameters	Sampling Method	Annual Sampling Frequency	Monitoring Year							
				Pre (2002-2005)	Post-Restoration (2006-2012)						
					1	2	3	4	5	6	7
			10/09, 3/12/10; 2/11/11; 10/10/12								
	Sediment Characteristics (bulk density, organic matter content, sediment type)	Sediment cores (soil samples) Paired samples: (30 ml syringe with base cut and 5 cm x 15 cm core).	CHV: 25 paired samples, 7/02; 23 paired samples, 10/06; 9/08; 9/10; 7/12 CHV-R: 19 paired samples, 10/06; 9/08; 9/10; 7/12	X	X		X		X		X
Vegetation	Composition Abundance Height	Point Intercept method (1 m^2 plots)	CHV: 129 plots, annually 8/02; 8/04; 8/06; 8/07; 8/08; 8/10; 7/12 CHV-R: 27 plots, annually 8/03; 8/06; 8/07; 8/08; 8/10; 7/12	X	X	X	X		X		X
	Habitat map	Aerial photograph, DGPS/GIS, Total Station, LiDAR, low-altitude aerial photography	Elevation survey – 25&26/11/10; 11/12 Aerial Photography (CHV only) – 29/10/10; 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: spring tide. 4 minnow traps, 3 pulls with beach seine and single deployment of fyke net per sampling date CHV: 18/10/05; 17/8/06, 8/9/06, 6/10/06; 1/8/07, 29/9/07, 28/10/07; 19/8/08, 19/9/08, 18/10/08; 12/8/10, 11/10/10; 18/9/12, 16/10/12 CHV-R: 19/10/05; 11/9/06, 7/10/06; 3/8/07, 30/9/07, 27/10/07; 20/8/08, 18/9/08, 20/10/08; 11/8/10, 9/10/10; 15/10/12	X	X	X	X		X		X
Benthic and Other Aquatic Invertebrates	Abundance and species richness of intertidal benthic invertebrates	Reference Condition Approach (RCA) – 9.2L sediment sample	CHV – 8/9/05; 29/8/06; 4/9/07; 2/9/08; 30/8/10 CHV-R – 9/9/05; 30/8/06; 5/9/07; 3/9/08; 30/8/10	X	X	X	X	X	X		
	Abundance and species richness of aquatic invertebrates	Invertebrate Activity Traps (IAT)	CHV – 20/9/05; 15/8/07; 15/7/08; 6/7/10, 16/8/10 CHV-R – 16/8/07; 15/7/08; 6/7/10, 16/8/10; 26/7/12, 16/8/12	X		X	X		X		X
	Larval mosquito (abundance)	Six Dip samples per panne (dipper)	CHV: 10 pannes; monthly from 6/04 to 9/04; 7/05 to 9/05; 7/06 to 8/06; 6/07 to 9/07	X	X	X					

Category	Parameters	Sampling Method	Annual Sampling Frequency	Monitoring Year							
				Pre (2002-2005)	Post-Restoration (2006-2012)						
					1	2	3	4	5	6	7
			CHV-R: monthly from 6/04 to 9/04; 7/05 to 9/05; 7/06 to 8/06; 6/07 to 9/07								
Winter Conditions	Ice/snow conditions	Structured winter walk; photographs along each transect	15/3/11; 6/3/13	X	X	X	X	X	X	X	X
Waterfowl (conducted by DUC)	Abundance and Species richness	Bird counts	Appendix D	X	X	X	X	X	X		

3.0 Methods

Sampling was conducted at both the restoration and reference site using transects (Lines) established in a non-biased, systematic sampling design. Twenty-six transects were established at CHV, 50 m apart (as measured along the upland edge), running perpendicular to the main river channel and marked along the upland edge by two permanent wooden stakes (Figure 7). Eight transects were established at CHV-R in the same manner (Figure 8). A combination of 100 m field tape, compass, GPS Trimble® Pathfinder Pro XR[4] and Leica TCR-705 Total Station[5] were employed to produce straight, reproducible transects. Data collection was conducted at sampling stations established at equal intervals (50 m) along transects at each site.

3.1 Geospatial Attributes

Habitat Map and Digital Elevation Model (DEM)

The habitat maps and DEM's for CHV and CHV-R were developed pre-restoration and updated during year one, three, five and seven. It was based on the 2007 DEM for CHV (Bowron et al. 2008) that the estimate of 43.04 ha of total marsh area (38.04 ha or 380,400 m^2 of restored tidal wetland) was identified.

The initial DEM's and habitat maps were developed using the 1994 1:10,000 aerial photographs, differential global positioning system (DGPS) and a Leica TCR-705 Total Station. These were updated in 2007 using LiDAR[6] data that was flown in April 2007, processed and provided by the Applied Geomatics Research Group (Centre of Geographic Sciences). The estimate of restorable area was determined using the original DEM and subsequently revised based on the post-restoration surveys and the inclusion of the LiDAR data.

In 2012, the CHV(-R) DEM's were produced using a combination of the 2007 LiDAR data, on-site elevation survey and low-altitude photography as described in Bowron et al. (2011a) (Figure 21; Figure 25). Geo-spatial surveys were performed using a Trimble G8 GNSS RTK surveying unit (RTK), and DEM's for each site were created in ArcGIS. The changes in elevation at both sites were illustrated by comparing pre- and post-restoration sample plot elevation statistics and transect profiles. The habitat maps and surface cover maps were produced based on vegetation community structure and other important habitat features identified from the 2012 orthophotographs and elevation survey.

As an indicator of changes in habitat condition (recovery of tidal wetland) the spatial variation in the abundance of *Spartina alterniflora* (target salt marsh vegetation species) over time at CHV was examined. Vegetation survey plot data from the pre-restoration vegetation survey (2002 – 2004) was compared to 2012 vegetation survey. If *S. alterniflora* was recorded in a plot, but not dominant it was classed as 'present' and if it was the most abundant species in the plot then it is dominant. A simple factor matrix (Table 2) was constructed to produce a series of *S. alterniflora* colonization maps (Figure 24).

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

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

[6] *LiDAR* (Light Detection and Ranging) employs an airborne scanning laser rangefinder to produce detailed and accurate topographic surveys and provides superior accuracy to traditional survey methods in this context.

Table 2 Spatial variation in abundance of *S. alterniflora* factor matrix.

	2012 Present	2012 Dominant	2012 Absent
Pre-restoration present	Always present	New dominant	No longer present*
Pre-restoration dominant	No longer dominant	Always dominant	No longer present*
Pre-restoration absent	New colonist	New dominant	Never present

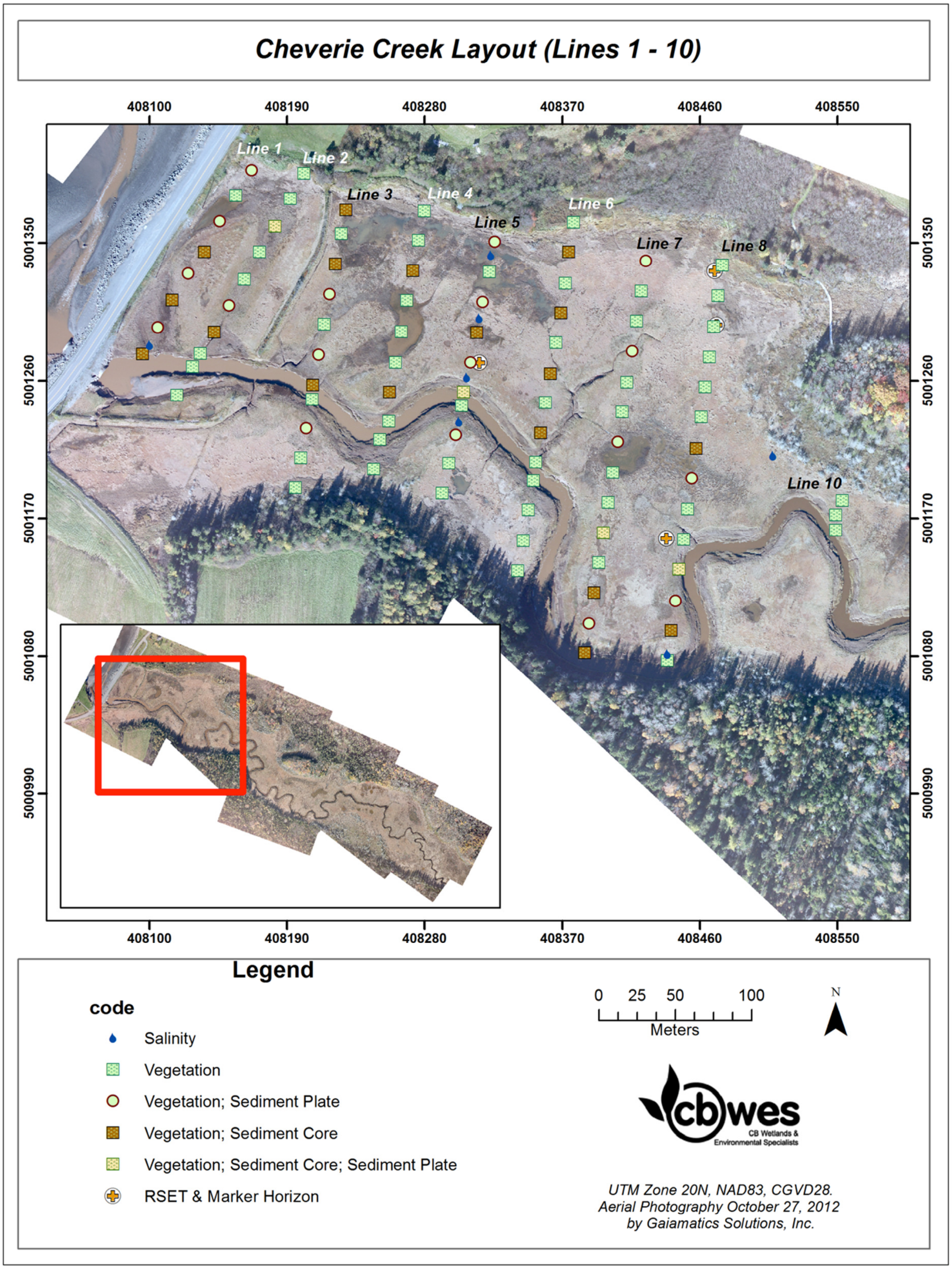
* Plots dominated by *S. patens, D. spicata* or *C. paleacea*.

Figure 6 Small format aerial photographic platform using helium filled blimp with a suspended camera system. Photograph taken at Antigonish site by T. Bowron, September 2010.

Site Setup and Data Management

A change in data management methods was made in 2007 that altered the system of how sampling stations were identified and labeled. When sampling stations were initially established in 2002, the first sampling station on each transect was located 0.5 m from the creek edge with subsequent stations extending along the transect to the upland and were labeled accordingly. Station labels were reversed so that the front stakes on each transect became the first station (S1) along the upland edge, with subsequent stations extending towards the creek. This was done in order to make the setup at CHV consistent with CBWES’ other restoration monitoring programs, all of which have S1 located along the upland edge. A table showing the original and the new sampling station labeling system for CHV is presented in Appendix B. For the purpose of this year's report, the new labeling system was used for the vegetation and pore-water analysis, while the original labels were used for the sediment analysis. The location of the transects and sampling locations at CHV and CHV-R are shown in Figure 7(a,b) and Figure 8.

a.)


Cheverie Creek Layout (Lines 1 - 10)
408100
408190
408280
408370
408460
408550
5001350
5001260
5001170
5001080
5000990
Line 1
Line 2
Line 3
Line 4
Line 5
Line 6
Line 7
Line 8
Line 10
Legend
code
Salinity
Vegetation
Vegetation; Sediment Plate
Vegetation; Sediment Core
Vegetation; Sediment Core; Sediment Plate
RSET & Marker Horizon
0 25 50 100
Meters
N
cbwes
CB Wetlands & Environmental Specialists
UTM Zone 20N, NAD83, CGVD28.
Aerial Photography October 27, 2012
by Gaiamatics Solutions, Inc.

b.)

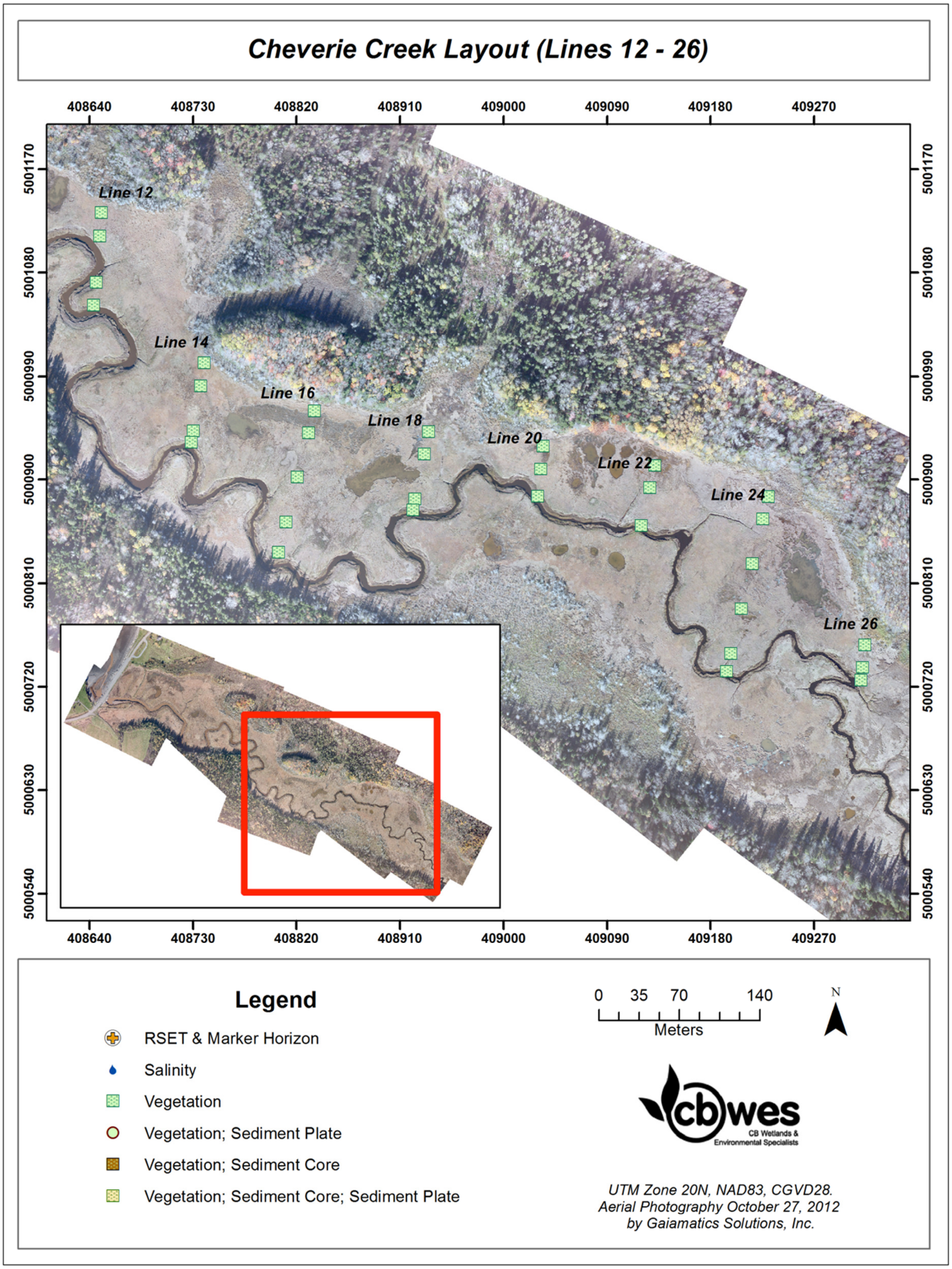


Figure 7 (a,b) CHV monitoring program layout – location of transects and main sampling sites.

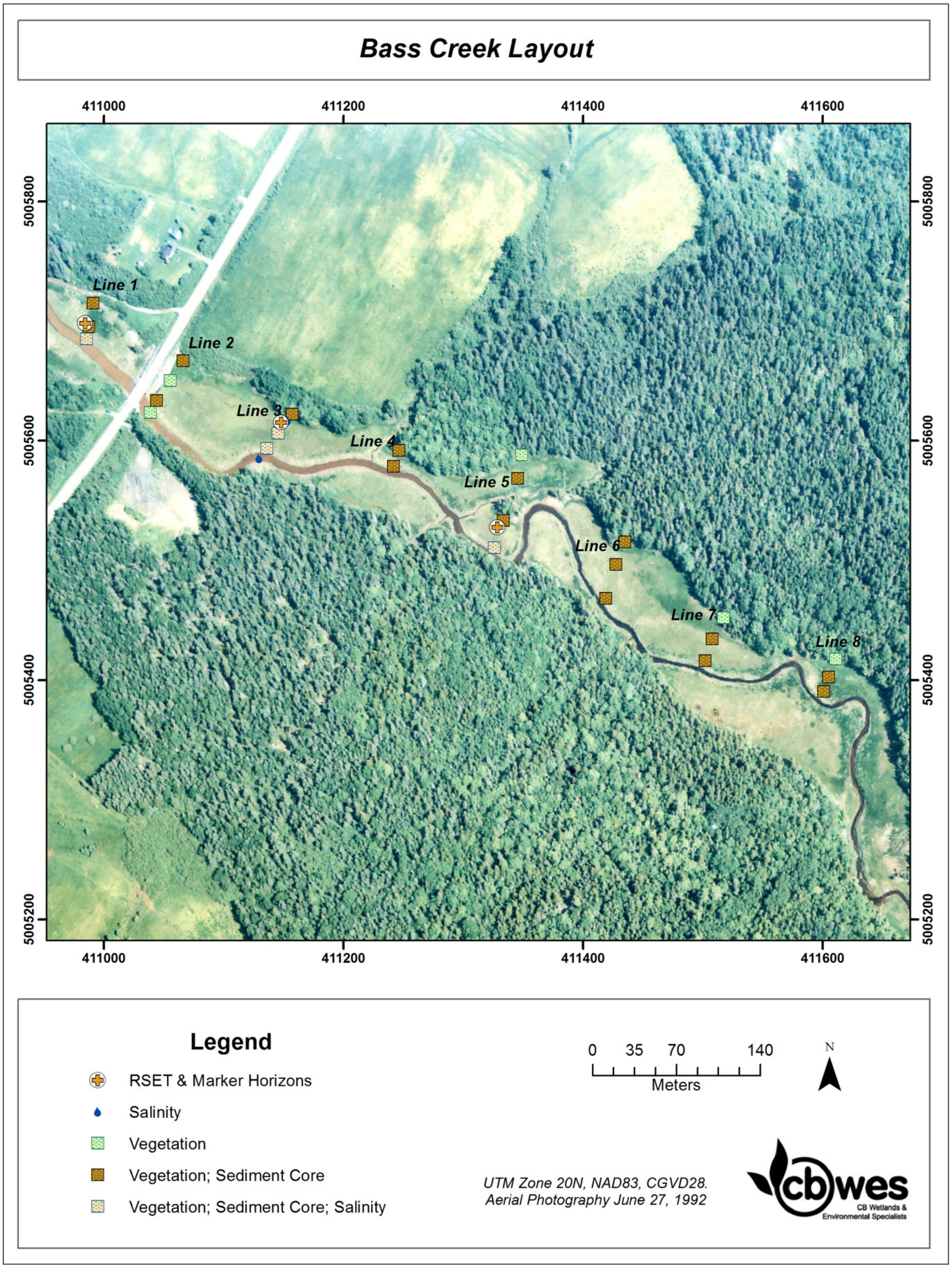


Figure 8 CHV-R sampling design layout (transects and sampling locations).

3.2 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 of a salt marsh that determines the area of marsh directly available as fish habitat. The hydroperiod (frequency and duration of tidal flooding) of a salt marsh is determined by the tidal signal (pattern of water level change with respect to a reference point) and marsh surface elevation. When attempting to understand changes in vegetation, groundwater level can be a valuable parameter to monitor as it provides information on the degree of waterlogging or drainage that is occurring on a marsh (Roman et al. 2002). Surface water quality (salinity, dissolved oxygen, pH and temperature) of both flood waters and of surface waters (salt pannes) can influence the diversity, distribution and abundance of plants and animals in a salt marsh.

Hydroperiod and Tidal Signal

The hydroperiods for CHV and CHV-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 Model 3001 Levelogger Golds[7] (water elevation and temperature) and a Solinst Barologger[8] (atmospheric pressure and temperature).

For CHV, one Levelogger was placed upstream of the culvert in the main river channel (in a still well; Figure 9) in line with the third transect, while the second Levelogger was placed in the pool downstream of the culvert (Figure 7a). This configuration yielded a tidal signal for both upstream and downstream of the crossing, which could be compared in order to determine if, and to what degree, the new culvert restricted tidal flow. At CHV-R, a single Levelogger was installed in the main river channel, in line with the third transect. All Leveloggers were installed below the low water line in order to ensure that they would remain submerged at all times during the sampling period.

The Barologger collected 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 at CHV. The instrument was installed in the upland above the restoration site to avoid submergence by water.

The loggers were deployed on 25 May 2012 and retrieved 5 October 2012, in order to capture water levels throughout a series of complete spring and neap tide cycles. 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 the Trimble RTK. Following retrieval, the data from the loggers were downloaded into the Solinst Software Version 3[9] for post-processing and analysis.

Minimum, mean and maximum (min/mean/max) water levels (upstream and downstream) were calculated using all the readings from the water level recorders. Min/mean/max tide levels were also calculated, but were done so using only the high tide readings. Both water level and tide

[7] www.solinst.com/Prod/3001/3001.html
[8] Barologger is required for barometric compensation.
[9] www.solinst.com/Downloads/

level are necessary to use in the analysis because min/mean/max tide levels provide average tidal coverage, whereas, mean water level provides the lower marsh boundary elevation.

Water levels from both water level recorders were used to determine if, and to what degree, the restoration site was tidally restricted. The recorded water levels from the upstream unit were combined with the DEM to determine hydrological conditions under a variety of tidal scenarios. Hydrological modeling was conducted in ESRI ArcGIS using the recorded water level data rather than the predicted tide heights. A set of tide signal graphs comparing water levels upstream to downstream on spring and neap conditions, 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 and describe the pattern and extent of flooding as tide height increases. 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.

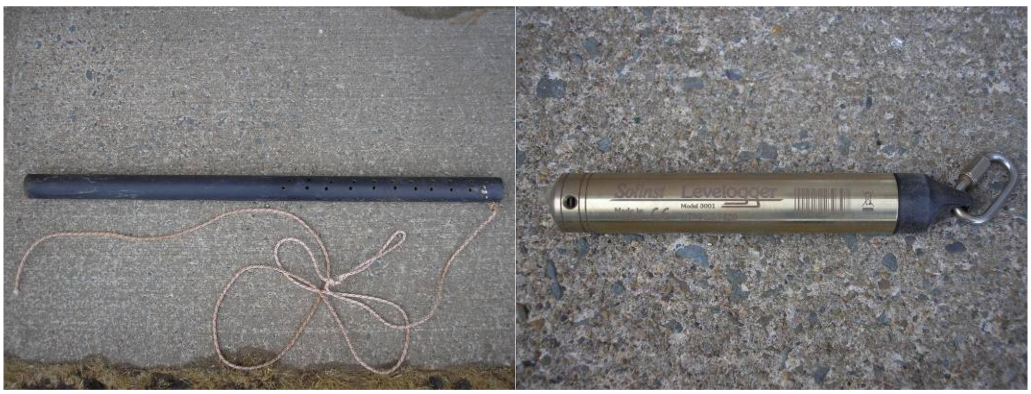


Figure 9 Solinst Model 3001 Levelogger Gold and still well. Photograph by N. Neatt, January 2008.

Depth to Groundwater

Field Methods

Depth to groundwater was sampled using groundwater wells constructed from 1 m long plastic pipe (1/2” diameter) with seven 3 mm holes drilled in alternating sides at 2.5 cm intervals, extending 5-25 cm from the base of the well. Each well was sealed at the base with duct tape and topped with a removable cap. A single hole was drilled just below the cap to allow venting. Groundwater wells were installed to a depth of 90 cm and sand was poured around each well where it enters the ground to prevent the intrusion of surface water into the space around the well. Seven groundwater wells were installed at CHV (Figure 7) and six at CHV-R (Figure 8). Groundwater depth sampling stations were coupled with soil salinity sampling stations at both sites.

Depth to groundwater was measured at low tide on the 13 June, 11 July, 7 August, and 12 September 2012. A single measurement from each well per sampling event was taken using a hollow metal rod (1 m long, 4 mm diameter) and an attached flexible rubber tube. The metal tube was gradually lowered into the well while forcing air through it by blowing into the rubber tube. Insertion would continue until the first sound of bubbles could be detected from the well. The position of the top of the well was marked on the metal rod, the rod removed and the distance from that mark to the end of the rod measured using a meter ruler.

Statistical Methods

For both CHV and CHV-R descriptive statistics, including mean, range, and standard error were calculated for depth to groundwater wells. These statistics were used to create graphs that illustrated temporal and spatial 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 (pre versus post). For tests comparing CHV and CHV-R and post-restoration to pre-restoration, two-sample t-tests assuming unequal variances were performed. All t-tests were run at a 95% Confidence Interval ($p<0.05$) in Microsoft Excel software.

Water Quality

A YSI 650 MDS Handheld Dissolved Oxygen Instrument[10] was used to measure four physical components of water: temperature (±0.1 C°), dissolved oxygen (DO) (± 0.1 mg/L), salinity (± 0.1 ppt) and pH. A minimum of two samples were taken per sampling event within 30 minutes of peak tide (spring tide). Sampling was matched in time and location with nekton sampling: 18 September 2012 and 16 October 2012 at CHV; 15 October 2012 at CHV-R. The YSI probe was submerged approximately at mid-depth in the vicinity of nekton sample area.

3.3 Soils and Sediments

Monitoring pore water salinity, sediment accretion rates, sediment elevation and soil characteristics can provide insight into the processes controlling vegetation type, cover and productivity and the vertical growth of marsh following restoration (Neckles and Dionne 2000). Soil salinity (interstitial pore water salinity) is one of the main controls on the distribution and abundance of plant species in salt marshes (Niering and Warren 1980; Crain et al. 2004). Measuring pore water salinity throughout the early to mid growing season and in conjunction with groundwater depth monitoring can help explain changes in environmental conditions regulating plant growth, distribution and abundance and habitat responses to restoration activities.

Accretion of inorganic and organic materials deposited onto the marsh surface by floodwaters and vegetation is one of the main processes that allow marshes to build vertically over time, offsetting increased tidal flooding. Failure to keep pace with increased flooding could result in the loss of salt marsh features and functions important to fish (loss of productivity and extent of habitat). Monitoring sediment accretion rates, elevation and determining organic content of marsh soils prior to engaging in restoration activities can reveal insights regarding pre-restoration conditions to the marsh (subsidence due to oxidation of organic matter in sediments) and the process of recovery following restoration.

Marsh soil characteristics are determined by the sediment source and tidal current patterns (Mitsch and Gosselink 2007). As tidal waters flow over the marsh surface, increasing elevation and vegetation slows the velocity of water allowing coarse-grained sediment to drop out of suspension close to the main channel edge while finer sediments drop further inland (Redfield

[10] www.ysi.com

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

Sampling locations for interstitial pore water salinity were matched with the depth to groundwater stations at both sites (Figure 7; Figure 8). During the 2003 to 2012 monitoring seasons, shallow (15 cm) and deep (45 cm) pore water samples were taken using a soil probe (sipper; Roman et al. 2001; Figure 10) and a handheld temperature compensated optical refractometer (nearest 2 ppt). For the 2012 monitoring season a FieldScout EC 110 Meter[11] was used to collect the in-situ readings. The previous method used refraction techniques to record salinity, while the EC 110 Meter, which uses electrical conductivity, allowed for a more precise reading to be recorded in the field and less prone to user error. Sampling was conducted at low tide on 13 June, 11 July, 7 August and 12 September 2012 at each of the seven (CHV) and six (CHV-R) sample plots.

Figure 10 Photograph of a soil probe (sipper) used to take an interstitial pore water samples to test for pore water salinity (Roman et al. 2001).

For both CHV and CHV-R descriptive statistics, including mean, range, and standard error were calculated for shallow and deep salinity samples. In order to compare salinity values across years (2012 EC 110 Meter data to the 2003-2010 refractometer data), a linear regression model was created. The model correction converted the refractometer values to approximate EC 110 Meter values and explained 61% of the variation between the values. This enabled an over time trend analysis. Using just the 2012 EC 110 Meter data, T-tests comparing between sampling depths and between restoration and reference site were conducted. For tests comparing CHV and CHV-R (shallow samples, deep samples, and all samples) a two-sample test was run, assuming

[11] http://www.specmeters.com/nutrient-management/ph-and-ec-meters/ec/ec110/

unequal variances. For tests comparing shallow to deep samples a paired two-sample test was performed. All t-tests were run at a 95% Confidence Interval ($p<0.05$) in Microsoft Excel software.

Sediment Accretion and Elevation

Changes in surface elevation and sediment accretion were measured annually at CHV since 2005 and CHV-R since 2006 using Road Surface Elevation Tables (RSET) and marker horizon cores. The RSETs and marker horizons were installed and measured according to the methods developed by Cahoon and Lynch (Cahoon et al. 2002; USGS 2005). Project specific application and methods for the marker horizons are described below. To determine the change in surface elevation between sampling years (e.g. 2012 and 2011), the difference in elevation at each pin is first calculated by subtracting the value in 2012 from the value in 2011. It is important that the same point be measured each year (e.g. same measurement direction and pin position). If the value is negative, the surface has lowered, and if it is positive, the elevation of 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 2011 to 2012. Given that 2012 was the seventh and final year of post-restoration, in addition to determining the change in elevation during the preceding year, the overall change in marsh surface elevation over the past seven years was also calculated (subtracted the 2012 value from the 2005 baseline measurement).

Changes in surface elevation measured by the RSET incorporate both subsurface processes such as root production and sediment deposition whereas sediment accretion measured by the marker horizon cores represents the amount of inorganic and organic material deposited by tidal waters on the marsh surface. Subtraction of the RSET and marker horizon values should provide a measure of the amount of change in surface elevation due to shallow subsidence processes such as root growth, compaction, decomposition and pore water flux (Cahoon et al. 2002). Both surface (e.g., accretion) and subsurface processes will be highly influenced by the elevation of the marsh surface within the tidal frame which affects the frequency and duration of inundation by tidal waters. Sediment accretion will also be affected by other factors such as the proximity to sediment source, for example, the tidal creek network (van Proosdij et al. 2006b). Figure 11 and Figure 12 depict the number and the location of the RSETs and marker horizons at CHV, as well as the elevation of the marsh surface. The locations of the three RSETs at CHV-R are shown in Figure 8.

Three 0.5 m^2 marker horizons per RSET station were established at the time of original RSET installation. Vertical accretion at each marker was measured annually in conjunction with RSET sampling using a Cryogenic Corer (Cahoon et al. 1996). The Cryogenic Corer consists of a small (15 L) stainless steel self-pressurized liquid nitrogen (N_2) Dewar (Figure 13), a stainless steel tubing with an inner sleeve attached (copper tubing; Figure 13) and an outer sleeve or bullet over the inner sleeve. To collect cores with the Cryogenic Corer, the bullet was pushed into the marsh surface three to four inches and the tank valve opened to allow N_2 to circulate through the tubing and bullet. Once the core was frozen, the N_2 would be turned off, and the bullet removed from the soil (Figure 13). When removed, the bullet would have a “cryo-core” of sediment frozen to the outer surface. If sediment deposition had occurred, the marker horizon would appear as a distinct white band within the core. A measurement would then be taken from the surface of the core (representing the marsh surface) to the top of the feldspar clay band (in millimeters). A minimum of three, preferably four, readings per core were taken, as the distance between the top of the clay band to the surface of the core could vary. If the feldspar was observed on the marsh surface then zeros were recorded. Three coring attempts per marker horizon station were made to detect a horizon. If after three coring attempts, no marker horizon was detected, the station was deemed to be missing or compromised (eroded). The distance from the surface to the white feldspar line was measured using calipers to the nearest millimeter and recorded for the three cores. A mean was determined from these three cores 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 was determined by subtracting the accretion value of the previous year from the current year.

The RSETs and marker horizons at CHV and CHV-R were sampled on 10 October 2012.

In addition, a total of 25 buried aluminum plates were installed in 2002 at CHV by SMU to measure sediment accretion using the method outlined in van Proosdij et al. 2006a (Figure 11). These plates were measured annually between 2002 and 2008 and previously analyzed in Bowron et al. (2009). The plates were not measured in 2010 or 2012 (unable to relocate sufficient number to allow for meaningful analysis) and were not included in this report.

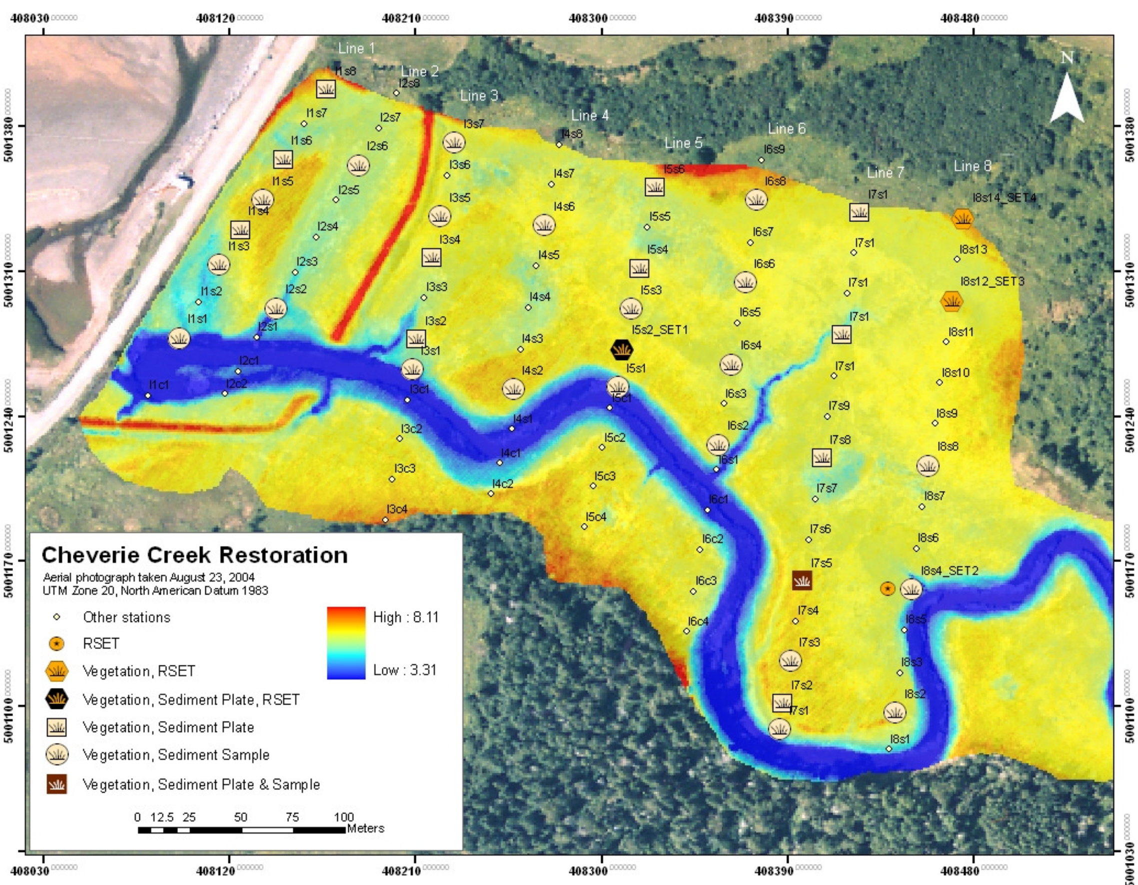


Figure 11 Position of RSET stations and sediment plates on the CHV superimposed on a lidar elevation surface. Lidar provided by T. Webster of the Advanced Geomatics Research Group at COGS, 2007. Elevations expressed relative to CGVD28 vertical datum.

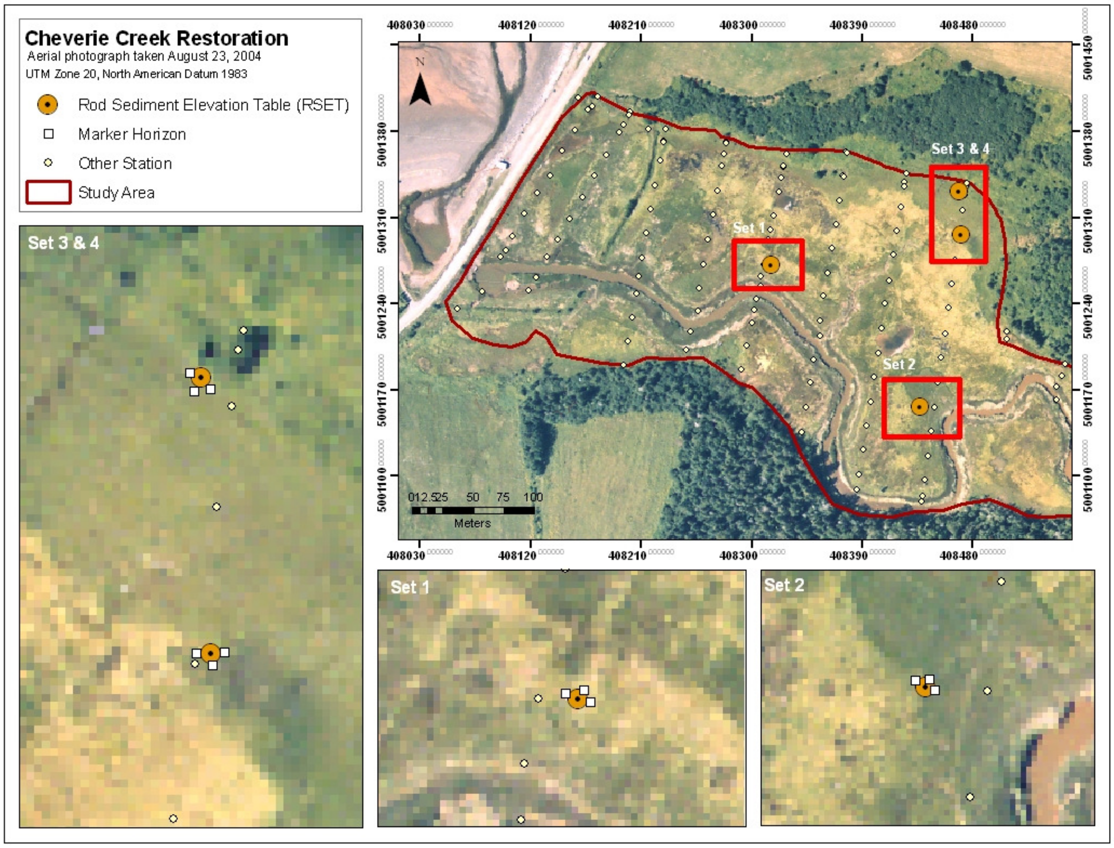


Figure 12 Location of RSETs at CHV and the relative position of the marker horizons at each location.

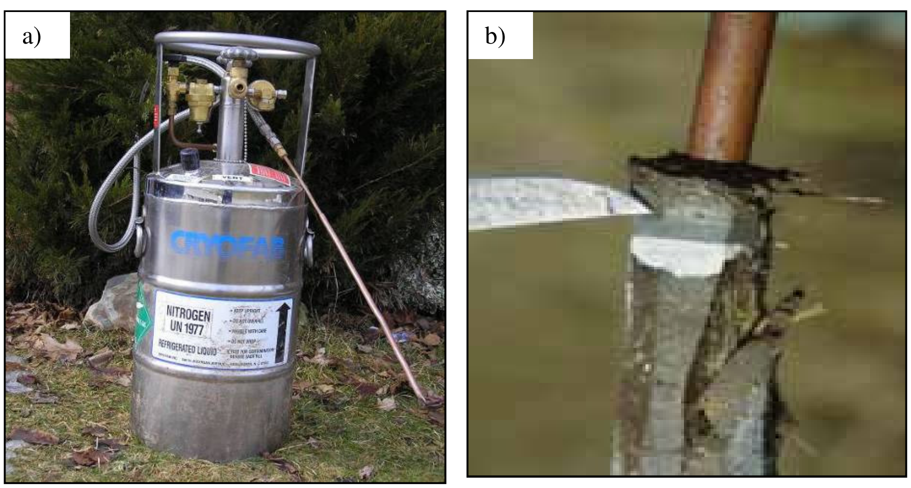


Figure 13 a) Cryogenic corer - Liquid Nitrogen tank with stainless steel tubing and copper "bullet" (photograph by N. Neatt 2008) and b) core on bullet or "marsh-cicle" (USGS 2005) used for RSET and marker horizon calculations.

Soil Characteristics

Field Methods

Sediment cores (bulk density, organic matter (OM) and grain size) were collected at both CHV and CHV-R on using a stratified random sampling procedure paired with a subset of vegetation sampling plots (Figure 7; Figure 8). Sampling was conducted on 23 July 2012 (CHV) and 25 July 2012 (CHV-R).

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 plastic resealable bags, sealed, labeled and transported in a cooler with ice back to the lab where they were placed in a freezer and frozen. Some soil compaction did occur during the coring process, but every attempt was made to avoid further compaction of the samples during transport and storage prior to freezing. The metal tubes were capped on both ends using plastic caps, bagged and labeled. All cores were carefully labeled and sealed using duct tape.

Laboratory Methods

Sediment samples were analyzed by the In_CoaST Research Unit at SMU for organic content using loss on ignition and water content using 'standard' protocols as published in the literature.

<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.

<u>Organic content (using a loss-on-ignition technique):</u> The sediment cores were thawed and removed from the tubes and a known volume of the core was removed, weighed and placed in a crucible for drying at 105 ˚C for 24 hours to determine water content. Once dried, each sample was weighed and placed in a muffle furnace for two hours at 550 ˚C. Samples were then cooled and weighed again to get loss on ignition (LOI) of organic material.

<u>Bulk Density:</u> Dry bulk density was determined from a known volume of material extruded from the syringe cores. Wet samples were weighed and dried at 105 ˚C for 24 hrs, cooled and dry weight determined. The dry weight was divided by the volume to determine dry bulk density.

<u>Sediment Type:</u>

Sediment size (using laser diffraction):

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

Sediment type (using Coulter Laser Multisizer):

The grain size sample was dried at 65 ˚C to prevent fusing of clays and crushed using a mortar and pestle. A small subsample were placed in a 20 ml beaker and treated with 5 ml of 30% hydrogen peroxide within a fume hood to remove organic matter without damaging the particles. The beaker was then filled with an electrolight solution, sonified and processed through the Coulter Multisizer using standard protocols. The 100 micron tube was chosen since this would analyze grain sizes from 2.0 (clay) to 60 microns (coarse silt) which was the anticipated grain size distribution. The average of two runs were used for analysis. The grain size distributions were analyzed using a customize script in Excel and size classes determined using a modified Udden-Wentworth scale (Blott and Pye 2001).

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

Figure 14 Size scale adopted in the GRADISTAT program, 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 below.

3.4 Vegetation

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

Field Methods

The marsh vegetation community was surveyed using a modified point intercept method (Roman et al. 2001). The point intercept method utilizes permanent 1 m^2 plots positioned along each transect. A total of one hundred twenty-nine plots were established at CHV and twenty-seven plots at CHV-R. Landscape photographs were taken along each transect, as well as close-up photographs of each plot.

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

For CHV, plots were positioned every 20 m, starting 0.5 m from the river edge, along transects one through eight. For even numbered transects ten through twenty-six, plots were positioned, starting at the front stake, at 20 m, 60 m, and 100 m with the final plot 0.5 m from the river edge.

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 glabriuscula*, *C. paleacea*, *Distichlis spicata*, *Glaux maritima*, *Juncus gerardii*, *Limonium nashii*, *Plantago maritima*, *Ruppia maritima*, *Salicornia europaea*, *S. alterniflora*, *S. patens*, *S. pectinata*, *Suaeda maritima*, *Triglochin maritima*. For this set of analyses, 2002 and 2004 data from CHV were both used together to define “pre” restoration conditions. For Table 19 (comparison of abundances and plot frequencies for main species) only plots sampled in all years were included. For the univariate analyses (richness, halophytic richness, halophytic abundance, and unvegetated area), the same plots were used. In the ordination, all plots from 2002-2004 and 2012 were included. Only species found in more than one plot are included in the ordination and summary table (Table 19; Figure 54). These were also analyzed using repeated-measures ANOVA. To compare species composition and abundance between sites, we used non-metric multidimensional scaling on Bray-Curtis distances among plots to graph plot differences in vegetation. These analyses were performed using R (v. 2.11.1) using the vegan package for ordination.

3.5 Nekton

Salt marshes support a wide range and abundance of organisms that swim, collectively referred to as nekton, which include fish and many types of invertebrates. Fish and macrocrustaceans are an important ecological link between the primary producers of the marsh (plants) and near shore fisheries (Neckles and Dionne 2000). Their position in the upper levels of the coastal food webs and their dependence on a wide range of food and habitat resources serve to integrate ecosystem elements, processes and productivity (Kwak and Zedler 1997).

Fish are a challenging group to quantify due to their mobility and temporal variability, as well as the difficulties of sampling in, what can be, a heavily vegetated environment with a varied hydrological regime. 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* dominated low marsh areas of salt marshes is one of the substrates Atlantic silversides use for reproduction (egg attachment) (Fay et al. 1983). Atlantic silversides 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 18 September and 16 October 2012 at CHV and on 15 October 2012 at CHV-R, using a combination of beach seine, fyke net and minnow traps (Figure 15; Figure 16). 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).

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. Sampling efforts focused on the marsh surface areas between the causeway and transect three, with draws typically being made from the base of the causeway, the upland edge of marsh between transect one and two and from the dyke between transects two and three (Figure 17). Beach seine sampling at CHV-R was conducted upstream of the causeway-bridge (Figure 18).

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 remained submerged. The fyke net was deployed at a different location each sampling event along the high marsh-low marsh boundary between transect two and transect four at CHV (Figure 17) and between transect two and three at CHV-R (Figure 18).

Smaller species utilizing the salt pannes and tidal creeks were sampled using the minnow traps baited with bread. Traps were set in pannes intersected by transect one, four and seven and in the secondary tidal creek near transect six on each occasion at CHV (Figure 17). At CHV-R, traps were set within the main river channel at transects one, two and three and within the secondary channel adjacent to transect 4 (Figure 18). 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 15 Fish sampling with a beach seine (left) and a minnow trap (right). Photograph by T. Bowron 2006.

Figure 16 Fish sampling with the fyke net at CHV-R. Photograph by T. Bowron, 2008.

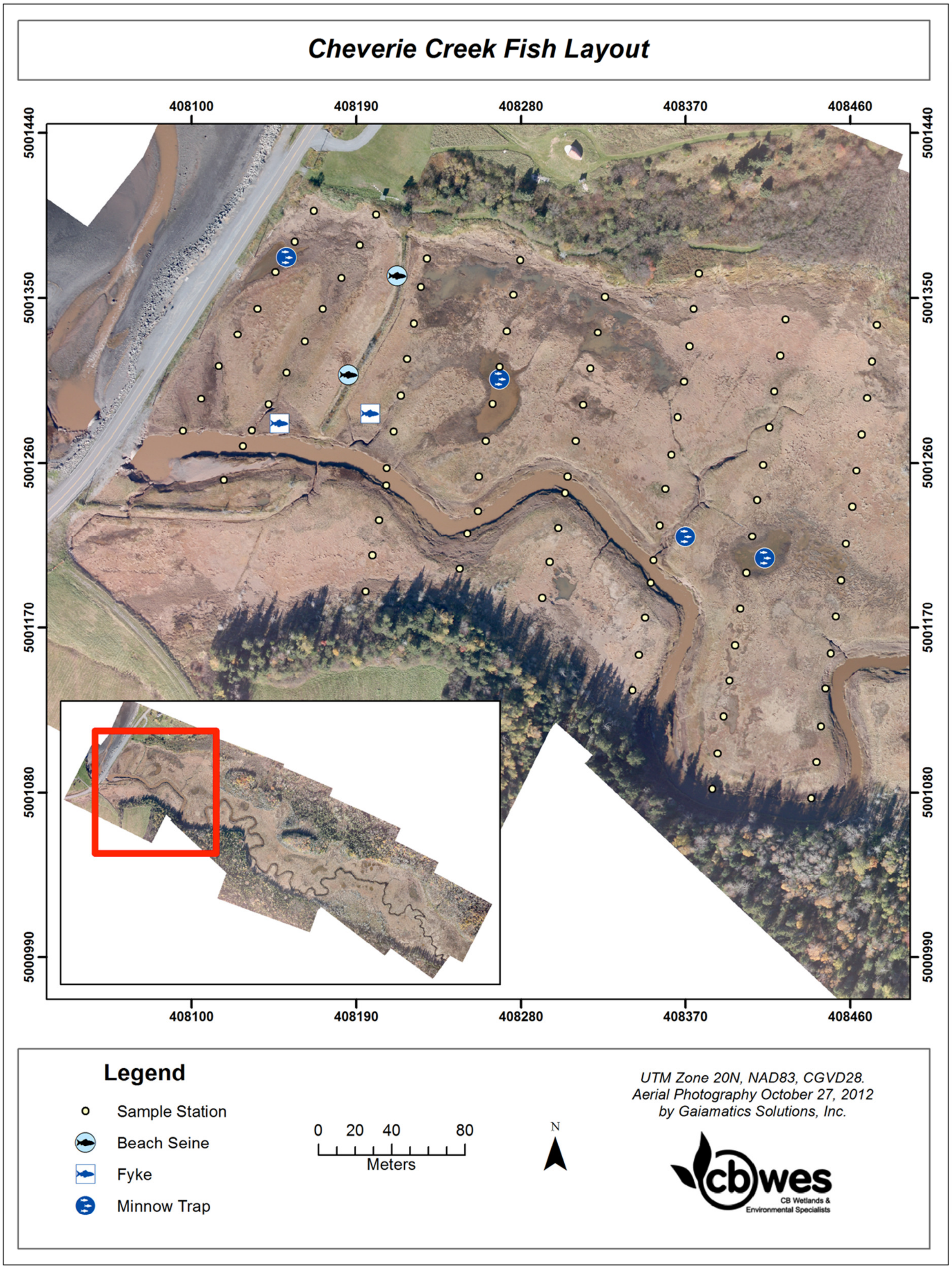


Figure 17 Location of fish sampling with the beach seine, fyke net and minnow traps at CHV during the 2012 field season.

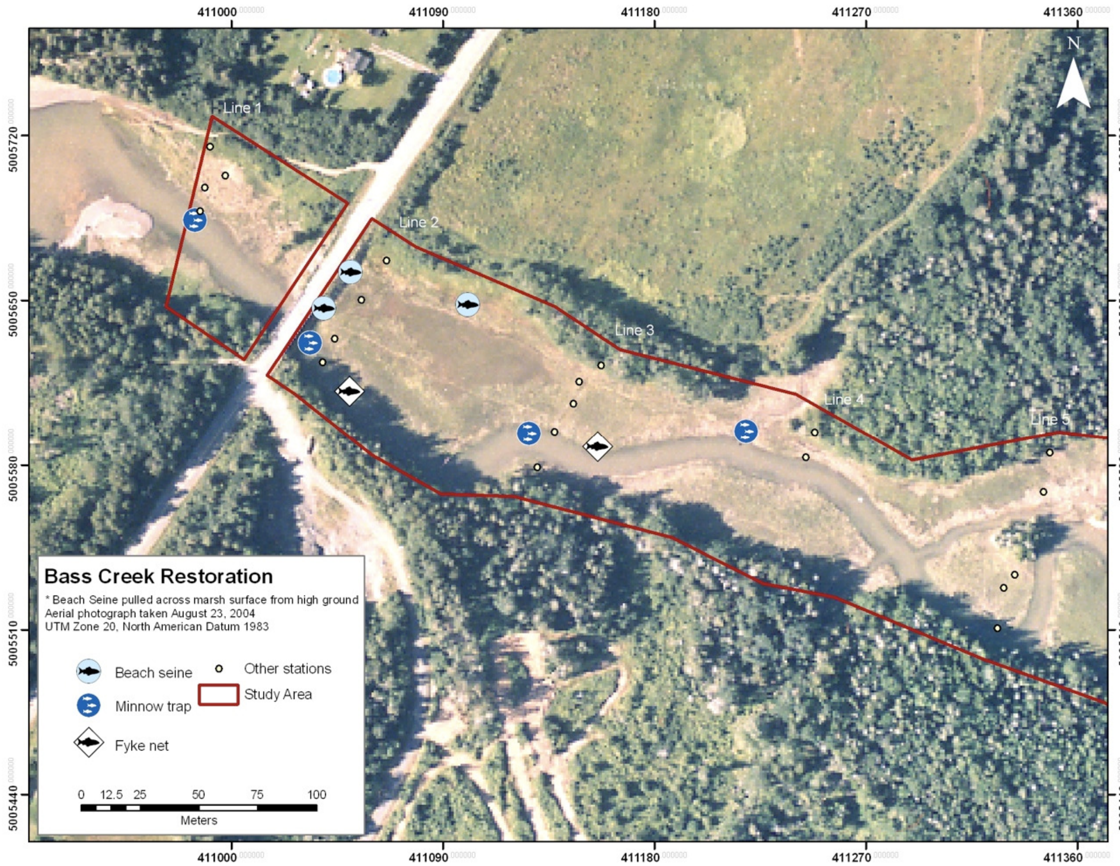


Figure 18 Location of fish sampling with the beach seine, fyke net and minnow traps at CHV-R during the 2012 field season.

3.6 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 - Reference Condition Approach

A Reference Condition Approach or Model (RCA) (Armanini et al. 2012; Reynoldson 2005; Reynoldson et al. 1997; Westhead 2005) was used between 2005 and 2010 to monitor the benthic invertebrate community of the mudflat seaward of the causeway. The results of this monitoring were presented in Bowron et al. 2011a. RCA sampling was only conducted for the first five years following restoration and was not conducted during the seventh (2012) year.

Aquatic Invertebrates

Aquatic invertebrate assemblages within the water column of pannes at CHV and CHV-R were sampled at both sites on 26 July and 16 August 2012 using Invertebrate Activity Traps (IAT; passive sampling). The IAT were left to sample over twenty-four hour period during a neap tide cycle. IATs enable the sampling of a cross-section of organisms from the aquatic biological community including freshwater, estuarine, and marine macroinvertebrates; meiofauna (small organisms such as nematodes, ostracods, copepods); and plankton (e.g. copepods and planktonic stages of invertebrates). Abundance in IAT samples was expressed as the total of all organisms present on a "per sample" basis.

The IAT were constructed from two litre clear plastic (pop) bottles; the top portion was cut off, inverted and taped in place with duct-tape (Figure 19). The top of each bottle was capped with a 3 mm screen in order to reduce the likelihood of capturing fish. The IAT were placed in four pannes (two at CHV and two at CHV-R), submerged and anchored to ensure the trap remained within the panne. Upon retrieval, samples were sieved (0.5 mm) and remaining materials and organisms were field preserved in 70% isopropyl alcohol. Envirosphere Consultants Limited then performed the species identification according the approach described for the RCA sample.

Figure 19 Invertebrate Activity Trap (IAT). Photograph by T. Bowron 2007.

3.7 Structured Winter Walk

On 6 March 2013 a structured winter site-walk was conducted at CHV and CHV-R. Landscape photographs were taken along the first nine transects at CHV and eight transects at CHV-R. Photographs were taken along each transect from a reproducible location (back stake). Additional photographs were taken of key features such as snow/ice, sediment deposition, erosion, river channel, causeway and culvert (CHV).

4.0 Results and Discussion

4.1 Geospatial Attributes

Habitat Map and Digital Elevation Model (DEM)

The 2012 DEM for CHV incorporated LiDAR data obtained in 2007 from the Applied Geomatics Research Center (AGRG) and the 2012 Trimble R8 GNSS RTK survey data. The 2012 DEM is presented in Table 3, Figure 20 and Figure 21. To construct the 2012 DEM, contours were extracted from the LiDAR surface to maintain integrity of the creek bank and upland edges while platform elevations were derived primarily from the 2012 marsh surface elevation survey. The 2012 DEM maintained the overall marsh morphology to a reasonable degree while updating elevation along surveyed transects with greater accuracy. The two areas that continued to display the most notable difference were around the main river channel and along the upland, or terrestrial edge, of the marsh (Figure 22). The habitat map for CHV was also updated in 2012, taking advantage of the geo-referenced low-altitude aerial photography (Figure 23). As can be seen by the expansion of *S. alterniflora* throughout the marsh (Figure 24), increasing tidal flow to the site has resulted in the recovery of salt marsh habitat conditions as indicated by the increased spatial extent of key halophytic vegetation species throughout the site.

The 2012 DEM for CHV-R showed little change over the previous elevation surveys (Table 3; Figure 24). This was evident in both the DEM and the representative transect elevation profiles (Figure 26). The variation in elevation profiles between the years was primarily a result of the sampling intensity, particularly along the creek edge; greater number of survey points taken during the 2006 survey and an artifact of the GIS program used to produce the DEM. The elevation profiles for CHV show a similar pattern along the creek edge because of the accuracy of the source data (LiDAR) (Figure 22). Extreme changes in elevation, such as those present along the creek edge at both CHV-R and CHV, are challenging for many interpolation methods to accurately model. While Topogrid is designed to correctly represent ridges and streams, it also maintains surface continuity of global interpolations (ESRI Desktop help, ArcGIS 9.3). As such it produces a smooth elevation in un-surveyed areas[12]. The length and sinuosity of the channels at CHV and CHV-R create several data voids, which results in much of the difference between the pre- and post-restoration elevation profiles for both sites along the creek edge.

Table 3 DEM details for CHV and CHV-R.

	CHV-R				CHV			
	2006	**2008**	**2010**	**2012**	**2005**	**2007**	**2010**	**2012**
Minimum elevation (m)	3.37	4.09	4.09	3.51	2.63	3.3	3.39	3.46
Maximum elevation (m)	9.14	10.32	9.29	9.29	9.78	8.11	7.98	9.55
Mean elevation (m)	5.62	5.97	5.9	5.90	5.71	5.92	5.76	5.90
Standard deviation (m)	1.01	0.88	0.79	0.79	1.09	0.57	0.66	0.58

CHV-R marsh surface tended to exhibit a continuous increase in elevation from the creek edge to the upland (Figure 27), whereas CHV experienced an increase in elevation with distance from

[12] http://gisdata.usgs.net/WebAppContent/HydroSHEDS/datasets.php

the creek edge and peaking in what can be characterized as the mid-high marsh zone (Figure 22). This is followed by a decrease in elevation before again rising into the upland. The presence of this elevation plateau at CHV is expected for a larger tidal marsh system and for one that has a history of being tidally restricted. The presence of the tidal barrier at CHV resulted in the reduced frequency and extent of tidal flooding of the marsh surface as well as an increase in the residency time of floodwaters on the marsh surface (longer period of time required to drain through small culvert). This would have resulted in those areas of the marsh (low to mid marsh zones) that did experience tidal inundation to experience higher rates of sediment accretion than those areas of marsh not regularly flooded. As the marsh surface plateau developed it would further reduce the extent and frequency of flooding of the upper reaches of the marsh, further reducing the supply of sediment to these areas. This would, over time, result in the development of the elevation profile that can be seen for CHV.

The same phenomenon has also resulted in a similar elevation profile with distance from the causeway (upstream). The elevation of the marsh surface at the front/mouth of the system, as a result of flooding during the sites hydrologically restricted period, are higher than those further upstream. This is particularly evident by the flood pattern of the site which shows tidal waters reaching "breakout" elevations and flooding the back portion of the site while remaining confined to the channel in the front portion of the marsh (Figure 33).

Particularly over the first three years of post-restoration monitoring it was observed that the elevation plateau at CHV had significant implications for habitat conditions and the recovery process following restoration of a larger, more natural tidal regime to the site. The development of the marsh surface plateau would have greatly influenced the hydrology of the site as it would have reduced the number of tides capable of flooding the broader marsh surface, while at the same time reducing or preventing the drainage of flood and surface water from those areas. This could explain the presence of large wet areas within the high marsh zone of CHV (i.e. transects 3 to 5) prior to culvert replacement that were observed retaining water for part of the season, but which tended to dry up towards the end of the summer (Bowron and Neatt 2007). Following restoration many of these same areas have been observed to be retaining water for greater lengths of time, developing into actual salt pannes, and the establishment of new pannes in areas were none previously existed (e.g. transect 7 and 8). The improved habitat quality of the salt panne complex between transect 4 and 5 was discussed in Bowron et al. (2008), as was the establishment of a new panne near transect 3. Similar elevation patterns and habitat conditions were not present at CHV-R due to the absence of a tidal barrier and the size of the marsh.

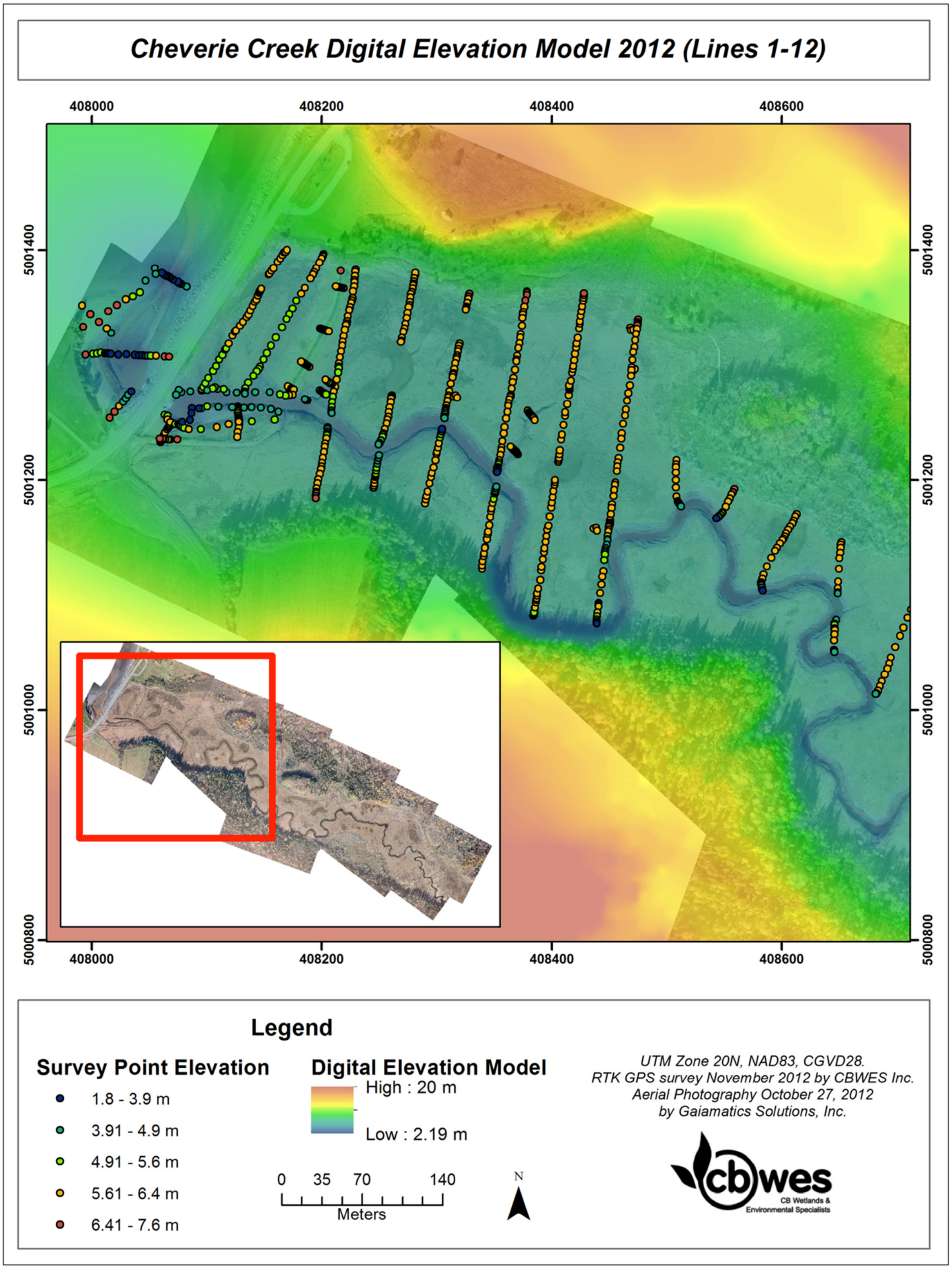


Figure 20 DEM for the front portion of CHV (transects 1 – 12).

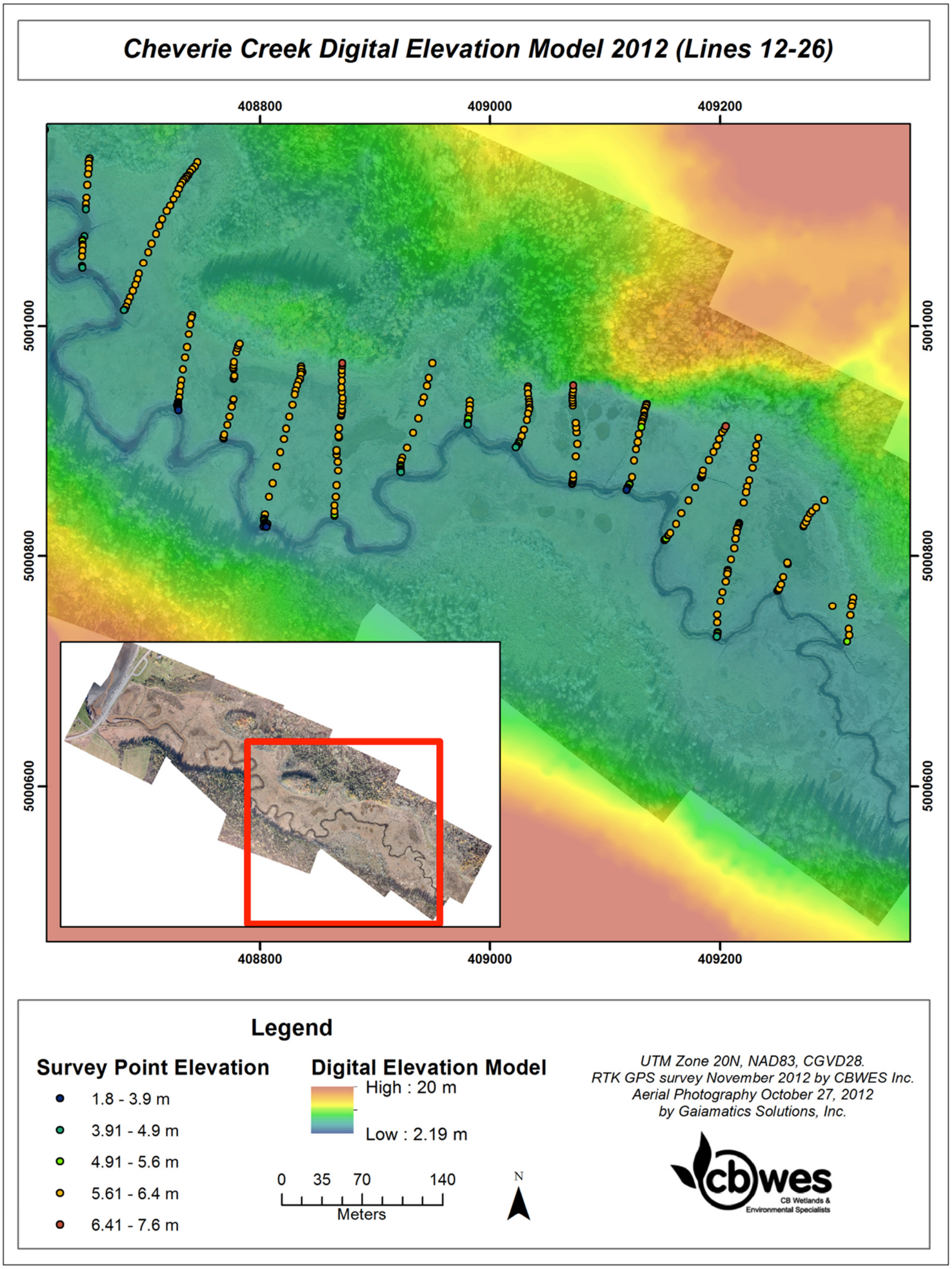


Figure 21 DEM for the CHV back half of CHV (transects 12-26).

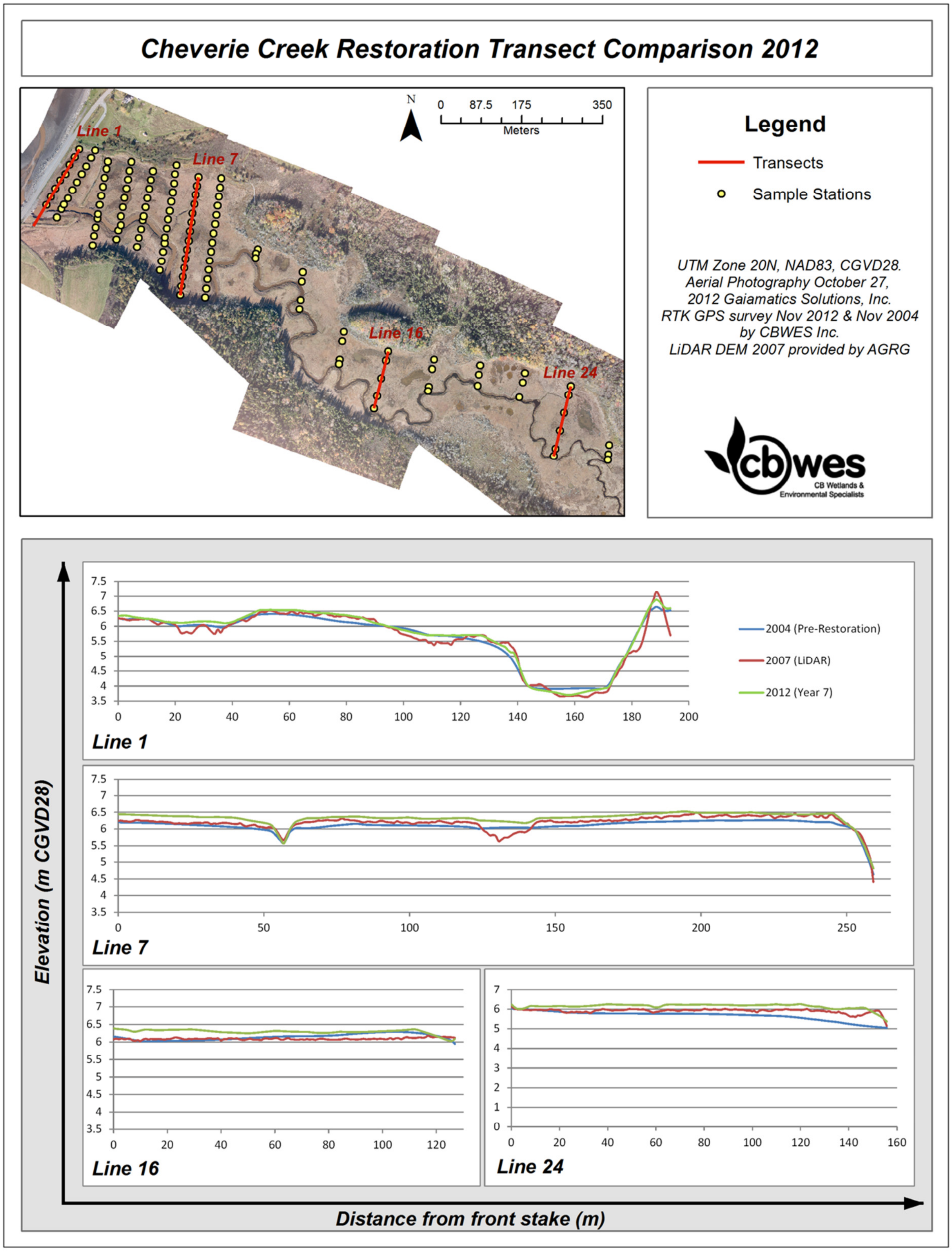
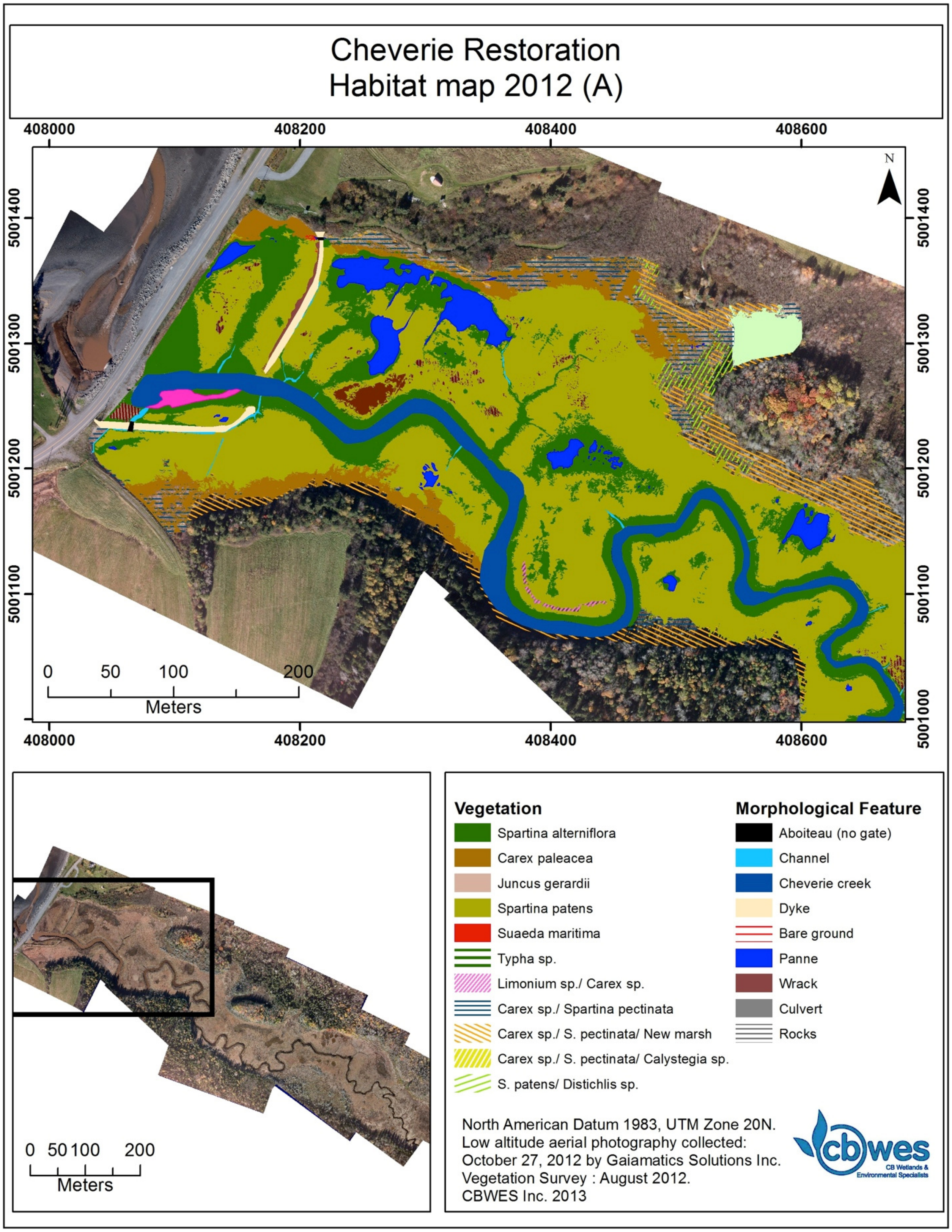
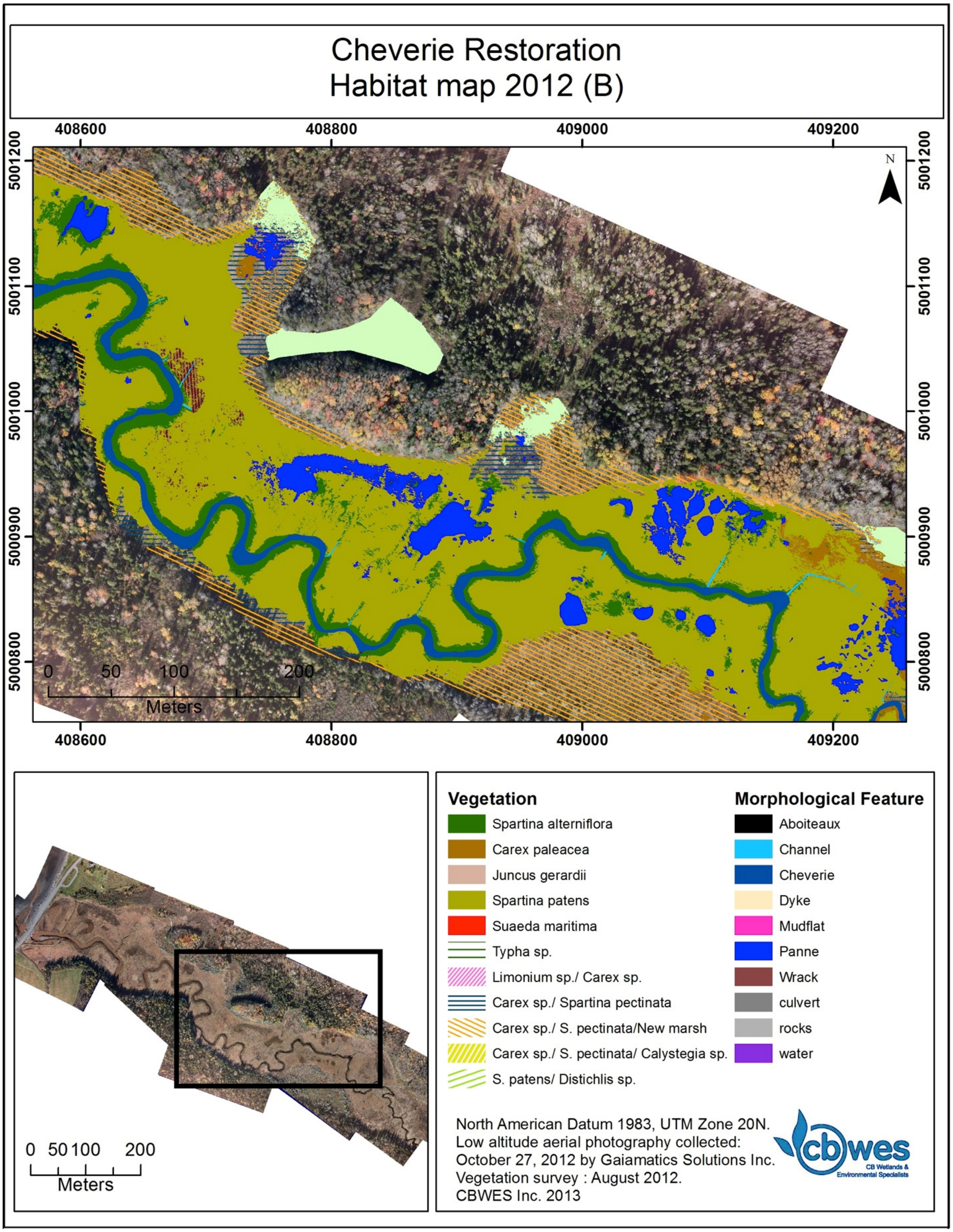


Figure 22 Change in marsh surface elevation at CHV pre- versus post-restoration, utilizing representative transects.



Cheverie Restoration
Habitat map 2012 (A)
408000
408200
408400
408600
5001400
5001300
5001200
5001100
5001000
N
0 50 100 200
Meters
0 50 100 200
Meters
Vegetation
Spartina alterniflora
Carex paleacea
Juncus gerardii
Spartina patens
Suaeda maritima
Typha sp.
Limonium sp./ Carex sp.
Carex sp./ Spartina pectinata
Carex sp./ S. pectinata/ New marsh
Carex sp./ S. pectinata/ Calystegia sp.
S. patens/ Distichlis sp.
Morphological Feature
Aboiteau (no gate)
Channel
Cheverie creek
Dyke
Bare ground
Panne
Wrack
Culvert
Rocks
North American Datum 1983, UTM Zone 20N.
Low altitude aerial photography collected:
October 27, 2012 by Gaiamatics Solutions Inc.
Vegetation Survey : August 2012.
CBWES Inc. 2013
cbwes
CB Wetlands & Environmental Specialists


Cheverie Restoration
Habitat map 2012 (B)
408600
408800
409000
409200
5001200
5001100
5001000
5000900
5000800
N
0 50 100 200
Meters
Vegetation
Spartina alterniflora
Carex paleacea
Juncus gerardii
Spartina patens
Suaeda maritima
Typha sp.
Limonium sp./ Carex sp.
Carex sp./ Spartina pectinata
Carex sp./ S. pectinata/New marsh
Carex sp./ S. pectinata/ Calystegia sp.
S. patens/ Distichlis sp.
Morphological Feature
Aboiteaux
Channel
Cheverie
Dyke
Mudflat
Panne
Wrack
culvert
rocks
water
0 50 100 200
Meters
North American Datum 1983, UTM Zone 20N.
Low altitude aerial photography collected:
October 27, 2012 by Gaiamatics Solutions Inc.
Vegetation survey : August 2012.
CBWES Inc. 2013
cbwes
CB Wetlands & Environmental Specialists

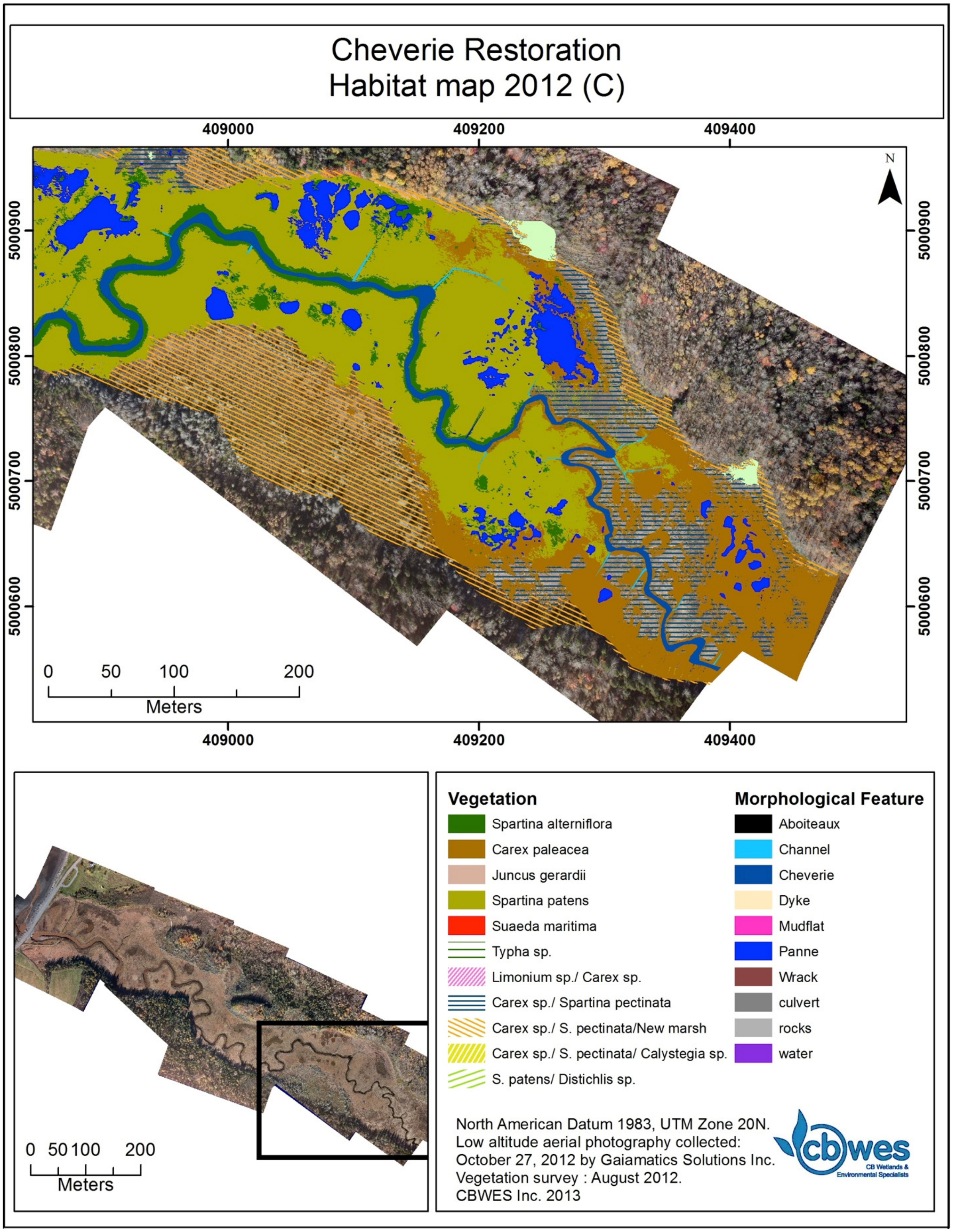
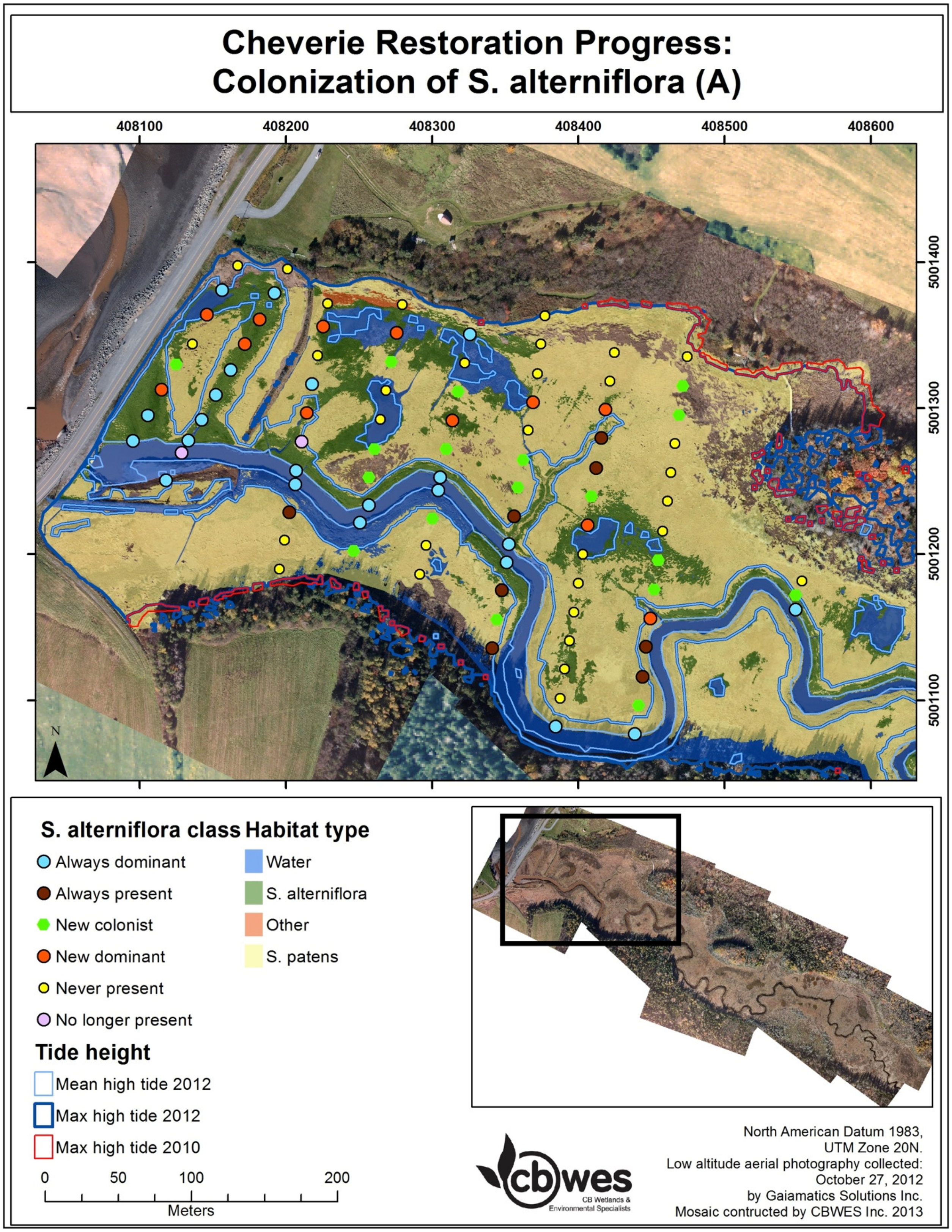
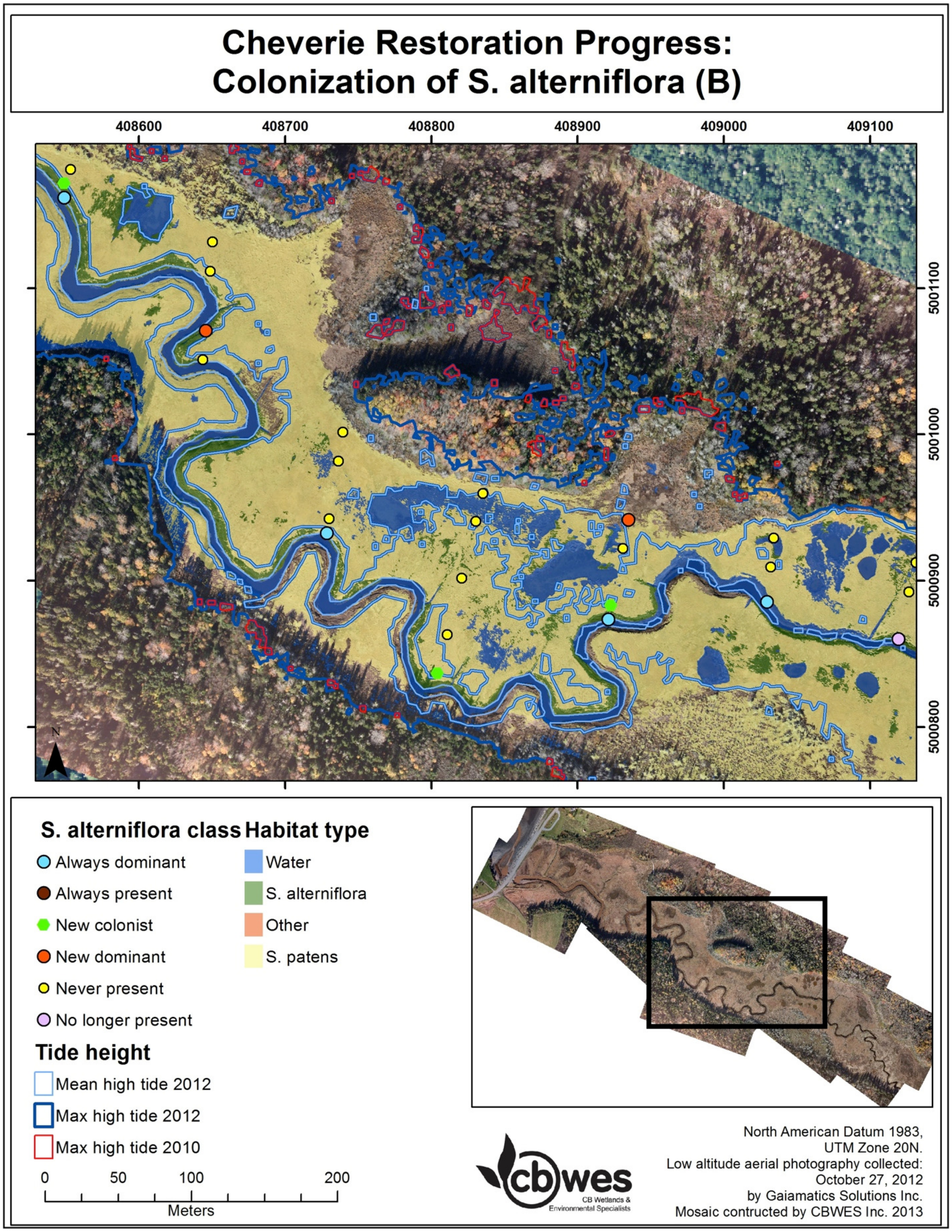


Figure 23 (a-c) 2013 habitat map for CHV, based on 2007 lidar, 2012 DEM and the 2012 vegetation survey.


Cheverie Restoration Progress:
Colonization of S. alterniflora (A)
408100
408200
408300
408400
408500
408600
5001400
5001300
5001200
5001100
N
S. alterniflora class
Always dominant
Always present
New colonist
New dominant
Never present
No longer present
Habitat type
Water
S. alterniflora
Other
S. patens
Tide height
Mean high tide 2012
Max high tide 2012
Max high tide 2010
0
50
100
200
Meters
cbwes
CB Wetlands & Environmental Specialists
North American Datum 1983,
UTM Zone 20N.
Low altitude aerial photography collected:
October 27, 2012
by Gaiamatics Solutions Inc.
Mosaic contructed by CBWES Inc. 2013


Cheverie Restoration Progress:
Colonization of S. alterniflora (B)
408600
408700
408800
408900
409000
409100
5001100
5001000
5000900
5000800
N
S. alterniflora class
Always dominant
Always present
New colonist
New dominant
Never present
No longer present
Habitat type
Water
S. alterniflora
Other
S. patens
Tide height
Mean high tide 2012
Max high tide 2012
Max high tide 2010
0
50
100
200
Meters
cbwes
CB Wetlands & Environmental Specialists
North American Datum 1983,
UTM Zone 20N.
Low altitude aerial photography collected:
October 27, 2012
by Gaiamatics Solutions Inc.
Mosaic contructed by CBWES Inc. 2013

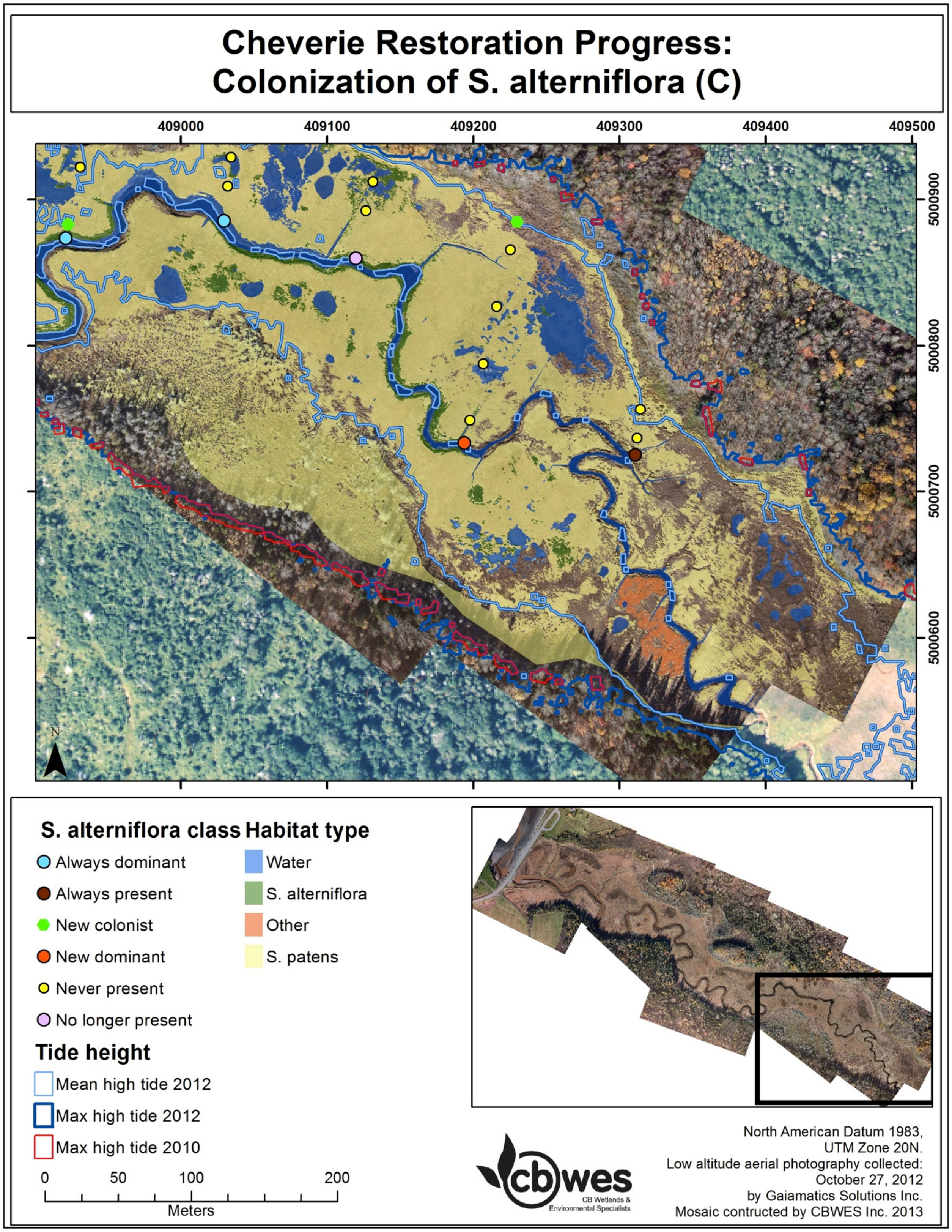


Figure 24 (a-c) Salt marsh habitat recovery at CHV following restoration indicated by the expansion (colonization) of *S. alterniflora* throughout the site.

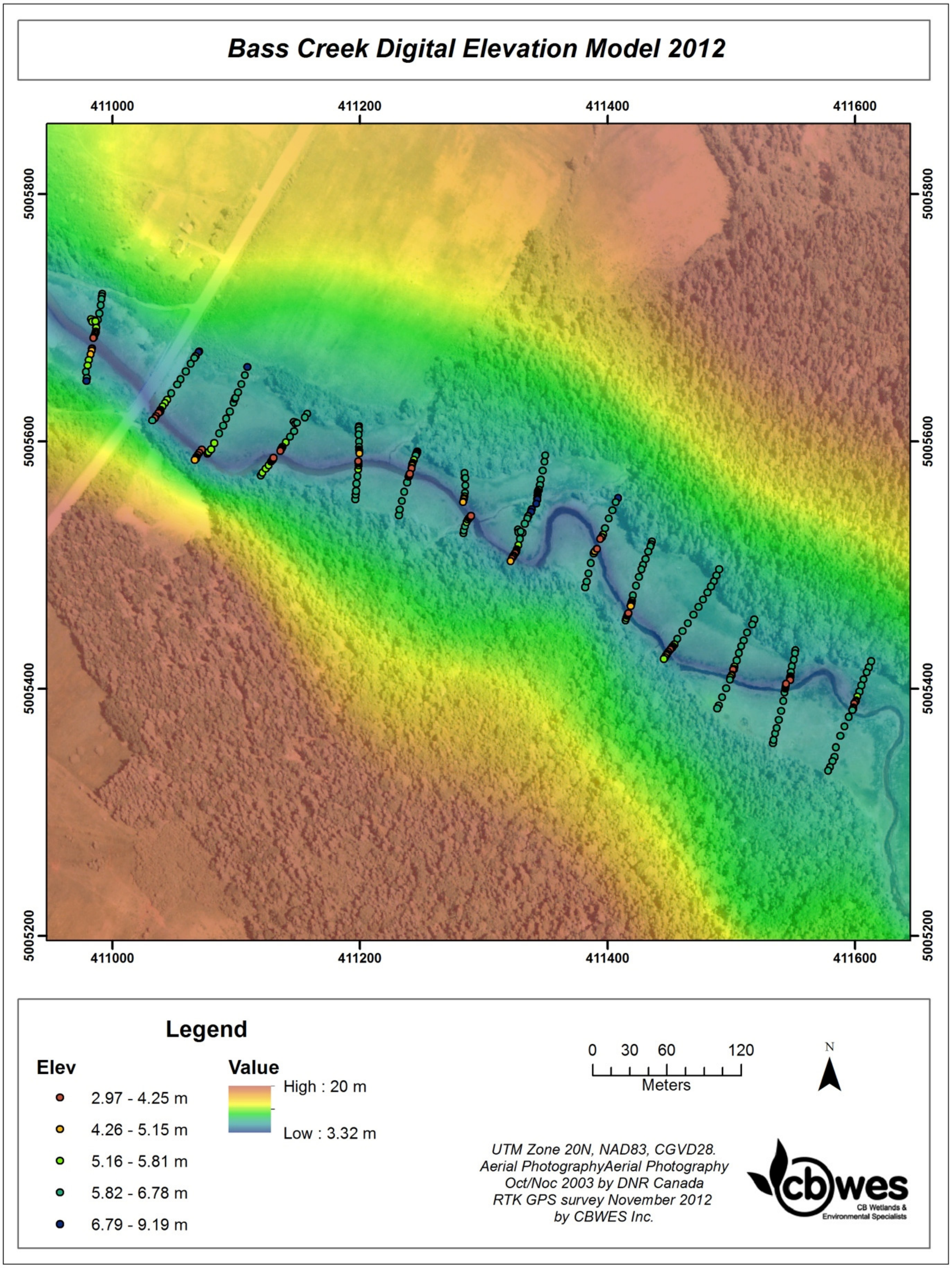


Figure 25 The DEM for CHV-R.

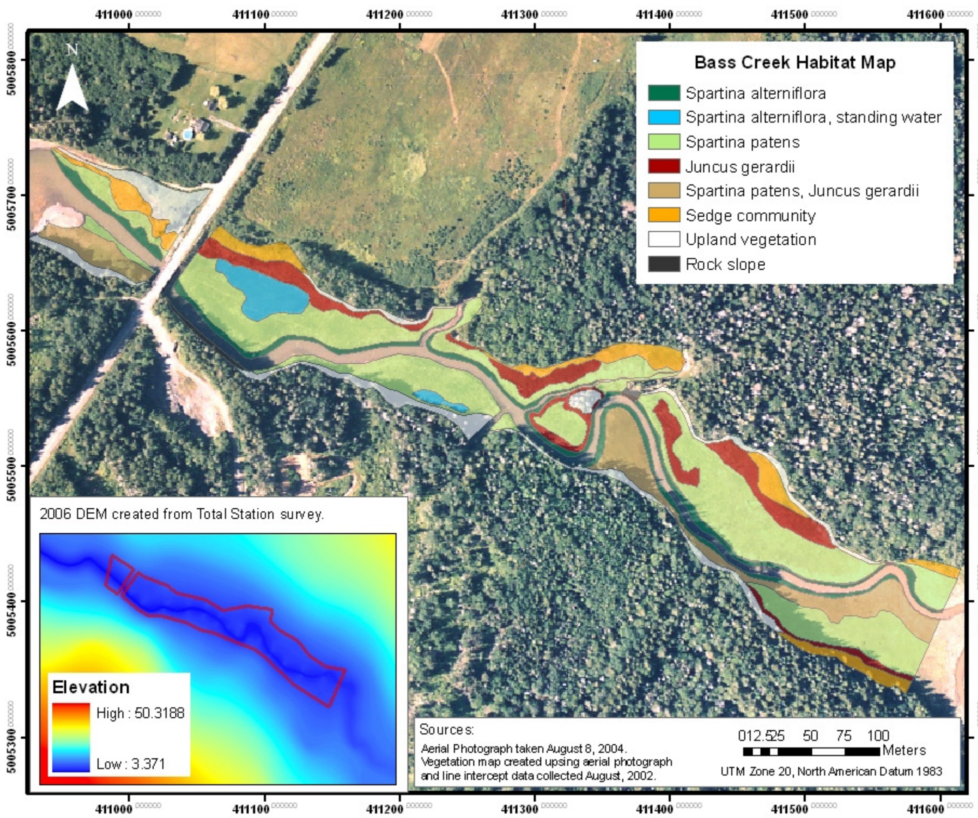


Figure 26 CHV-R habitat map with DEM (insert).

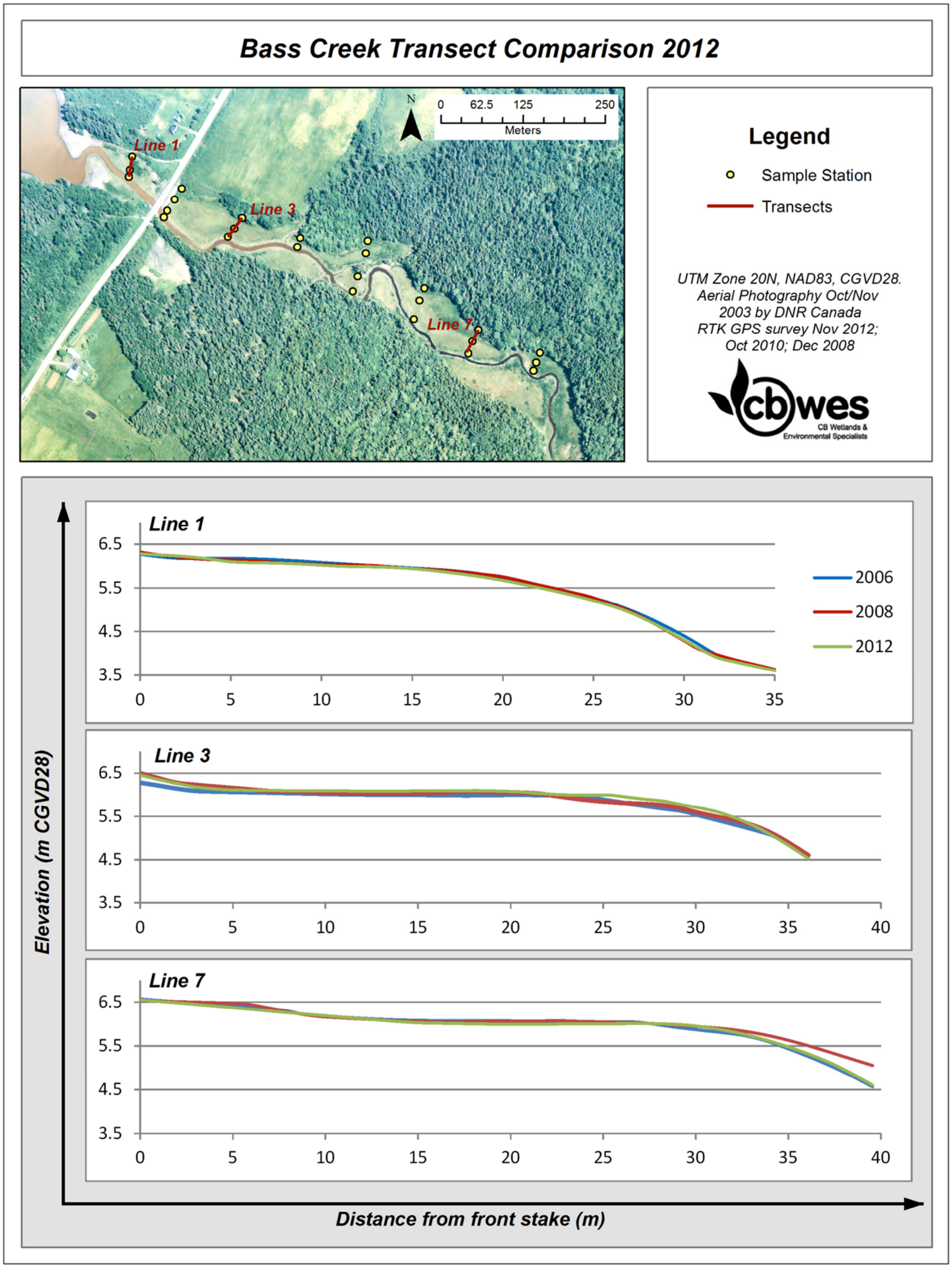


Figure 27 Change in marsh surface elevation at CHV-R utilizing representative transect profiles (2006, 2008, 2012).

4.2 Hydrology

Hydroperiod and Tidal Signal

As in previous years, a comparison of the upstream and downstream tidal signals continues to show variation in water levels on either side of the causeway at CHV following restoration (Table 4; Figure 28). Based on the 2012 tide data for CHV, the tidal range upstream was 3.75 m (CGVD28) while the downstream tidal range was 4.01 m (CGVD28), for a difference in water level of 0.27 m. The differences in elevations between years (Table 4) is mainly due to the time of year in which sampling was conducted, as one would expect there to be a difference in mean high water levels throughout the year and between years, as well as a difference in base flow levels in the river (freshwater), and position within the 18.6 year Nodal tide cycle (Desplanque and Mossman 2004; Baart et al. 2012). By comparing just the peak water levels upstream and downstream within each year, the difference in elevation was approximately 0.30 m for each year (Bowron et al. 2008; Bowron et al. 2011b; Figure 28).

A comparison of water levels over a single spring tide (18 September 2012) and a single neap tide (10 September 2012) event indicated that the new culvert continues to have a limited restrictive influence on hydrological conditions upstream of the causeway (Figure 29; Figure 30). This restriction manifests as a reduced tidal range (the 30 cm difference indicated previously), and a delay in peak elevation (~10 minutes). This restriction only occurs on tides greater than 7.11 m (CGVD28) in elevation, which represents only 4% of recorded tides for 2012 and ~15% of predicted tides for the study period (2005-2012). During neap tide conditions there was more variation in water levels upstream and down, which was due to the reduced influence of tidal conditions and a stronger influence of freshwater (including precipitation) on the upstream (Figure 30).

The upstream and downstream tidal signals for CHV and CHV-R are presented in Figure 28 and Figure 32. During this period, the highest recorded tide downstream at CHV was 7.25 m (CGVD28) (7.13 m upstream). The highest recorded tide during this period at CHV-R was 7.30 m (CGVD28). Utilizing the recorded tide signals and DEMs, hypsometric curves for the two sites were produced (Figure 32).

Based on the hypsometric curve, a 7.2 m tide would flood the full 5.4 ha (53,762 m^2) of marsh at CHV-R (Figure 34), while a 7.1 m tide (elevation at which the culvert begins to restrict flow) would flood approximately 43 ha of marsh at CHV (Figure 33). Based on the tide level recorder data from 2006, 2008, 2010 and 2012 for CHV, we know that exceptionally high tides will flood an area upstream of the causeway on the order of 45 ha (Table 4). However, it is known from on-site observations, vegetation surveys and LiDAR data that there was no die-off of upland/terrestrial vegetation at these higher elevations, nor replacement by wetland species. Therefore, although this zone may occasionally experience tidal flooding, it was not considered new marsh area (not wetland).

It was based on the 7.1 m (CGVD28) tide elevation (a level exceeded by ~15% of predicted high tides for the period of 2005-2012), which matched to the on-site surveyed vegetation die-off boundary (new high marsh – upland boundary) and the LiDAR based DEM, that the area of restored marsh (43 ha) was calculated (Figure 33).

The two sites, because of elevation, share a similar flood pattern. The “break–out” tide level (flooding beyond the main channel) for both sites is approximately 5 m, while flooding the majority of the marsh surface occurs on tides greater than 5.5 m. It is interesting to note that the mean tide flood pattern for CHV shows tidal waters confined to the channel in the front portion of the marsh, while flooding half of the marsh platform at the back (Figure 33). Such a flood pattern supports the impact of the previously restricted status of this site; reduced tidal flooding of the back portion of the site resulted in less deposition of materials and thus a lower elevation than the front portion of the marsh, which did experience tidal flooding.

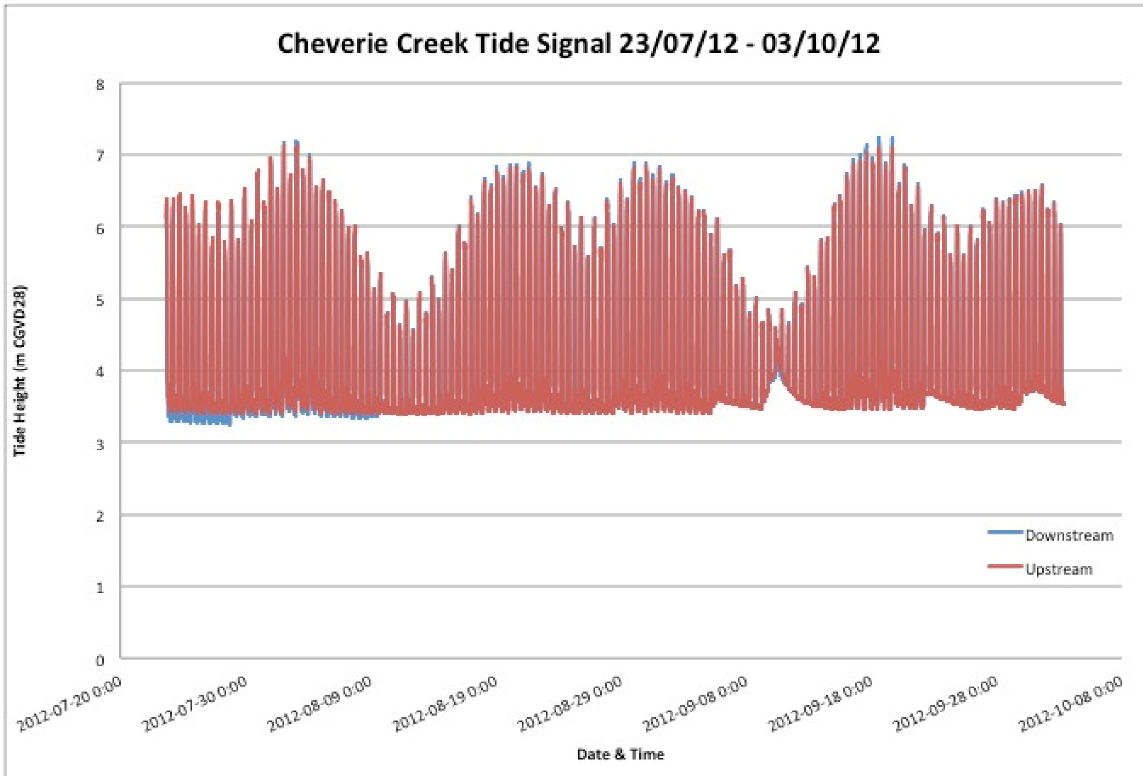


Figure 28 Tidal signal for CHV, upstream (US) compared to downstream (DS).

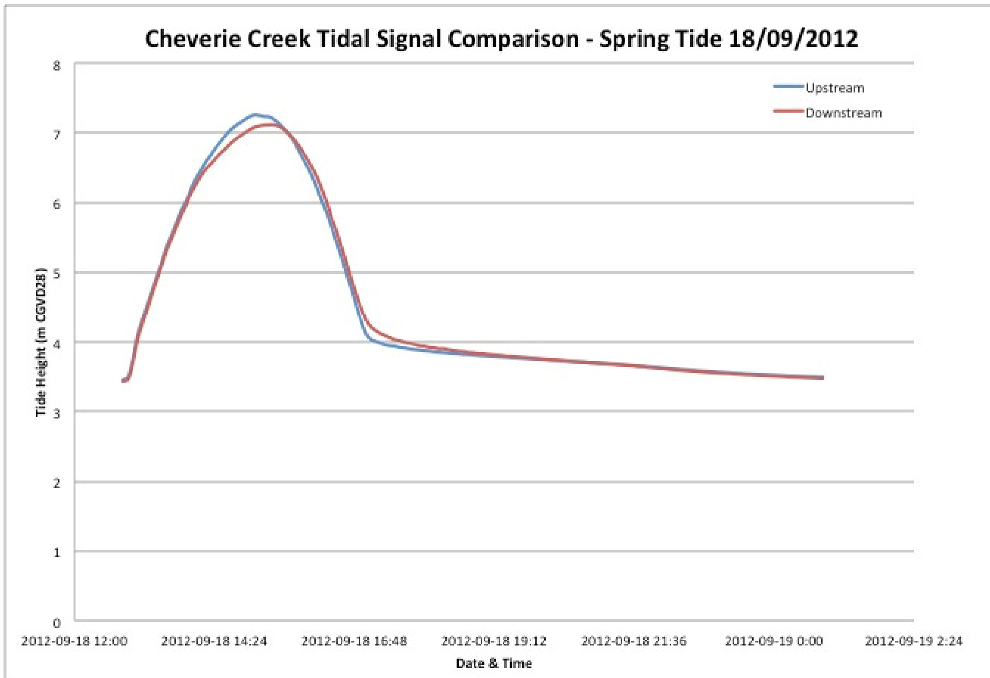


Figure 29 Upstream and downstream tidal signal for CHV over a single spring tide (high water) event.

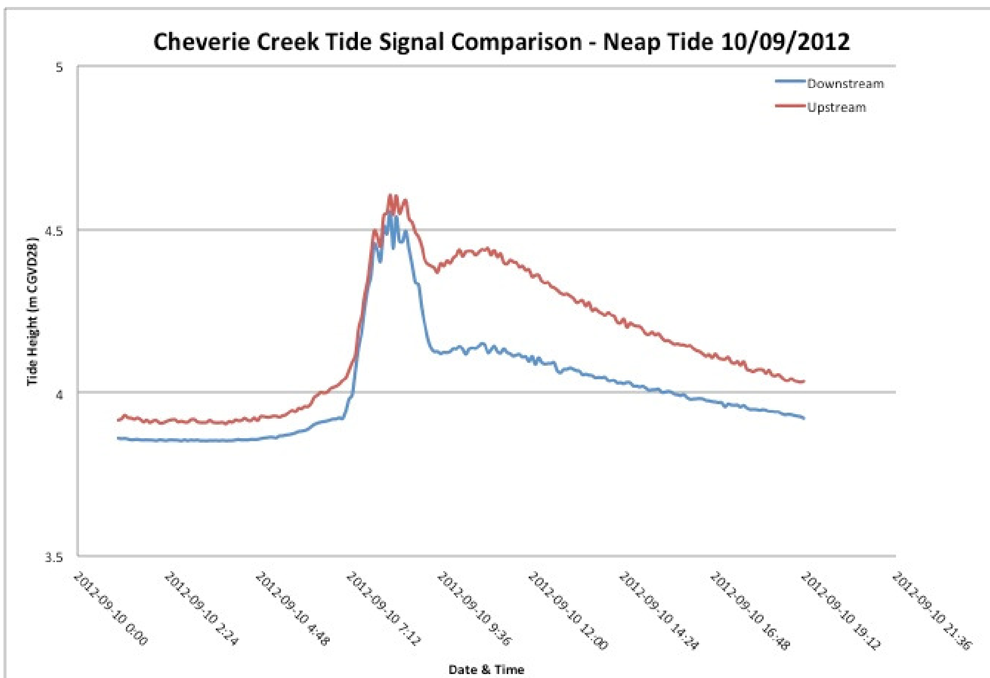


Figure 30 Upstream and downstream tidal signal for CHV over a single neap tide (low high water) event.

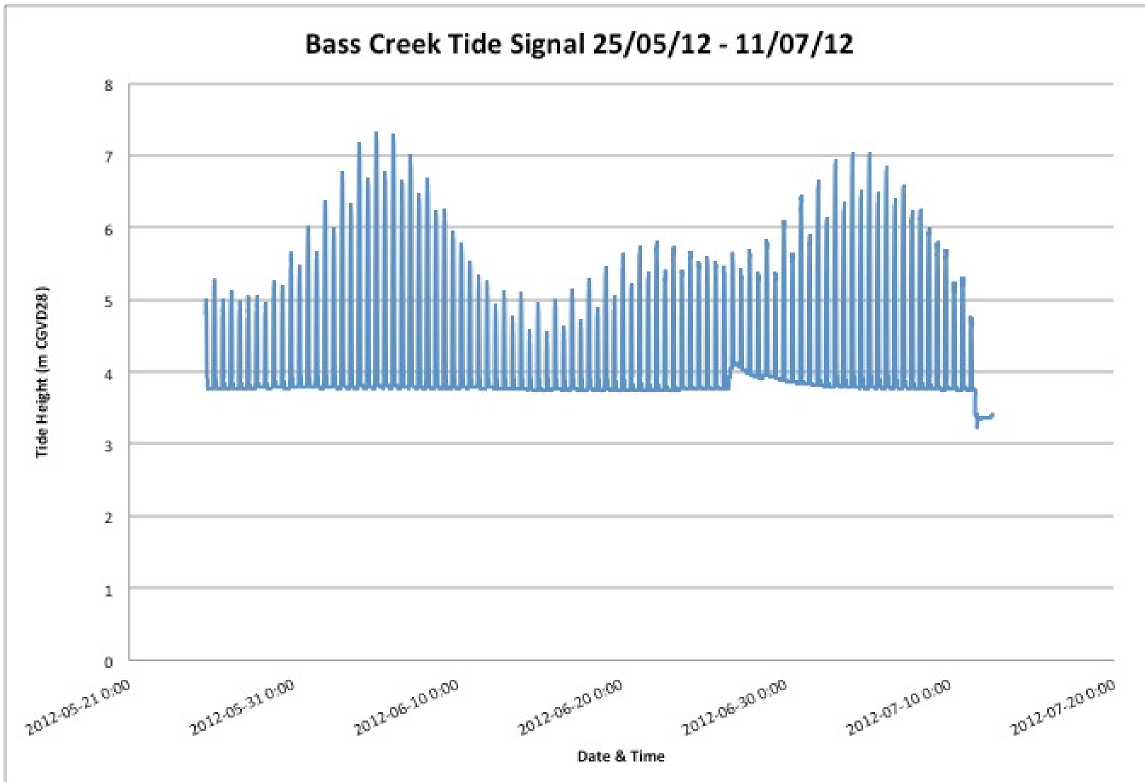


Figure 31 Tidal signal for CHV-R, 2012.

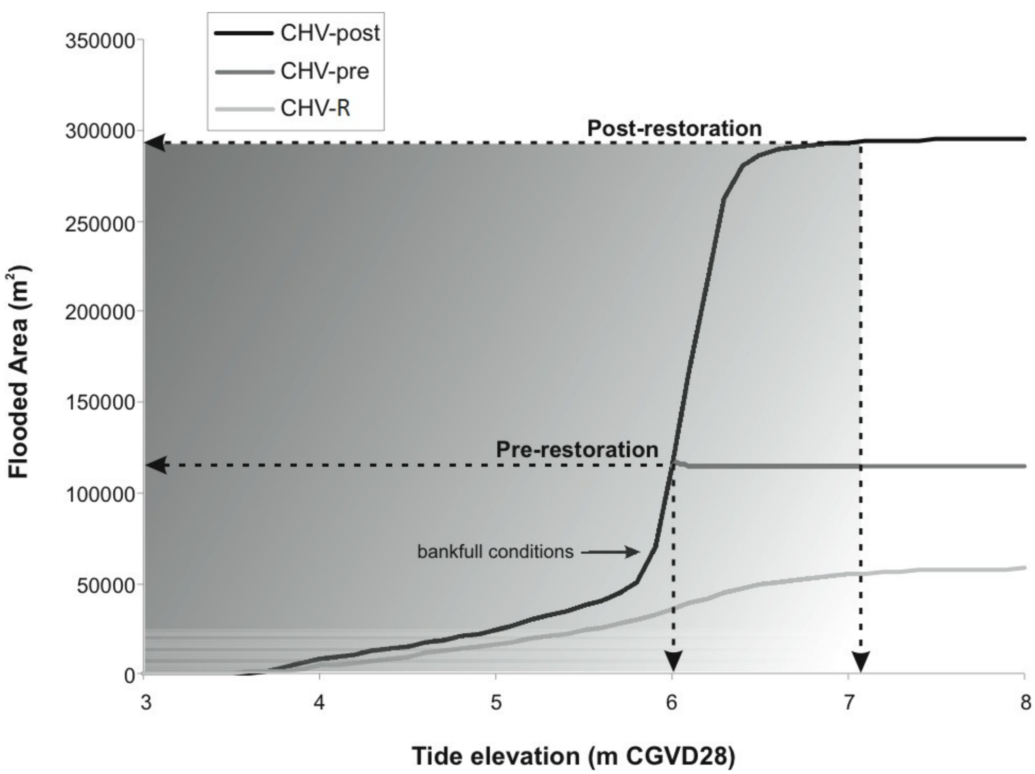
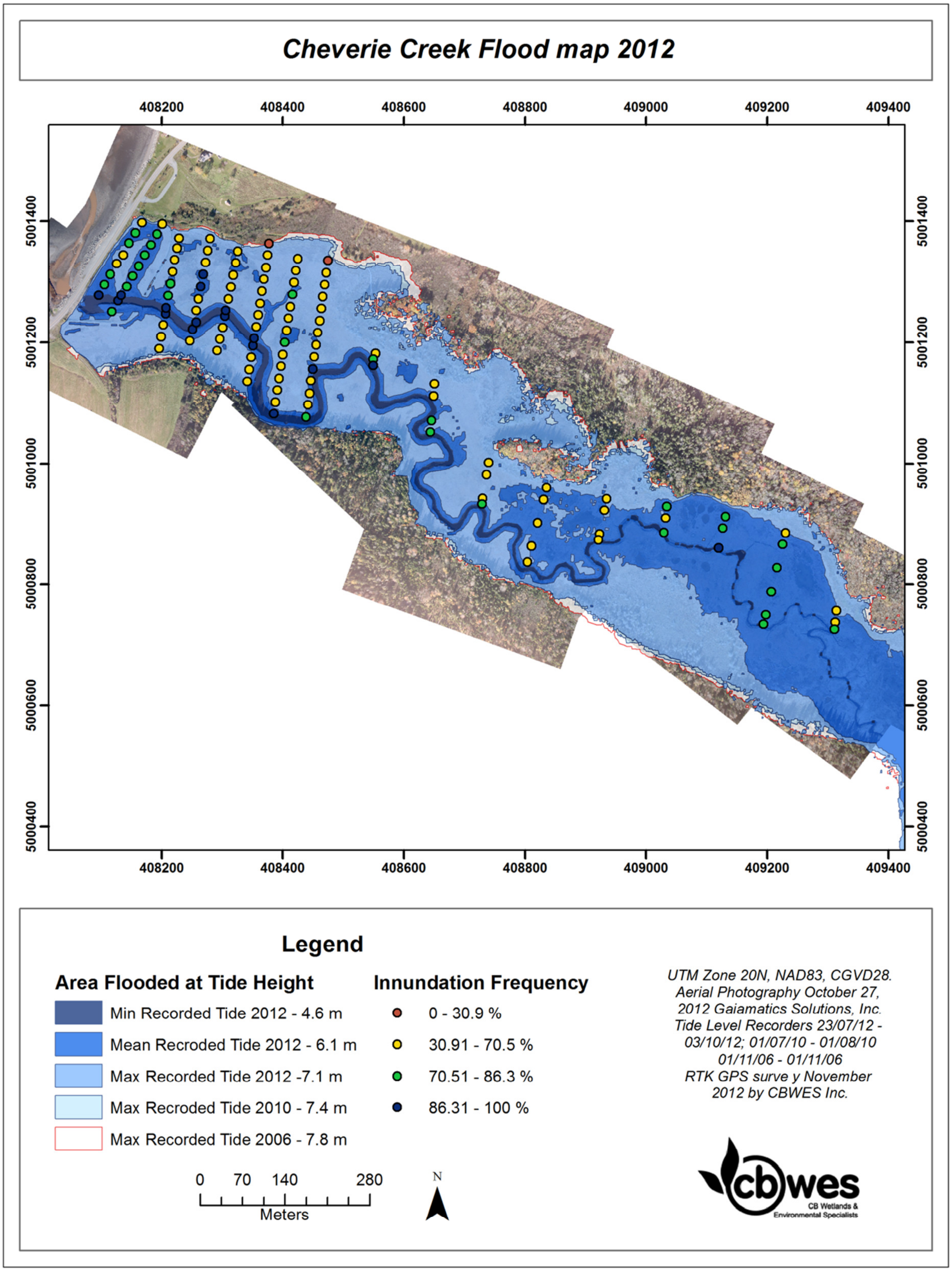


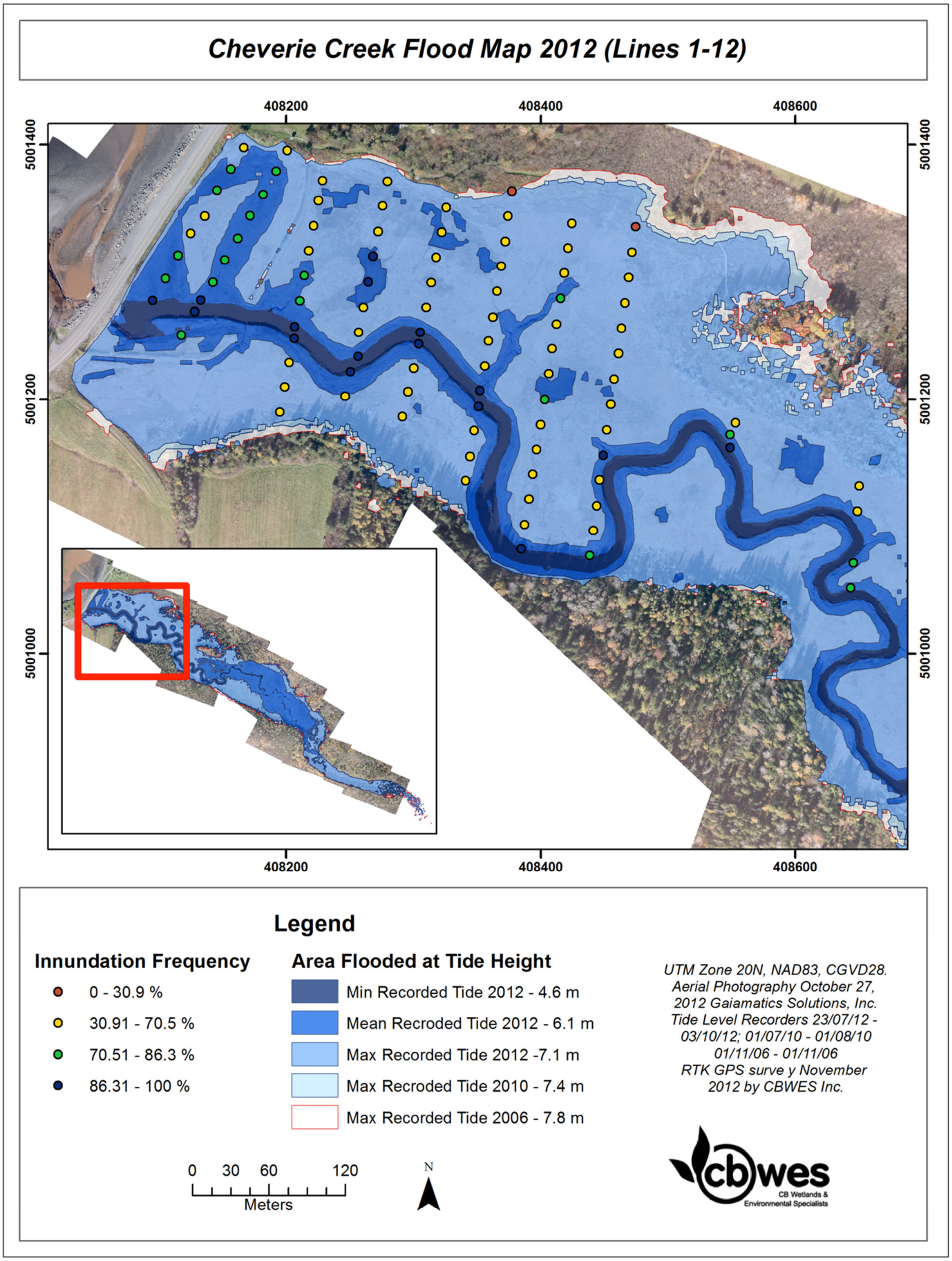
Figure 32 Hypsometric curve for CHV and CHV-R.

a)



Cheverie Creek Flood map 2012
408200
408400
408600
408800
409000
409200
409400
5001400
5001200
5001000
5000800
5000600
5000400
Legend
Area Flooded at Tide Height
Min Recorded Tide 2012 - 4.6 m
Mean Recroded Tide 2012 - 6.1 m
Max Recorded Tide 2012 -7.1 m
Max Recroded Tide 2010 - 7.4 m
Max Recorded Tide 2006 - 7.8 m
Innundation Frequency
0 - 30.9 %
30.91 - 70.5 %
70.51 - 86.3 %
86.31 - 100 %
UTM Zone 20N, NAD83, CGVD28.
Aerial Photography October 27,
2012 Gaiamatics Solutions, Inc.
Tide Level Recorders 23/07/12 -
03/10/12; 01/07/10 - 01/08/10
01/11/06 - 01/11/06
RTK GPS surve y November
2012 by CBWES Inc.
0 70 140 280
Meters
N
cbwes
CB Wetlands & Environmental Specialists

b)


Cheverie Creek Flood Map 2012 (Lines 1-12)
408200
408400
408600
5001400
5001200
5001000
Legend
Innundation Frequency
0 - 30.9 %
30.91 - 70.5 %
70.51 - 86.3 %
86.31 - 100 %
Area Flooded at Tide Height
Min Recorded Tide 2012 - 4.6 m
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RTK GPS surve y November 2012 by CBWES Inc.
0 30 60 120
Meters
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c)

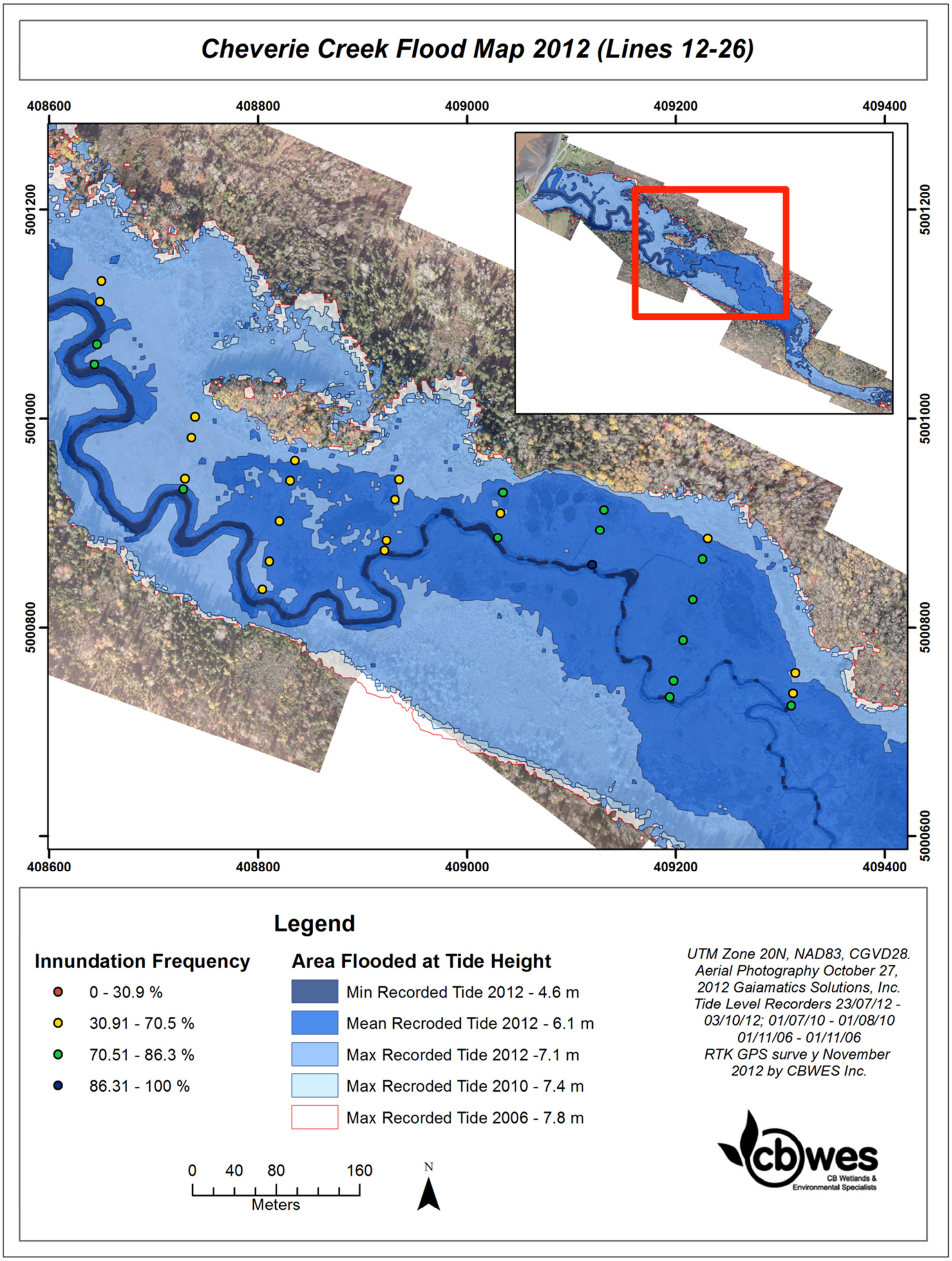


Figure 33a,b,c Flood maps for CHV based on recorded tide levels between 2006 and 2012.

Table 4 Tide elevation statistics for CHV, 2006, 2007, 2010 and 2012.

	Tide level (m CGVD28)				Area covered at tide height (ha)			
	2006	**2007**	**2010**	**2012**	**2006**	**2007**	**2010**	**2012**
Recording Period Start	1-Nov-03	1-Nov-11	1-Jul-06	23-Jul-12	--	--	--	--
Recording Period Finish	1-Nov-24	1-Dec-18	1-Aug-16	3-Oct-12	--	--	--	--
Recording Period Duration (Days)	21	37	41	70	--	--	--	--
Min Upstream	4.16	3.82	3.50	4.6	--	--	--	--
Max Upstream	7.76	7.47	7.40	7.13	48.44	45.70	45.01	44.74
Min Downstream	--	3.79	3.07	4.55	--	--	--	--
Max Downstream	--	8.37*	7.70	7.25	--	--	--	--

*A downstream tide elevation of 8.37 m was recorded on 25 November 2007 (during a neap tide cycle), but with no corresponding upstream peak – unexpected high water event (storm) combined with heavy ice.

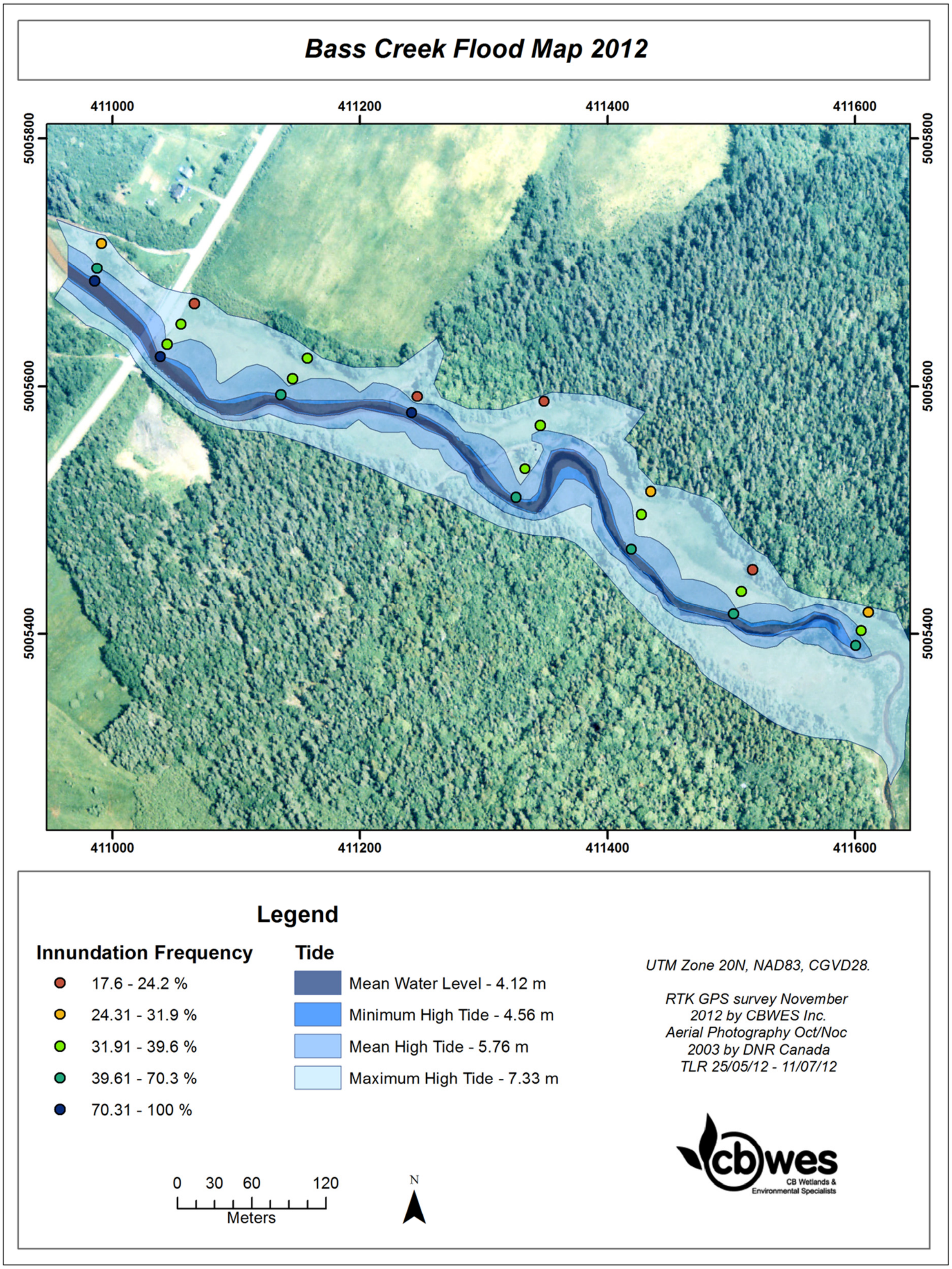


Figure 34 Flood map for CHV-R based on 2012 recorded tide elevations.

Depth to Groundwater

The fifth year post-restoration was the only year that no significant difference in depth to groundwater between CHV and CHV-R was detected (2010: *t*-test, t=-1.42, df=28, p=0.165); for all other monitoring years, 2012 included, a statistically significant difference was present between the two sites (2012: t=3.88; p = 0.00076). For the first two years following restoration, no difference in depth was detected between pre and post measurements; however, by year three a significant difference in depth to groundwater was detected between post- and pre-restoration measurements at CHV, which continued through to the 2012 data (t = 9.09; p = 3.61E-12). A similar difference between pre and post was not detected at any point following restoration at CHV-R (t = -0.84; p = 0.41).

Depth to groundwater measurements (all years) from both sites were averaged to show the trend over time. Average depths for 2012 ranged from -5 cm (groundwater wells extend 10 cm above the marsh surface; negative number indicates distance above the surface) to 12 cm for CHV, and from 0 cm to 75 cm at CHV-R (Figure 35). Throughout the post-restoration monitoring program CHV-R exhibited a general trend of greater depth to groundwater (2012 CHV-R mean depth 22.26 compared to 2.78 at CHV). The smaller size and higher elevation of the CHV-R marsh platform, smaller hydroperiod and potentially greater influence of freshwater (precipitation and runoff) could account for this. Water content of soil samples taken at both sites was found to be highly variable within each site and between years, and although mean water content was similar between the two sites (2012: 48% CHV-R and 49% CHV), the range was greater. However the water content of soil samples from CHV was higher than the levels recorded for CHV-R (34% to 81% CHV; 15% to 59% CHV-R) (Table 11; Table 14).

The trend over time (2003 – 2012) graph illustrates this very well (Figure 36). Although depth to groundwater at CHV-R is variable, the overall trend is fairly consistent, with depth to groundwater neither increasing nor decreasing over time. Whereas at CHV depth to groundwater clearly decreased over time following restoration. This agrees with what was observed in other indicator categories (e.g., increased hydroperiod; wetter marsh surface/larger pannes; increased presence of *Spartina alterniflora*). It would have been expected, given the natural increase in mean high water levels associated with the 18.6 year Nodal tide cycle (Desplanque and Mossman 2004; Baart et al. 2012), that depth to groundwater would have showed a decreasing trend over this time period. However, given that both t-tests and an ANOVA comparison (f = 0.91; p = 0.48) of pre- to post-restoration depth to groundwater levels at CHV-R determined that there was no significant difference. This would suggest that the significant difference that was detected at CHV (ANOVA f = 11.33; p = 5.44E-11), was likely the result of restoration.

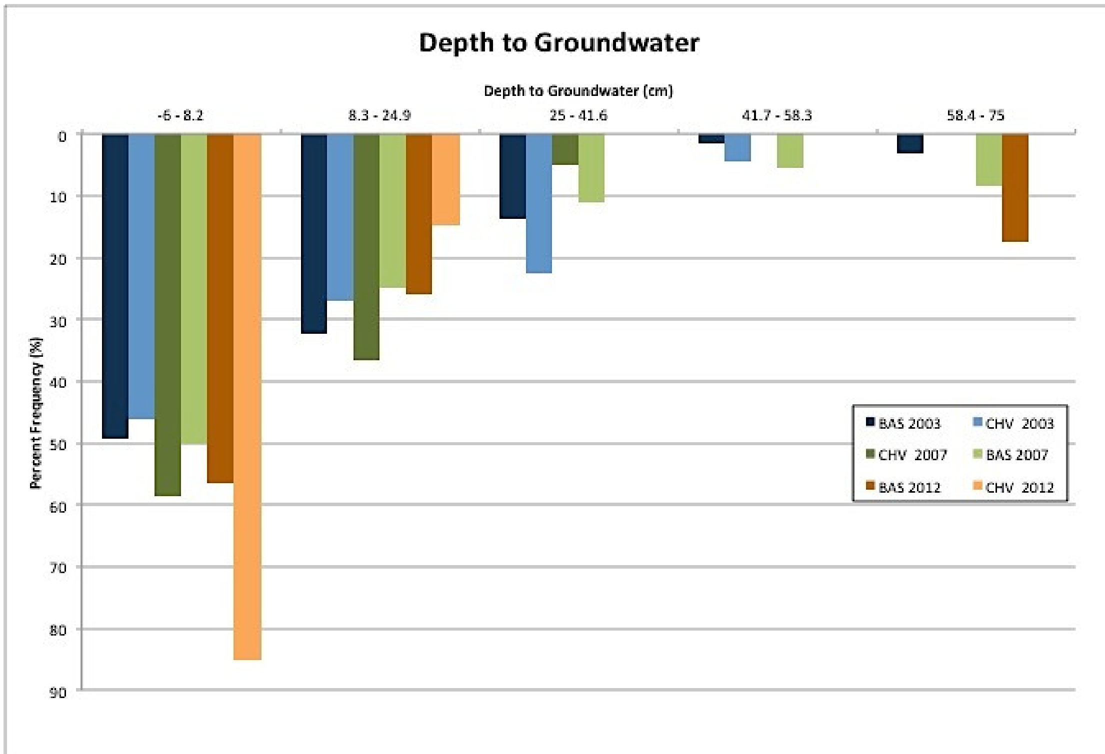


Figure 35 Frequency of depth to ground water for CHV and CHV-R.

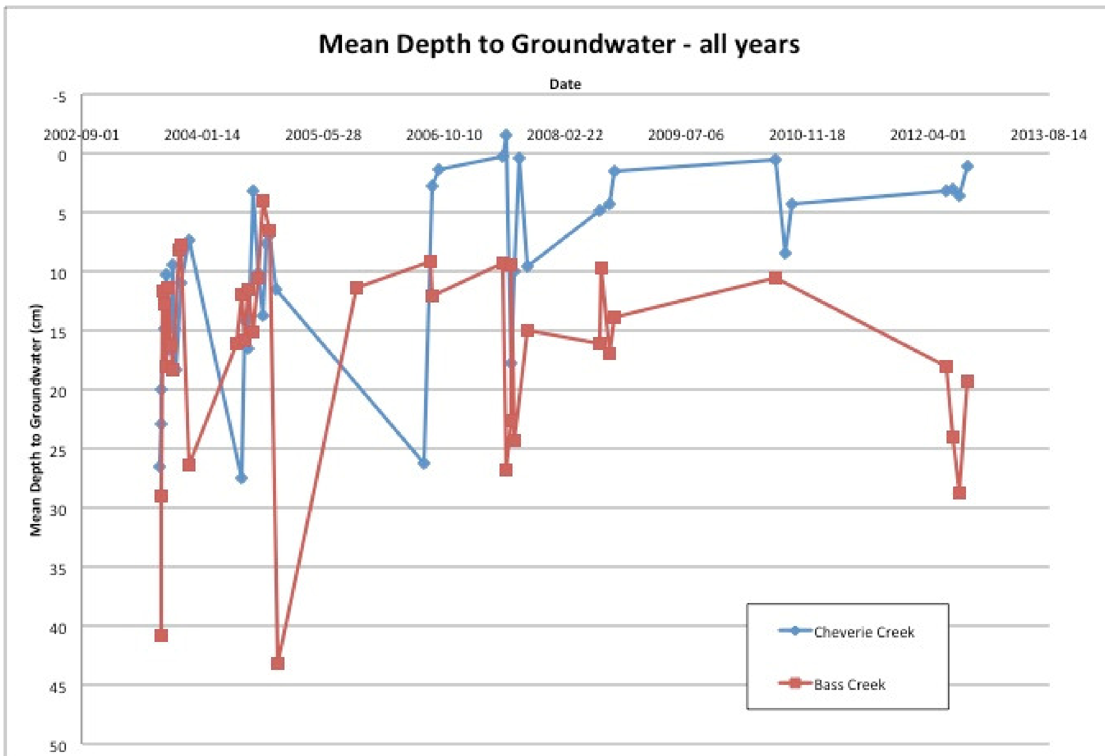


Figure 36 Mean depth to groundwater for CHV and CHV-R, 2003 – 2012.

Water Quality

Water quality conditions (salinity, temperature, DO, and pH) were measured for tidal floodwaters at CHV and CHV-R in conjunction with fish sampling (Table 5). There was little difference in the abiotic factors between the two sites over the seven years when looking at comparable sampling periods.

The normal pH range for seawater is 7.5 to 8.5 and the pH of floodwaters at both sites continued to fall within this range for all but three sampling occasions. The expected seasonal trend of higher water temperatures in the summer and lower in the fall was evident across all years, with highest temperatures recorded for August and early September and the lowest for October. Salinity levels of tidal flood waters vary across the tide cycle (flood, peak/slack, ebb). For the majority of years and sampling events, salinity levels ranged between 26 and 30 ppt, with only two events falling below this range, likely a result of the timing of the sample. Salinity has varied very little over the course of the monitoring program, with the majority of the readings at the high end of the polyhaline (salinity category) range of 18 to 30 ppt (Tiner 2005: Odum 1988). This is expected for salinity in the Bay of Fundy waters. Cold water has a higher oxygen saturation point than warm water and therefore can expect DO levels to vary daily and seasonally. Most estuarine fish species can survive on concentrations of 4 ppm and can exist comfortably at concentrations of 6 to 8 ppm (Kaill and Frey 1973). Mummichogs can survive at levels much lower than this, hence their ability to thrive in the often poor water quality conditions present in impaired wetlands. In keeping with this seasonal expectation, an increase in DO levels was observed for both sites throughout the monitoring program with a decrease in temperature.

Table 5 Water quality of tidal flood waters at CHV and CHV-R.

Date	Sampling Site	Sample Location	Salinity (ppt)	Temperature (^oC)	Dissolved Oxygen (mg/l)	pH
17/7/06	CHV *	L1/L2	28.08	18.34	6.8	8.14
1/8/07	CHV*	L1/L2	30.3	22	8.07	7.79
19/8/08	CHV	L2	27.01	20.3	6.51	6.08
20/8/08	CHV-R	L2	17.43	18.04	8.08	7.47
11/8/10	CHV-R*	L2/L3	29.74	22.08	7.88	6.94
12/8/10	CHV*	L3	29.44	22.55	7.49	7.6
8/9/06	CHV	L1/L2	26	19.4	9.10	7.5
11/9/06	CHV-R	L2	30	19.1	9.08	7.7
29/9/07	CHV*	L1/L2	29.73	17.12	8.21	7.33
30/9/07	CHV-R*	L2	30.6	16.95	8.98	7.58
18/9/12	CHV	L2	28.97	18.42	8.4	7.8
18/9/12	CHV	L3	29.03	18.28	8.81	7.7
18/10/05	CHV	L1	18.57	13.3	4.7	7.74
2/10/06	CHV-R	L2	32	14.8	10.63	7.8
6/10/06	CHV*	L1/L2	30.5	13.95	10.04	7.85
28/10/07	CHV*	L1/L2	30.15	13.99	9.03	7.78
27/10/07	CHV-R*	L2	30.73	12.43	9.72	7.78
18/10/08	CHV*	L2	29.49	12.48	8.87	7.86
17/10/08	CHV-R	L2	20.95	14.25	8.65	7.71

Date	Sampling Site	Sample Location	Salinity (ppt)	Temperature (°C)	Dissolved Oxygen (mg/l)	pH
9/10/10	CHV-R*	L2/L3	30.06	12.64	44.1 Doch**	8.13
11/10/10	CHV	L3	29.85	13.63	105.9 %**	8.24
16/10/12	CHV-R	L2	29.34	14.65	8.84	8
16/10/12	CHV	L2	30.15	14.91	8.67	7.9

*Average of two samples events.
**Equipment error, could not get mg/L reading.

4.3 Soils and Sediments

Pore Water Salinity

Utilizing the 2003 to 2010 refractometer data, mean pore water salinity levels at CHV post-restoration were significantly higher (*t* test, *t*=-10.69, df= 455, p= 5.98E-24) than pre-restoration levels. The largest changes in salinity were observed at the high marsh sampling stations and those further upstream. This was consistent with the expectation that soil salinity levels would increase as a result of increased frequency, extent and duration of tidal flooding following culvert replacement. In addition, mean pore water salinities at CHV were found to be significantly higher than those of CHV-R (2010 *t* test, *t*=-10.69, df= 455, p= 5.98E-24) during years 2, 3 and 5 post-restoration (Bowron et al. 2011a).

Consistent with expectations, pore water salinity levels at CHV increased following restoration, a pattern that is quite uniform across all stations. The trend of decreasing salinities towards the back (upstream) of the marsh and from the low to high marsh that was observed over most years is an indication of the development of a salinity gradient that is similar to other marshes (Crain et al. 2004).

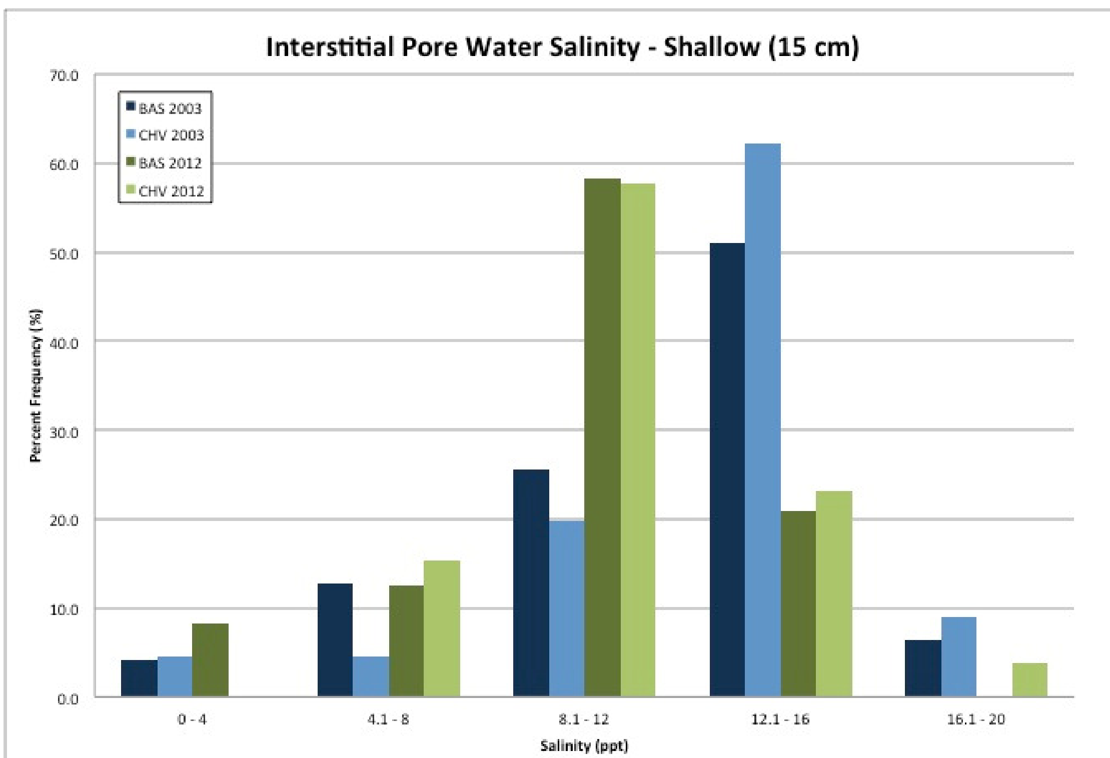
Stations in the mid and high marsh experienced the greatest increases in salinity levels post-restoration (L5 and L9), consistent with evidence of increased flooding and vegetation die-back. The changes in salinity levels observed at CHV stations L5MM and L5HM could, in part, be the result of the expansion of salt pannes in these areas. The high marsh salinity station at L9 had the highest increase in salinity levels, which also agrees with the die-back and flood line. The only exception to this trend was the sampling station on the south side of the creek on L5. This station, likely due to its location (positioned on the low marsh slope on the edge of the creek) displayed very little change in salinity over time.

A comparison of pore water salinity levels at CHV-R before and following restoration at CHV, found a significant difference with post levels being lower than pre (2010 *t* test, t=7.22, df=312, p= 3.99E-12). It was expected that salinity levels would remain relatively constant over time at the reference site, or if a change was to occur that it would be a gradual increase as a result of the natural increase in mean high water levels resulting from the 18.6 year Nodal tide cycle (Desplanque and Mossman 2004; Baart et al. 2012). One possible explanation for this decrease in salinity level could be the influence of precipitation and runoff from adjacent upland habitat. Because of the smaller size of the CHV-R marsh, the influence of precipitation and more specifically freshwater runoff could be greater. A review of the monthly precipitation rates for the months of June through October for the period of 2002 through 2010 did show a trend of increased precipitation. This could account for both the decrease in depth to groundwater (Section 4.2) and lower pore water salinity levels that were observed at CHV-R.

For 2012, seven years post-restoration, soil salinity (all samples) ranged between 5.08 – 16.16 ppt (mean 10.39 ppt) at CHV and 1.41 – 13.12 ppt (mean 8.37 ppt) at CHV-R and were generally lower in the summer and increasing in the fall. T-tests (95% CI) preformed between shallow and deep samples showed a significant difference at CHV-R ($t = -5.93$; $p = 4.77E-06$), where shallow samples were more saline than deep. At CHV, no significant difference was found between deep and shallow samples ($t = -1.71$; $p = 0.10$). T-tests confirmed a significant difference between the study and reference site when all samples were tested together ($t= -3.46$; $p = 0.0008$) and when deep samples were tested alone ($t = -3.46$; $p= 0.0012$). However, shallow samples showed no significant difference between sites when tested alone ($t = -1.68$; $p = 0.099$).

Taken together the differences between sample depths and sites may be associated with the differences in elevation of the marsh platform at the two sites. CHV-R readings were less saline, with greater variability between deep and shallow samples (Figure 37). The lower elevation of marsh platform at CHV leads to more frequent flooding of the marsh surface (station mean inundation frequency at CHV 71.7% compared to 46.9% at CHV-R) and higher mean inundation times (CHV = 111.13 minutes; CHV-R = 98.51 minutes).

a)



b)

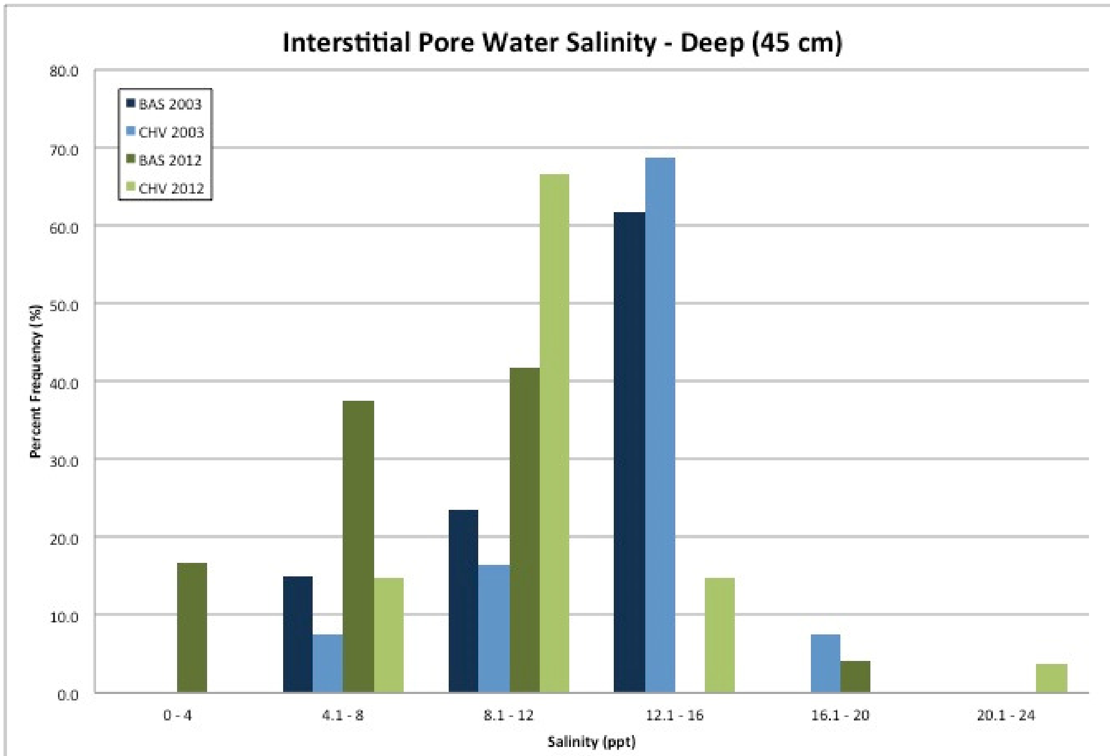


Figure 37 Change in mean pore water salinity for (a) shallow and (b) deep readings for CHV and CHV-R from 2003 to 2012.

Sediment Accretion and Elevation

Changes in surface elevation and sediment accretion were measured at CHV since 2005 and CHV-R site since 2006 using RSETs and marker horizon cores. In addition, a total of 25 buried aluminum plates were installed in 2002 at CHV by Saint Mary's University to measure sediment accretion using the method outlined in van Proosdij et al. (2006a) (Figure 7; Figure 8). These plates were not measured after 2009 and were not included in this report. Changes in surface elevation measured by the RSET incorporate both subsurface processes such as root production and sediment deposition, whereas sediment accretion measured by the marker horizon cores represents the amount of inorganic and organic material deposited by tidal waters on the marsh surface. Subtraction of the RSET and marker horizon values should provide a measure of the amount of change in surface elevation due to shallow subsidence processes such as root growth, compaction, decomposition and pore water flux (Cahoon et al. 2002). Both surface (e.g., accretion) and subsurface processes will be highly influenced by the elevation of the marsh surface within the tidal frame which affects the frequency and duration of inundation by tidal waters. Sediment accretion will also be affected by other factors such as the proximity to sediment source, for example, the tidal creek network (van Proosdij et al. 2006b) (Figure 11; Figure 12).

Since the RSET stations were not installed until 2005, no RSET data were available pre-restoration. One year post-restoration the change in surface elevation was highest at RSET-02 and RSET-03, both with a net rate of change of 2.2 $cm \cdot yr^{-1}$ (Table 6). Both of these sites were at relatively low elevations (Table 10) and were either located in a depression zone or adjacent to a sediment source (e.g. RSET-02). The lowest recorded change in surface elevation was in the sedge community at RSET-04 with 0.6 ±0.1 cm·yr^{-1} (±SE). A similar trend was recorded by the marker horizons. The highest value rate of accretion (1.85 cm·yr^{-1}) was measured at RSET-03 (Table 8) within the cattail zone.

There was no significant difference between years at CHV (repeated measures ANOVA: $F_{1,3}$ = 0.155, p= 0.0925) nor were there any statistically significant differences by 2012 between CHV and CHV-R (repeated measures ANOVA; $F_{1,3}$ = 1.334; p= 0.300). The highest rate of change in surface elevation seven years post-restoration was recorded at RSET-03 (2.7±0.3 cm·yr^{-}1±SE) in the former cattail area (Table 10; Figure 38; Figure 41). Based on the marker horizon data, 1.13 cm can be attributed to sediment accretion whereas 1.14 cm is due to subsurface below ground production or surface expansion (Table 8). The lowest rate of change was recorded at RSET-04 (0.7 ± 0.1 cm·yr^{-}1±SE) (Figure 42; Figure 43) near the upland where sediment accretion accounts for the majority of change (0.75 cm) (Table 8) with slight subsidence of 0.05 cm. This was similar to what occurred in 2009. The subsidence was supported by visual observations of decaying vegetated matter and increased ponding of water as the pannes at the back of the marsh continue to expand (Figure 43; Figure 46). The marked increase in surface elevation recorded at RSET-02, (6.9 cm·yr^{-1}; Figure 40; Figure 43) in 2009 was not repeated in 2010 or 2012. Rates of surface elevation change in 2009-2010 were moderate at 1.9 ±0.1 cm·yr^{-}1±SE with 2.08 cm of sediment accretion (Table 6, Figure 40). Field observations indicated that the area was getting flooded more frequently as evidenced by a shift in vegetation community to *Spartina alterniflora*. RSET-01 saw similar changes in surface elevation as RSET-02 at 1.6 ± 0.1 cm·yr^{-}1±SE (Table 6; Figure 38; Figure 39) with 1.08 cm due to accretion and 0.52 cm due to subsurface processes, likely due to below ground root production.

Although there has been considerable temporal and spatial variability in changes in surface elevation between years, a trend seemed to emerge if one examined the net change in surface elevation and net accretion over the seven years post-restoration period (Table 10). The greatest changes in surface elevation were not necessarily associated with the highest amounts of sediment accretion. The highest net change in surface elevation over the seven year period was recorded at CHV RSET-02 (13.79 ± 0.1 cm·yr^{-}1±SE) adjacent to the tidal creek and located at the lowest elevation relative to datum, therefore experienced the most frequent tidal inundation (Table 8). This site also had the highest net change due to subsurface processes as well (Table 8). The site with lowest net change in surface elevation was RSET-04 (2.77 ± 0.11 cm·yr^{-}1±SE) and was located at the highest elevation (Table 10). It also experienced the lowest amounts of sediment accretion, which was not surprising given the distance from sediment source and decreased inundation frequency. CHV RSET-03 within the cattail zone recorded the highest net rates of sediment accretion, however, also recorded net subsurface subsidence, likely due to the decay of the cattail root matter (Table 8; Figure 41).

When compared to CHV-R, the changes in surface elevation were markedly lower than those recorded at CHV seven years post-restoration; however, this observation was not statistically significant. The highest rate of change was recorded at CHV-R RSET-02 (1.0 ± 0.1 cm·yr^{-}1±SE) and the lowest at RSET -03 (0.5 ± 0.1 cm·yr^{-}1±SE) (Table 7; Figure 45). Overall the highest net rates of sediment accretion were recorded at RSET-01 (2.13 cm) at 5.98 m CGVD28 and the lowest at RSET-03 (1.55 cm) (Table 9; Figure 44). Both RSET-02 and 03 recorded decreases in elevation associated with subsurface processes, however, did maintain positive rates of change in surface elevation (Table 10).

Table 6 Change in surface elevation at CHV from 2005 to 2012 measured by the RSET device. (stdev = standard deviation, SE = standard error).

CHEVERIE CREEK RSET-01 Line 5		**Position**	**Bearing**	**Net change in elevation between sampling period (cm)**								
				Pin 1	**Pin 2**	**Pin 3**	**Pin 4**	**Pin 5**	**Pin 6**	**Pin 7**	**Pin 8**	**Pin 9**
2005-2006		1	240	0	1.3	1.4	0.3	1.1	1	0.8	1.6	1.1
mean (cm)	1.0	3	153	0.9	0.7	1.2	1.1	0.8	0.8	0.2	0.8	0.6
stdev	0.6	5	60	0.6	1.4	1.3	0.9	1.3	1.9	1.9	2.9	0.5
SE	0.1	7	337	0.4	0.5	1.5	1.3	1.7	1.2	-0.1	1.4	0.5
2006-2007		1	240	2	1	0.5	1.1	1.1	0.7	1.4	0.5	0.9
mean (cm)	0.9	3	153	0.6	1.7	0.8	2.2	1.1	0.9	1	1.4	1.8
stdev	0.7	5	60	0.9	0	1.3	0.7	1	0	-0.3	-0.9	2
SE	0.1	7	337	1.1	0.7	-0.2	1	2	0.8	2.2	0.1	0.8
2007-2008		1	240	0.1	0.2	0.2	0.9	-0.2	-0.3	0	0.3	0.1
mean (cm)	0.3	3	153	0.3	0.3	0.6	-0.5	0.7	0.8	0.8	-0.4	-0.5
stdev	0.5	5	60	0.9	1	-0.8	-0.3	0.4	-0.2	0.1	0.5	-0.4
SE	0.1	7	337	0.5	0.8	0.8	0.2	-0.1	1.1	0	1.1	0.5
2008-2009		1	240	1.1	0.6	-0.3	0.3	0.5	1	0.7	0	1.1
mean (cm)	0.5	3	153	0.9	0.2	0.4	0.5	0.1	0.4	0.2	0.6	0.9
stdev	0.5	5	60	0.7	0.7	0.7	1.5	0.1	1	0.8	1.9	-0.3
SE	0.1	7	337	0.1	0.6	0.5	0.6	-0.1	0.4	0.2	0.5	0.6
2009-2010		1	240	2	2.7	3.1	1.7	1.8	1.2	1.5	2	0.7
mean (cm)	1.6	3	153	1.6	1.4	0.8	2.2	2.2	0.9	1.4	1.6	1.8
stdev	0.6	5	60	1.2	0.8	1.5	1.6	1.8	1.9	2.1	0.4	2.3
SE	0.1	7	337	2.4	1.1	0.7	1.2	1.7	1.3	1.2	1.2	1.7
2010-2011		1	240	0.5	0.3	0.8	0.7	0.6	1.2	0.3	1.6	1.7
mean (cm)	1.0	3	153	0.4	0.9	0.9	-0.5	-0.3	1.1	2	-0.1	0.2
stdev	0.8	5	60	1.1	1	1.1	1	0.9	0.6	0.6	0.5	0.2
SE	0.1	7	337	0.7	2	1.8	1.5	3.2	3	2.3	2	1.1
2011-2012		1	240	0.6	0.7	1	0.5	0.5	0.6	1.1	0.8	1.1
mean (cm)	0.7	3	153	2.9	1	0.5	1.1	1.1	0.4	0.3	1.7	1.5
stdev	0.6	5	60	0.5	0.7	0.5	0.7	0.5	0.2	0.1	0.7	0.8
SE	0.1	7	337	0.7	0.2	0.6	0.7	-0.8	0	0.1	0.1	0.6
CHEVERIE CREEK RSET-02 Line 8 - Creek		Position	Bearing	Net change in elevation between sampling period (cm)								
				Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8	Pin 9
2005-2006		1	146	2.2	3.1	3.9	2.8	1.6	1.9	2.2	1	2.6
mean (cm)	2.2	3	237	1.3	1.8	1.8	2	1.6	2.8	1.9	1.8	2.5
stdev	0.7	5	326	2.1	1.2	1.9	3.2	3	2.5	2	0.8	3

SE	0.1	7	55	1.7	1.9	2.5	2.7	2.9	1.9	2.6	1.7	2.3
2006-2007		1	146	1	2.2	1.2	1.6	2.2	1.2	1.7	1.4	1.2
mean (cm)	1.6	3	237	1.4	2.1	1.4	1.3	2.1	0.3	1.7	1.2	1.3
stdev	0.6	5	326	2.3	2.9	2.2	0.3	0.8	1.1	2	2.8	0.8
SE	0.1	7	55	2	1.7	1.5	1.8	0.7	1.2	1.6	2.1	1.5
2007-2008		1	146	1.9	0.9	2.3	0.8	0.7	1.6	1	0.7	1
mean (cm)	1.3	3	237	1	1.3	1.7	1.1	0.6	2.2	1.1	1.5	1.4
stdev	0.5	5	326	1.3	1.3	1	1.1	1	1	0.8	1.4	1.8
SE	0.1	7	55	1.5	1.6	1.5	0.9	2	1.3	0.1	1.5	1.6
2008-2009		1	146	7.1	7.5	6.8	7.7	7.6	7.7	7.3	7	6.7
mean (cm)	6.9	3	237	5.8	5.6	6.9	7.4	7.1	6.7	7.5	6.3	6.9
stdev	0.6	5	326	5.9	6.4	7.5	7.1	7	6.4	7.3	7.3	7.1
SE	0.1	7	55	6.5	7	7.2	6.9	6.6	7.5	7.9	5	7.2
2009-2010		1	146	1.9	1.6	1.7	0.8	1.7	1.3	1.2	2.1	1.8
mean (cm)	1.9	3	237	2.4	2.2	0.8	2.6	1.7	0.1	1.1	2.2	1.9
stdev	0.7	5	326	2.6	2.1	1.4	1	2	2.8	2.7	1.8	1.9
SE	0.1	7	55	3.2	1.8	1.2	2.2	2.4	2	1.8	3.4	1.7
2010-2011		1	146	0.9	1.1	1.2	1.1	1.3	1.7	0.9	1.2	1.4
mean (cm)	1.2	3	237	1.4	0.9	2.2	0.4	1.1	2.4	1.7	1.2	1.1
stdev	0.7	5	326	1.4	1.3	1.2	2.2	2.1	2	0.9	-0.2	-0.4
SE	0.1	7	55									
2011-2012		1	146	-0.7	0.1	-0.2	0.8	0.5	0.7	0.7	0.5	0.5
mean (cm)	0.4	3	237	-0.6	1.4	0	0.3	0.7	1	0.6	0.9	0.4
stdev	0.7	5	326	0.3	0	0.1	0.3	-0.4	-0.8	0.1	1.9	1.7
SE	0.1	7	55									
CHEVERIE CREEK RSET-03 Line 8 - Cattails		**Position**	**Bearing**	**Net change in elevation between sampling period (cm)**								
				Pin 1	**Pin 2**	**Pin 3**	**Pin 4**	**Pin 5**	**Pin 6**	**Pin 7**	**Pin 8**	**Pin 9**
2005-2006		1	278	0.5	2.9	0.6	2.9	2.7	2.5	1.2	1.8	3
mean (cm)	2.2	3	6	1.6	1.9	1.6	1.5	1.1	3.5	3.6	2	2.2
stdev	1.2	5	94	3.6	2.1	1.1	1.6	3.1	3.9	4.1	2.7	3.5
SE	0.2	7	185	2.6	2.1	2.8	-2.1	1.6	2.1	3.6	2.1	1
2006-2007		1	278	0.3	1.1	1.1	0.7	1	1.1	2.1	1.3	3.3
mean (cm)	1.7	3	6	1.8	2.5	1.3	2.6	2.8	2.4	1.9	3.1	2.5
stdev	1.0	5	94	0.6	2.1	2.9	0.9	0.8	0.6	0.3	1.2	1.4
SE	0.2	7	185	1.2	0.3	0.5	2.9	1.4	3	3.3	1.3	2.9
2007-2008		1	278	-0.8	-0.2	0.4	1.2	0.4	0.9	1	1.6	-0.6
mean (cm)	0.2	3	6	0.2	-0.7	1	0.6	-0.3	-0.3	1.7	1.1	-0.8
stdev	0.9	5	94	-0.3	0	-0.9	-0.2	0.8	0.8	1.6	0.2	0.6
SE	0.1	7	185	-0.3	0.2	0.4	-1	-1.5	-1.6	-1.2	1.2	0.6
2008-2009		1	278	1.7	0	-1	-2.8	-0.1	0	-0.4	-0.6	-0.4
mean (cm)	-1.4	3	6	-0.3	-1.5	0	-0.5	-1.5	-3.3	-1.1	-2.1	0.7
stdev	1.6	5	94	-1.3	-1.6	-0.9	-4.4	-2.7	-4.3	-5.7	-2.6	-2.3

SE	0.3	7	185	-1.5	-1.6	-1.2	0	0.1	-3.4	0.2	-2.3	-3.1
2009-2010		1	278	1.5	1.8	1.3	2.9	0.4	2	1.1	2.5	3.6
mean (cm)	2.7	3	6	0.5	2.8	1.9	0.5	1.6	3.3	-0.6	1.5	1.2
stdev	1.8	5	94	3.1	2.9	3.9	9.1	2.4	4.2	4.9	3.9	4.3
SE	0.3	7	185	5.9	3.8	2.9	1	2.1	5.4	2.4	3.3	3.5
2010-2011		1	278	1.7	0.2	2.2	2.3	3	-0.1	1.2	0.7	0.3
mean (cm)	1.4	3	6	2.1	1.9	1.1	2.5	2.4	2.5	1.3	0.7	0.3
stdev	1.3	5	94	2.6	1	2	-0.9	2.4	3.5	3	1.1	0.3
SE	0.2	7	185	1.1	1.9	2.1	3.2	1.2	1.6	-2.4	0.5	-0.9
2011-2012		1	278	0.8	-0.3	-0.1	0.4	-0.3	-1	-2.4	-3.4	-0.1
mean (cm)	-0.1	3	6	-1.8	-1.8	-1.8	-1.5	-0.5	0.1	0.4	0.4	0.5
stdev	1.6	5	94	-0.5	1.6	-0.9	0.2	0.9	-0.1	-0.1	0.5	0.9
SE	0.3	7	185	-3.7	1.2	-0.8	0.8	0.8	-0.3	3.6	1.6	4.1

CHEVERIE CREEK RSET-04 Line 7 - upland		**Position**	**Bearing**	**Net change in elevation between sampling period (cm)**								
				Pin 1	**Pin 2**	**Pin 3**	**Pin 4**	**Pin 5**	**Pin 6**	**Pin 7**	**Pin 8**	**Pin 9**
2005-2006		1	294	1.0	0.7	1.1	0.6	0.3	0.8	1.3	1.1	1.4
mean (cm)	0.6	3	18	0.3	1.5	2.2	-0.3	-1.6	-1.0	0.3	1.6	0.6
stdev	0.8	5	115	0.7	0.4	1.4	0.9	0.7	1.1	0.4	-0.9	-0.4
SE	0.1	7	196	1.5	1.1	0.3	0.7	0.8	0.2	0.4	1.2	0.9
2006-2007		1	294	0.0	0.4	0.3	-0.1	0.7	0.8	0.6	2.8	3.0
mean	0.7	3	18	0.7	0.8	-1.1	1.0	2.2	0.6	0.0	0.2	-0.3
stdev	0.8	5	115	1.0	0.9	0.3	1.2	0.2	0.5	0.3	1.3	0.9
SE	0.1	7	196	-0.1	0.5	0.5	0.5	1.2	0.9	0.4	0.0	0.5
2007-2008		1	294	0.1	0.6	0.2	1.1	0.4	0.0	0.0	-1.6	-2.0
mean	0.4	3	18	1.2	-0.1	1.3	0.7	-0.4	0.2	0.4	0.4	0.6
stdev	0.8	5	115	0.5	0.6	0.8	2.7	0.8	-1.0	1.2	0.3	0.9
SE	0.1	7	196	1.3	0.8	0.5	1.1	0.0	0.3	0.4	1.3	0.3
2008-2009		1	294	0.6	0.7	1.0	0.7	0.9	0.9	0.7	0.4	0.8
mean	0.3	3	18	-0.3	0.5	1.0	0.3	0.6	0.1	0.1	0.2	0.9
stdev	0.6	5	115	0.6	0.2	-0.1	-1.6	0.4	1.6	0.2	-0.3	0.7
SE	0.1	7	196	-0.1	0.0	0.3	0.3	0.2	0.0	-0.1	-1.1	0.5
2009-2010		1	294	0.5	0.3	0.2	0.6	0.7	0.4	0.7	1.1	0.9
mean	0.7	3	18	1.5	1.0	0.2	0.5	-0.1	1.4	0.5	0.7	0.8
stdev	0.4	5	115	0.9	0.5	1.6	1.0	1.4	0.3	0.8	1.8	0.4
SE	0.1	7	196	0.5	0.4	0.8	0.4	0.6	0.5	0.7	0.4	0.3
2010-2011		1	294	0.6	0.4	0.5	0.3	0.1	0.3	0.3	0.3	0.4
mean (cm)	0.7	3	18	1.3	0.7	1.0	1.1	1.4	0.4	1.2	0.5	0.4
stdev	0.4	5	115	0.3	0.9	0.8	0.6	0.7	1.1	0.4	1.0	0.4
SE	0.1	7	196	0.7	0.8	0.5	0.9	1.2	1.0	1.2	0.8	0.3
2011-2012		1	294	0.3	0.4	0.4	0.2	0.3	-0.1	0.3	0.2	0.3

mean (cm)	0.1	3	18	0.0	0.6	0.4	0.3	0.0	0.0	-0.3	-0.2	0.1
stdev	0.3	5	115	-0.1	0.1	0.0	-0.2	-0.1	0.0	0.0	-0.8	0.0
SE	0.0	7	196	0.3	0.1	0.4	0.5	0.0	0.0	-0.1	0.2	0.5

Table 7 Change in surface elevation at CHV-R from 2006 to 2012 measured by the RSET device. (stdev = standard deviation, SE = standard error).

BASS CREEK RSET-01 Line 1 (LM)		Position	Bearing	Net change in elevation between sampling period (cm)								
				Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8	Pin 9
2006-2007		1	240	0.2	0.1	0	0.2	0.2	0.2	-0.1	0.1	-0.1
mean	0.4	3	153	1.4	0.9	0.5	0.3	0.5	0.6	1.6	0.4	0.5
stdev	0.4	5	60	0.4	0.5	0.1	0.4	0.7	0.3	0.2	0.4	0.7
SE	0.1	7	337	0.1	0.2	0.2	0.3	0.1	0.1	0.2	0.2	0.5
2007-2008		1	240	0.5	0.3	0.5	0.4	0.6	0.6	0.3	0.5	0.7
mean	0.4	3	153	0.8	0.5	0.4	0.6	0.5	0.3	-1	0.5	0.5
stdev	0.3	5	60	0.4	0.4	1	0.6	0.4	0.5	0.4	0.3	0.2
SE	0.0	7	337	0.8	0.4	0.6	0.3	0.3	0.3	0.3	0.4	0.5
2008-2009		1	240	2.1	2.1	2.4	2.5	2.2	2.4	3	2.2	1.8
mean	2.3	3	153	3.2	2.6	2.3	2.2	2.4	2.4	2.5	2.5	2.3
stdev	0.3	5	60	2.4	2	1.5	2	2.3	2.1	2.5	1.9	1.8
SE	0.1	7	337	2.3	2.2	2.1	2.4	2.4	2.8	2.5	2	1.8
2009-2010		1	240	1.1	1.5	1.1	1.4	1.3	1.1	0.9	0.8	0.7
mean	0.9	3	153	-0.1	0.8	1	1.1	1	0.9	0.8	0.5	0.6
stdev	0.3	5	60	0.8	1.7	1.1	1.1	0.8	1.1	0.4	1.1	0.8
SE	0.1	7	337	0.3	0.8	0.7	0.8	1.1	0.7	1.1	0.8	1
2010-2011		1	240	12.2	10.8	11.2	10.7	10.9	10.9	10.7	10.6	10.8
mean (cm)	11.0	3	153	11.5	11.5	11	10.8	10.7	11.4	11.2	10.8	10.9
stdev	0.6	5	60	11.9	9.9	10.3	10.4	9.9	9.9	10.9	11.2	11.4
SE	0.1	7	337	11.5	11.5	10.9	11.4	11.3	11.7	11.8	11.7	11.2
2011-2012		1	240	0.2	0.6	0.3	0.8	0.3	0.6	0.4	0.2	0.4
mean (cm)	0.3	3	153	0	-0.2	0.3	0.6	0.4	0.1	0.3	0.5	0.4
stdev	0.3	5	60	1	1.5	0.3	0.1	0.2	0.5	0.3	-0.1	0.3
SE	0.1	7	337	0.1	0.1	0.6	0.2	-0.1	0.2	0.1	0	0

RSET-02 Line 3(HM)		Position	Bearing	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8	Pin 9
2006-2007		1	110	-0.1	0.9	0.4	0.5	0.4	0.6	0.1	0.5	0.6
mean	0.3	3	200	0.4	-0.1	0.4	0.1	0	0.2	-0.1	-1.8	0.6
stdev	0.5	5	290	0.9	0.1	0.6	0.5	0.1	0.1	0.5	0.3	0.6
SE	0.1	7	20	0.1	0.3	0.1	0.4	0.3	0.7	0	0.5	0.7
2007-2008		1	240	0.5	0.3	0.5	0.4	0.6	0.6	0.3	0.5	0.7
mean	0.4	3	153	0.8	0.5	0.4	0.6	0.5	0.3	-1	0.5	0.5
stdev	0.3	5	60	0.4	0.4	1	0.6	0.4	0.5	0.4	0.3	0.2
SE	0.0	7	337	0.8	0.4	0.6	0.3	0.3	0.3	0.3	0.4	0.5

2008-2009		1	100	0.1	0.2	-0.3	-0.1	0.6	-0.1	0.2	-0.1	0
mean	-1.2	3	190	-2.2	-0.1	-1.1	-1.2	-1	-1.1	-1.2	-1.4	-0.4
stdev	1.8	5	285	-2.6	-2.7	-3.4	-3.8	-4.6	-4.5	-4.7	-4.7	-4.2
SE	0.3	7	20	-1.2	-0.5	0.9	0.6	0.3	0.2	0.4	1.2	0.2
2009-2010		1	**100**	1.6	1.4	1.2	1.1	1	1.2	1.3	1	0.8
mean	1.0	3	190	1.7	0.5	1.9	2	0.9	1.6	0.9	1.7	0.8
stdev	0.6	5	285	1.3	1.2	1.3	0.5	0.9	1.5	0.6	1.1	0
SE	0.1	7	20	1.4	1.3	0.1	-0.1	-0.1	0.1	0.5	-0.1	1
2010-2011		1	100	0.7	0.6	0.9	0.6	0.3	0.1	-0.4	-0.2	0.5
mean (cm)	0.2	3	190	0.8	0.7	-0.3	0.1	1	0.6	1.1	-0.1	0.3
stdev	0.6	5	285	-1	-0.9	-0.1	0.2	0.2	-0.1	-0.6	-1.5	0.1
SE	0.1	7	20	-0.2	0	-0.4	0.9	1.1	0.8	0.8	-0.3	-0.1
2011-2012		1	100	-0.8	0	-0.4	0	0	0.9	1.6	1	1.2
mean (cm)	0.6	3	190	-0.1	1	1	0.5	-0.2	-0.3	0.1	0.9	1.1
stdev	0.7	5	285	1.7	1.6	0.1	-0.3	0	0.3	1	2.4	-0.4
SE	0.1	7	20	0.5	0.4	1.1	0.3	0.7	1	0	1.5	1.1

RSET-03 Line 5(MM)		**Positio n**	**Bearin g**	**Pin 1**	**Pin 2**	**Pin 3**	**Pin 4**	**Pin 5**	**Pin 6**	**Pin 7**	**Pin 8**	**Pin 9**
2006-2007		1	240	0.1	-0.2	0	-0.3	-0.5	0.4	0.2	0.8	-0.1
mean	0.1	3	333	-0.4	0.1	1	0.3	0.4	0.2	0.2	0.1	-0.8
stdev	0.4	5	60	-0.4	-0.6	0.1	0.2	0.1	0.4	0.2	0.3	0.2
SE	0.1	7	153	0.8	0	0.1	0.1	0	0.4	0.8	0.6	-0.1
2007-2008		1	110	0.7	0.4	0.4	0.4	0.3	0.6	0.5	0.2	0.6
mean	0.4	3	200	0.5	0.8	0.7	1.1	0.5	0.7	1.1	0.2	-0.2
stdev	0.3	5	290	0.2	0.2	0.3	0.4	0.5	0.2	0.5	0.2	0.1
SE	0.0	7	20	0.7	0.7	0.6	0.4	0.4	0	0	0.3	0.3
2008-2009		1	240	0.3	0	0.1	0	0.1	-0.5	-0.7	-0.3	-0.1
mean	0.1	3	333	0.8	-0.2	0.5	0.3	0.2	0.1	2.3	0.4	0
stdev	0.5	5	60	0.3	-0.5	-0.4	0	-0.7	-0.2	0.3	-0.4	0.1
SE	0.1	7	153	0.5	0.7	0.6	-0.3	1	-0.1	0.4	0	0.2
2009-2010		1	240	0.6	0.9	0.9	0.1	0.3	1	0.7	0.3	0.2
mean	0.5	3	333	0.1	0.3	0.1	0.4	0.5	0.5	-1.8	0.4	0.4
stdev	0.5	5	60	0.3	0.8	0.9	0.5	1.3	0.9	0.8	0.7	0.5
SE	0.1	7	153	0.3	0.2	0.7	0.8	0.3	0.6	0.5	0.8	0.8
2010-2011		1	240	1.6	1.5	0.9	1.2	1.4	1	0.8	0.8	1.1
mean (cm)	1.0	3	333	0.9	0.8	0.6	1.1	0.7	1.2	0.8	0.7	0.9
stdev	0.3	5	60	1.1	1.3	1	1.2	1.1	1	1	1.6	1.1
SE	0.0	7	153	1.8	1.4	0.8	0.9	0.5	1	0.6	1.2	1.1
2011-2012		1	240	0.2	-0.1	0.1	-0.6	-0.3	-0.2	0.2	-0.3	-0.3
mean (cm)	-0.1	3	333	0	0.3	0.2	0.1	0.1	-0.2	-0.2	0.1	-0.5
stdev	0.2	5	60	0	-0.3	-0.2	-0.3	-0.1	-0.1	-0.2	-0.2	-0.4
SE	0.0	7	153	-0.2	-0.3	0.1	0.4	0.2	0	0.1	-0.1	-0.2

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

Cheverie - Marker Horizons measurements 2011-2012					Net Accretion (cm/yr)						
RSET-01 line 5	mean (cm)	# cores	quality	notes	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12
core 1a	5.95	1	Good		0.00						
core 1b	6.18	1	Good		0.00						
core 1c	5.68	1	Good		0.00						
mean	**5.93**				**0.00**	**0.62**	**0.59**	**0.52**	**1.08**	**1.42**	**0.83**
RSET-02 - creek	**mean (cm)**	**# cores**	**quality**	**notes**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
core 2a	7.13	1	Ok		0.00						
core 2b	6.68	1	Good		0.00						
core 2c	4.98	1	Good		0.00						
mean	**6.26**				**0.00**	**0.74**	**0.67**	**0.82**	**2.08**	**0.53**	**0.47**
RSET -03 Line 8	**mean (cm)**	**# cores**	**quality**	**notes**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
core 3a	7.55	1	Ok	In water	N/A						
core 3b	5.65	4	Ok	In water	0.00						
core 3c	5.78	1	Ok	In water	0.00						
mean	**6.33**				**0.00**	**0.63**	**-0.17**	**2.65**	**1.13**	**-0.20**	**0.44**
RSET-04 Line 7	**mean (cm)**	**# cores**	**quality**	**notes**	**2005-06**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
core 4a	2.30	1	Great		0.00						
core 4b	3.80	1	Ok		0.00						
core 4c	2.48	1	Great		0.00						
mean	**2.86**				**0.00**	**0.90**	**-0.31**	**-0.03**	**0.75**	**1.03**	**-0.10**

Table 9 Sediment accretion measured by marker horizon cores at CHV-R.

Bass Creek - Marker Horizons measurements 2011-12					Net Accretion (cm/yr)					
RSET-01 Line 1	mean (cm)	# cores	quality	notes	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12
core 1a	2.40	1	Ok	cut w knife	0.00					
core 1b	4.07	1	Ok	cut w knife	0.00					
core 1c	2.00	3	Great	cut w knife	0.00					
mean	**2.82**				**0.00**	**0.39**	**0.38**	**1.16**	**0.28**	**0.42**
RSET-02 - Line	**mean (cm)**	**# cores**	**quality**	**notes**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
core 2a	2.73	2	Ok		0.00					
core 2b		4		no sample	0.00					
core 2c	2.63	2	Good		0.00					
mean	**2.68**				**0.00**	**0.38**	**0.30**	**0.75**	**0.91**	**0.10**
RSET -03 Line 5	**mean (cm)**	**# cores**	**quality**	**notes**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
core 3a	1.57	1	Great		0.00					
core 3b	2.10	1	Great		0.00					
core 3c	1.90	1	Great		0.00					
mean	**1.86**				**0.00**	**0.21**	**0.27**	**0.77**	**0.06**	**0.24**

Table 10 Net change in elevation post-restoration from 2006 to 2012 including surveyed elevations of RSET stations relative to geodetic datum (CGVD28) at CHV and CHV-R. SE = standard error.

Station ID	Zone	Line	Elevation (m)	Net change in surface elevation (cm +/- SE)	Net sediment accretion (cm)	Net change due to subsurface processes (cm)
CHV-SET-01	LM	5	6.50	6.05 (±0.10)	5.93	0.12
CHV-SET-02	LM	8	6.35	15.44 (±0.10)	6.26	9.18
CHV-SET-03	HM	8	6.45	6.64 (±0.22)	6.33	0.31
CHV-SET-04	HM	7	6.66	3.67 (±0.10)	2.86	0.71
CHV-R SET-01	LM	1	5.98	15.34 (±0.06)	2.82	12.52
CHV-R SET-02	HM	3	6.23	1.26 (±0.12)	2.68	-1.42
CHV-R SET-03	MM	5	6.15	2.06 (±0.06)	1.86	0.20

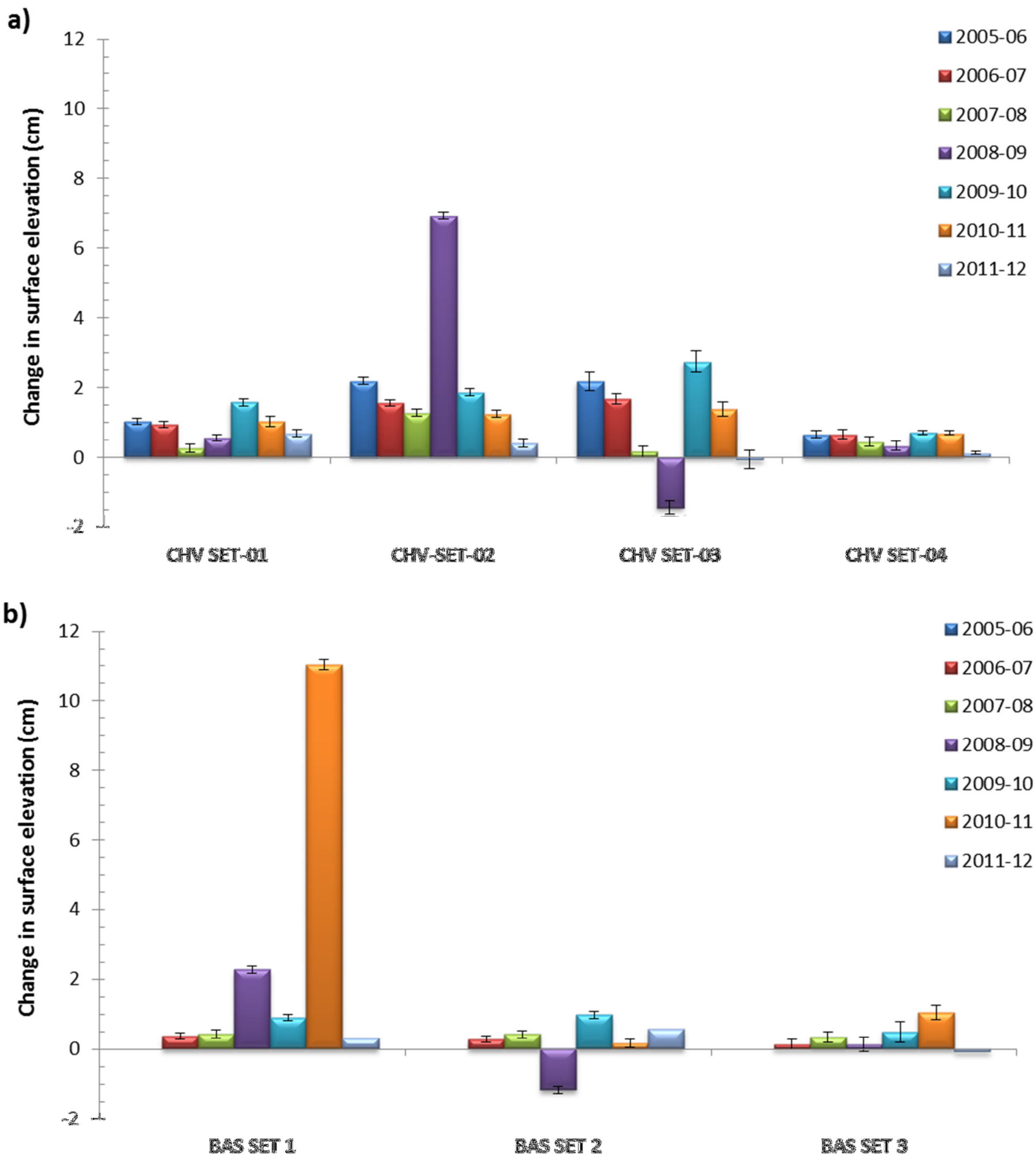


Figure 38 Mean annual change in surface elevation at CHV (a) and CHV-R (b). Error bars indicate ± 1 SE.

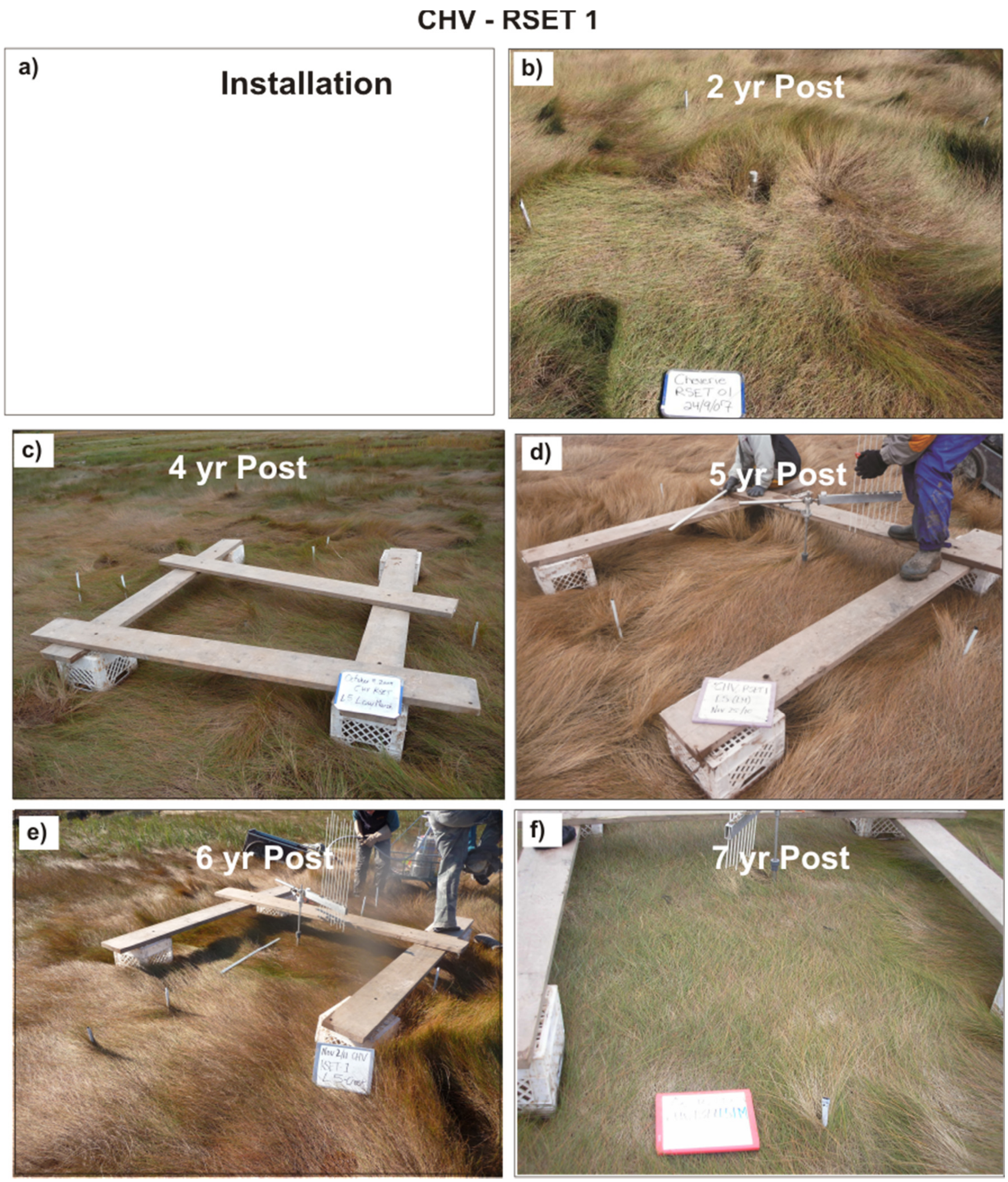


Figure 39 RSET-01 at CHV in *S. patens* on a) June 2005 (not available); b) 24 September 2007; c) Sept 10, 2009; d) November 25, 2010; e) Nov 2, 2011 and f) Oct. 10, 2012.

CHV - RSET 2

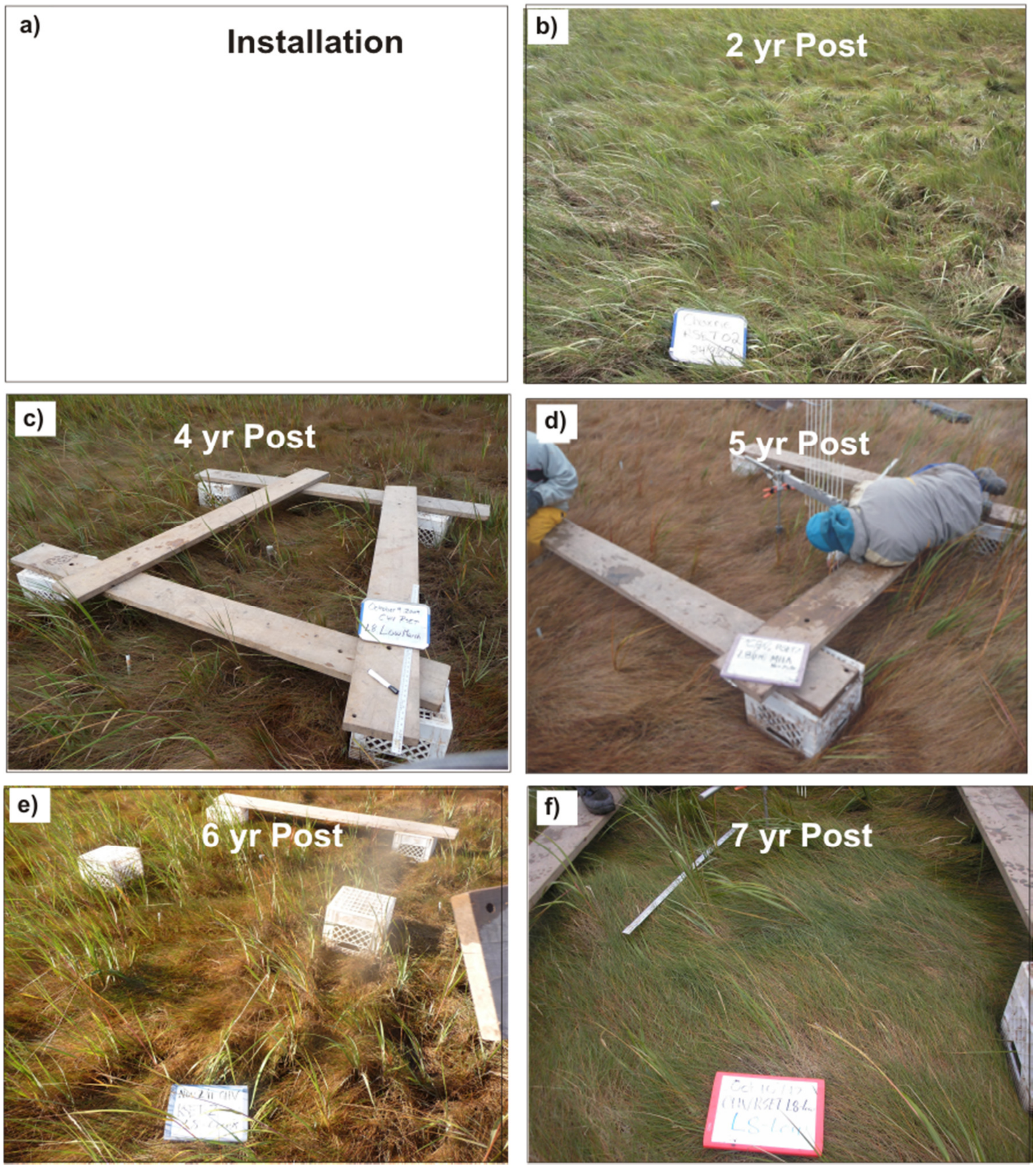


Figure 40 RSET-02 at CHV in *S. patens* on a) June 2005 (not available); b) Sept 24, 2007; c) Sept 10, 2009; d) November 25, 2010; e) Nov 2, 2011 and f) Oct. 10, 2012.

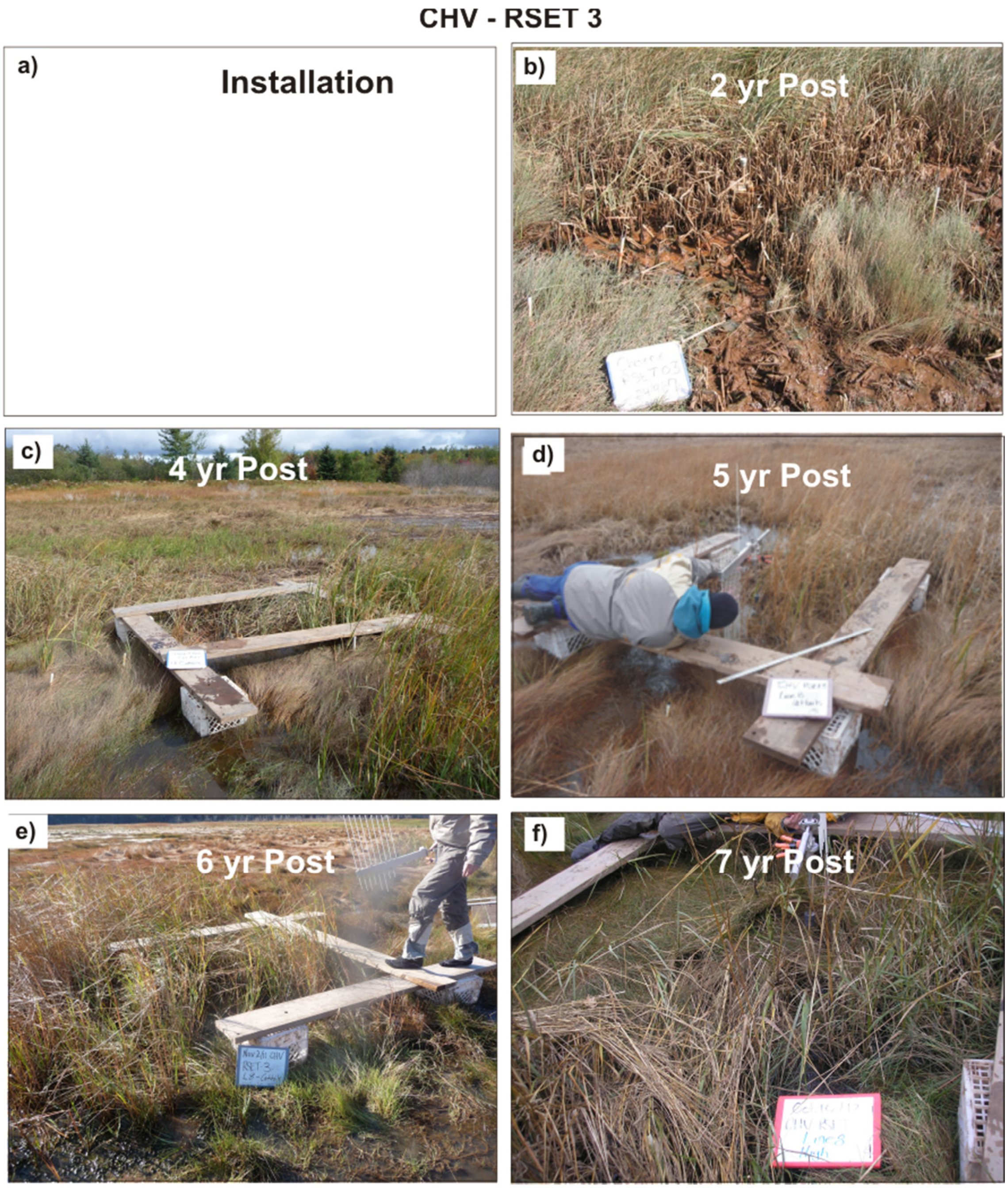


Figure 41 RSET-03 at CHV in *S. patens* on a) June 2005 (not available); b) Sept 24, 2007; c) Sept 10, 2009; d) November 25, 2010; e) Nov 2, 2011 and f) Oct. 10, 2012.

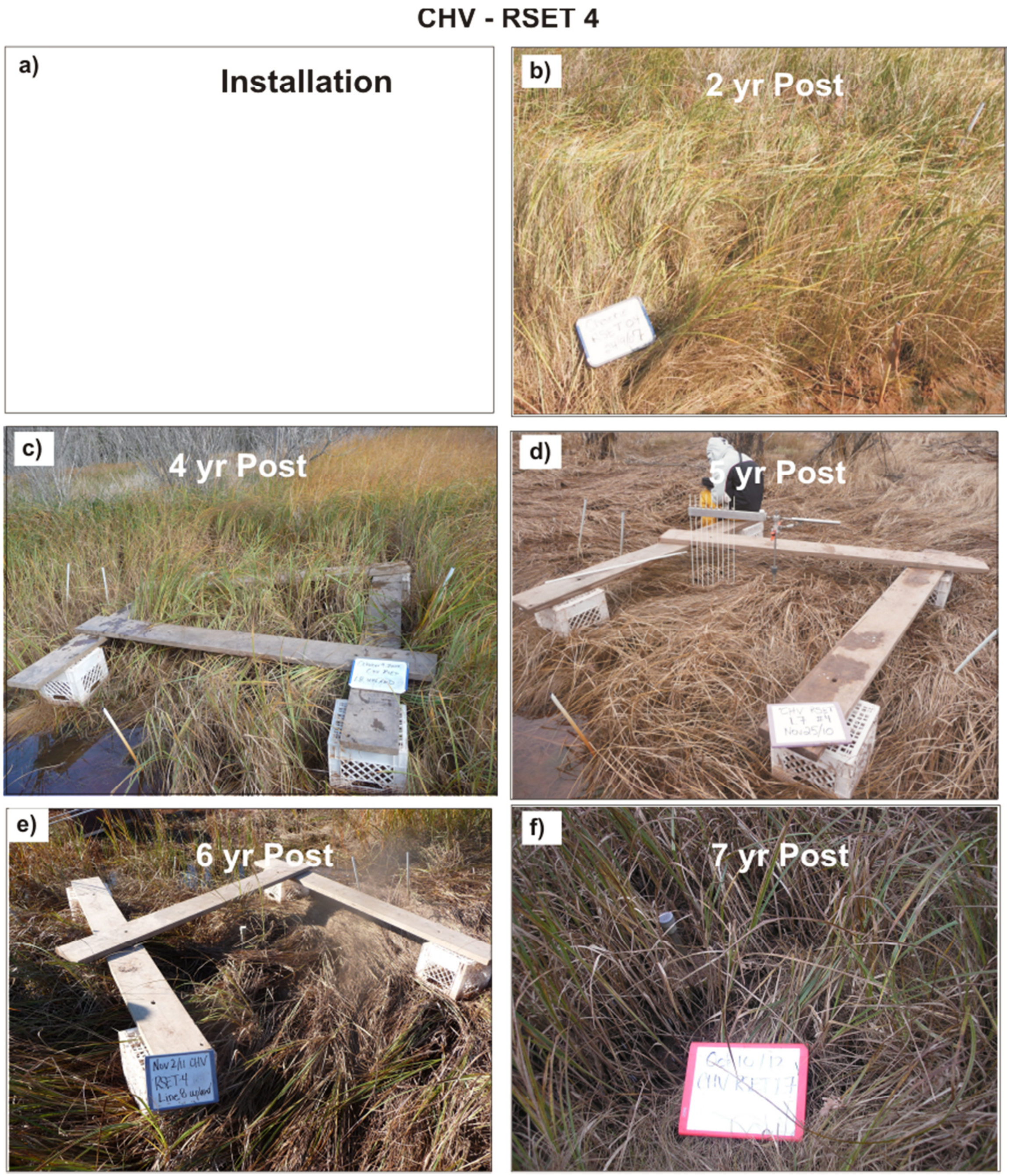


Figure 42 RSET-04 at CHV in *S. patens* on a) June 2005 (not available); b) Sept 24, 2007; c) Sept 10, 2009; d) November 25, 2010; e) Nov 2, 2011 and f) Oct. 10, 2012.

Figure 43 Marker horizon B at a) RSET-02 transect 8 in the low marsh on November 25, 2010 showing 5.48 cm of sediment accretion since 2006 and b) RSET-04 in water on November 25, 2010.

Figure 44 RSET-01 (LM) and associated marker horizon at CHV-R on a) Nov 2, 2011 and c) Oct 10, 2012. Note wrack material and debris in 2011.

Figure 45 RSET-03 at CHV-R transect 5 in the mid marsh on 10 October 2012.

Figure 46 Enlargement of existing pannes at the upland edge of transects 3-5 after replacement of culvert in Dec 2005. Photograph taken on 14 August 2007.

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). Increased tidal exchange post-restoration should induce changes in sediment characteristics with a general increase in inorganic materials.

A series of soil samples were collected at the restoration and reference sites and analyzed for organic matter content, bulk density and soil texture pre-restoration and 1, 3, 5 and 7 years post-restoration (Table 11). All cores were processed at the In_CoaST research lab for bulk density, water and organic matter content and grain size analyses performed at Mount Allison University using a Coulter Laser instrument in 2005, 2006 and 2008, but within In_CoaST using a Coulter Multiziser 3^{tm} in 2010 and 2012. The latter instrument is more accurate in the analysis of fines and results from the Coulter laser will need to be compared with caution since it tends to overestimate grain size (McCave et al. 2006) and miss the tail of fines. McCave et al. (2006) suggests that coarse clay and fine silt recorded using a Coulter Multisizer would show up as medium to coarse silt on the Coulter laser due to differences in the type of measurement. Fine sediments are typically platy in nature with a large surface area which is overrepresented using the laser method.

In general, a trend of decreasing bulk density and increasing organic matter content with distance from the main creek at CHV was common to the first three years of data collection following restoration. Year 5, however, recorded lower organic matter content and higher bulk density values with similar trends observed in Year 7. Bulk density depends on the mineral make-up of the soil and degree of compaction and is inversely proportional to porosity. Therefore, a more mineral soil will have a high bulk density (e.g. >1 $g \cdot cm^{-3}$) with less pore space. The shift in these soil variables with elevation over time can be examined in Figure 52 and compared with the pattern observed at CHV-R. It appears that by Years 5 and 7, the distribution pattern of water content, organic matter and bulk density at CHV begins to resemble the pattern displayed at the reference site; however, there was more variability at the upper elevation values. Water content was highly variable in all years, likely influenced by time of sampling relative to the last tide and previous rainfall. Organic matter content decreased over time and demonstrated a smaller range of values. For example, pre-restoration, organic matter content ranged from 5.04% (L3S1) to 74.3% (L6S8), yet in Year 3 the lowest value remained the same at 5.04% (L2S2), but the highest value 29.97% (L3S7) was almost three times lower. By 2010 the range had decreased even further (4.03% (L2S2) to 17.13% (L6S8)) (Table 1a). In 2012 organic matter ranged from 1.17% (L5S1) closest to the creek to 29.64% (L6S8) at the upland boundary. These later values were more consistent with the range in values recorded at the reference site in all years (Table 12) (Figure 52). Over time, it appears as though the sediments at the restoration site are becoming more minerogenic.

In general, the sampling stations with the highest organic matter content had the lowest dry bulk density values. The relationship between high bulk density and low organic matter content adjacent to a tidal creek or river was consistent with other studies within the region (e.g. Neatt et al. 2013; van Proosdij et al. 2011) and with the reference site (CHV-R, Figure 50; Figure 51). There was a general increase in bulk density across the marsh in all years post-restoration and a decrease in organic matter when compared to pre-restoration conditions. The highest bulk density values 7 years post-restoration were recorded at stations closest to the creek reflecting sediment accumulation in those regions.

Comparison of grain size statistics between the pre, Year 1 and 3 samples to the Year 5 and 7 samples was not directly possible due to the different instruments (and principles) that were used in their analyses. The pre-restoration, Year 1 and Year 3 samples were coarser than Years 5 and 7, which could be a reflection of the laser particle size analyzer that was used to analyze the earlier data (McCave et al. 2006). However, spatial variations in grain size parameters within a site and between CHV and CHV-R within a year were still possible. Pre-restoration, almost half of the stations reported very fine sand and the remainder very coarse silt (Table 15). Mean grain size decreased at the same stations one and three years post-restoration, with a mean of coarse silt, likely representing the grain size of suspended sediments. The one exception was at CHV L1S1 where it increased to fine sand (Table 15). Mean grain size decreased with distance from creek at CHV post-restoration, but exhibited no discernible pattern at CHV-R (Table 16). Sand (coarse material) decreased with distance from the creek at both sites, while silt and clay (fine material) increased with distance from creek. The ranges of percent sand, silt and clay were similar for both sites. In Year 5, the grain size ranged from fine silt to medium silt with finer materials generally along transects furthest from the new culvert (e.g. transects 6 and 7) (Table 15). The variability in grain size, as measured by the standard deviation, decreased over time.

Year 7 at CHV-R also displayed fine to medium silt with medium silt dominating, however, with slightly greater variability in CHV L3S1 (L3S7) and CHV L8S8.

A significant advantage of the Coulter Multisizer is the ability to perform disagregated grain size analysis and plot grain size versus normalized volumetric concentration (Figure 53). The shape of the curve is an indication of both source material and transport mechanism (Krank and Milligan 1985), specifically transport as single grains or as flocs. Flocculation is the development of an aggregate of fine particles, which assembles to fabricate a porous bunch of sediment larger than equivalent individual single grains. Sedimentation is greatly dependent on the flocculation of particles in both a matter of how much deposits and also where on the marsh it deposits. A floc contains particles of all grain sizes which would have a smaller settling rate if it were in single form. The settling rate of small particles which are included in flocs can be several orders of magnitude greater than it would be individually (Milligan et al. 2007). After flocs deposit, they are an amalgamation of both the flocculated flux and the single grain flux when consolidated on the bed. They cannot be distinguished from the single grains as both forms are now together on the bed. Analyzing the disaggregated inorganic grain size distributions of the sediment with the use of a parametric model, the inverse floc model, is a way to comprehend the depositional process that the particles carried through, therefore determining if the particle settled in floc form or single grain form (Curran et al. 2004). 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).

There were minimal differences in the grain size spectra at all stations at CHV-R with similar patterns observed at CHV at L1BS, L1S1, L1S3, L2S2, L3S1, L3S5, L3S6, L3S7, L4S2 and L6S6 (Figure 53). This implied similar source material and transport mechanisms. Several stations had very distinct coarser compositions with a steeper slope of fines (L2S6, L8S2, and L8S8) (Figure 53), which may indicate a difference in source material or reflect ice deposition. Samples L5S1, L6S2 and L6S4 also showed similarities to each other (Figure 53) with a larger proportion of coarser grain sizes and a minimal tail of fines. Stations L1S5 and L5S3 presented an even different trend. Overall, based on the changing sediment characteristics over time, CHV is trending towards the conditions displayed at the reference site, however, will retain some differences due to differences in elevation range and marsh width.

The second Matlab script used was *Drawers*, which used the inverse floc model developed by Curran et al. (2004) with results summarized in Table 17 and Table 18. Its output consisted of floc fraction (K_f) which is the portion of the deposited sediment deposited in flocculated form and the floc limit (d_f), which is the size that 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 ($^\wedge d$) that is the roll-off diameter and represents the size of the largest grain in suspension (Curran et al. 2004).

As expected, given the nature of Fundy sediments, the samples at CHV were moderately flocculated ranging from 54% (CHV L7S5) to 75% (CHV L8S8) (Table 17 and Table 18) and was within the range found at the reference site. Stations CHV L1S8, L3S7 and L6S8 all had low roll-off diameters (less than 12 microns) which indicated a strong dominance of fines rather than coarser grains. CHV L1S3 and L7S5 had the highest roll-off diameter which suggested potential differences in transport mechanisms. Overall however, the characteristics of sediments at CHV were similar to those recorded at CHV-R seven years post-restoration. Additional analyses are recommended to examine the spatial variability within each site in relation to vegetative communities and hydrologic patterns.

Table 11 Variation in water content derived from core samples pre- and post- (Years 1, 3, 5 and 7) restoration at CHV. Elevation relative to CGVD28 datum and distance relative to main creek.

CHV	**Elevation**	**Dist.**	**Water Content (%)**				
Station	**(m)**	**(m)**	**Pre**	**Yr 1**	**Yr3**	**Yr 5**	**Yr 7**
L1 s1	3.02	20	38.4	36.1	43.7	38.7	41.8
L1 s3	5.00	60	47.1	52.2	52.4	50.8	45.0
L1 s5	6.71	100	19.7	41.2	56.2	48.4	48.5
L1 s8	5.05	160	71.7	68.2	67.6	51.1	63.6
L2 s2	3.97	40	41.9	44.4	41.7	48.1	43.0
L2 s6	6.19	120	63.3	62.5	58.0	61.1	50.6
L3 s1	3.75	20	38.0	43.9	37.3	40.6	33.7
L3 s3	4.57	60	71.9	**n/a**	**n/a**	**n/a**	**n/a**
L3 s5	5.38	100	66.9	75.0	58.0	53.0	46.1
L3 s7	5.58	140	68.4	68.4	70.0	56.2	59.8
L4 s2	4.10	40	36.5	49.9	54.2	36.2	35.1
L4 s6	5.06	120	75.4	75.3	62.2	62.7	58.9
L5 s1	3.80	20	38.7	40.0	50.0	36.0	81.1
L5 s3	5.22	60	73.4	78.4	76.1	52.1	55.7
L5 s5	5.92	100	82.1	**n/a**	**n/a**	**n/a**	**n/a**
L6 s2	5.24	40	53.9	46.6	44.5	37.1	36.5
L6 s4	5.69	80	60.8	65.2	67.6	53.0	44.5
L6 s6	6.27	120	79.8	80.4	69.1	60.3	49.4
L6 s8	6.40	160	79.7	83.0	66.2	63.1	54.7
L7 s1	4.13	20	41.1	47.5	43.5	40.3	40.9
L7 s3	6.52	60	56.9	49.5	56.9	45.1	43.2
L7 s5	6.39	100	63.3	58.8	47.0	40.2	40.1
L8 s2	5.30	40	60.8	60.9	55.0	38.6	45.4
L8 s5	5.11	100	41.4	71.2	49.9	39.2	39.7
L8 s8	5.05	160	77.4	83.2	68.4	60.2	72.5

Table 12 Variation in organic matter content derived from core samples pre- and post- (Years 1, 3, 5 and 7) restoration at CHV. Elevation relative to CGVD28 datum and distance relative to main creek.

CHV Station	Elevation (m)	Dist. (m)	Organic Matter Content (%)				
			Pre	Yr 1	Yr3	Yr 5	Yr 7
L1 s1	3.02	20	5.53	4.27	5.44	5.30	7.28
L1 s3	5.00	60	10.29	9.19	8.37	10.76	6.31
L1 s5	6.71	100	25.99	11.55	21.04	16.86	9.70
L1 s8	5.05	160	45.89	28.24	14.27	20.49	12.38
L2 s2	3.97	40	13.05	6.07	5.04	4.03	6.76
L2 s6	6.19	120	20.12	12.32	8.95	8.86	11.51
L3 s1	3.75	20	5.04	4.93	5.05	6.02	7.54
L3 s3	4.57	60	24.79	**n/a**	**n/a**	**n/a**	**n/a**
L3 s5	5.38	100	44.36	41.99	11.71	8.87	6.94
L3 s7	5.58	140	43.00	30.41	29.97	14.62	13.20
L4 s2	4.10	40	26.09	19.21	17.49	7.00	5.81
L4 s6	5.06	120	39.16	34.34	13.39	12.96	9.91
L5 s1	3.80	20	5.99	4.58	7.09	4.62	1.17
L5 s3	5.22	60	47.08	34.69	24.39	8.30	8.01
L5 s5	5.92	100	56.53	**n/a**	**n/a**	**n/a**	**n/a**
L6 s2	5.24	40	26.88	12.16	8.86	7.19	5.54
L6 s4	5.69	80	24.86	15.40	16.11	8.01	6.67
L6 s6	6.27	120	63.30	41.27	18.62	12.83	7.09
L6 s8	6.40	160	74.30	48.20	20.57	17.13	29.64
L7 s1	4.13	20	7.75	7.11	6.48	5.46	6.70
L7 s3	6.52	60	34.26	15.55	14.70	8.68	7.50
L7 s5	6.39	100	38.59	23.36	9.38	7.37	6.89
L8 s2	5.30	40	32.52	22.79	14.08	10.41	6.14
L8 s5	5.11	100	13.19	20.33	10.66	7.49	6.80
L8 s8	5.05	160	52.09	48.09	18.68	12.19	18.73

Table 13 Variation in bulk density derived from core samples pre- and post- (Years 1, 3, 5 and 7) restoration at CHV. Elevation relative to CGVD28 datum and distance relative to main creek.

CHV Station	Elevation (m)	Dist. (m)	Dry Bulk Density ($g \cdot cm^{-3}$)				
			Pre	Yr 1	Yr3	Yr 5	Yr 7
L1 s1	3.02	20	0.68	0.91	0.68	0.92	1.18
L1 s3	5.00	60	0.62	0.40	0.50	0.57	0.48
L1 s5	6.71	100	0.54	0.73	0.48	0.57	0.80
L1 s8	5.05	160	0.53	0.36	0.29	0.90	1.34
L2 s2	3.97	40	0.67	0.74	0.48	0.84	1.09
L2 s6	6.19	120	0.47	0.42	0.38	0.47	0.23
L3 s1	3.75	20	1.05	0.80	0.72	1.01	1.05
L3 s3	4.57	60	0.29	**n/a**	**n/a**	**n/a**	**n/a**
L3 s5	5.38	100	0.33	0.26	0.17	0.42	0.72
L3 s7	5.58	140	0.39	0.32	0.26	0.41	0.36
L4 s2	4.10	40	0.52	0.54	0.67	0.86	0.79
L4 s6	5.06	120	0.19	0.22	0.31	0.39	0.53
L5 s1	3.80	20	1.04	0.81	0.60	0.85	1.10
L5 s3	5.22	60	0.26	0.18	0.13	0.43	0.49
L5 s5	5.92	100	0.30	**n/a**	**n/a**	**n/a**	**n/a**
L6 s2	5.24	40	0.54	0.66	0.48	0.82	0.85
L6 s4	5.69	80	0.43	0.35	0.27	0.45	0.59
L6 s6	6.27	120	0.25	0.20	0.20	0.63	0.52
L6 s8	6.40	160	0.19	0.15	0.30	0.40	0.22
L7 s1	4.13	20	0.84	0.62	0.84	0.92	0.91
L7 s3	6.52	60	0.43	0.67	0.65	0.61	0.55
L7 s5	6.39	100	0.34	0.35	0.45	0.66	0.69
L8 s2	5.30	40	0.36	0.39	0.44	0.63	0.90
L8 s5	5.11	100	0.65	0.28	0.54	0.93	0.96
L8 s8	5.05	160	0.23	0.16	0.20	0.44	0.24

Table 14 Variation in sediment characteristic derived from core samples post- (Years 1, 3, 5 and 7) restoration at CHV-R.

CHV-R Station	Elev. (m)	Water content (%)				Organic matter (%)				Dry bulk density ($g \cdot cm^{-3}$)			
		Yr 1	Yr 3	Yr 5	Yr 7	Yr 1	Yr 3	Yr 5	Yr 7	Yr 1	Yr 3	Yr 5	Yr 7
L1S1	6.20	51.07	59.30	51.98	58.02	13.43	17.73	15.11	17.40	0.55	0.47	0.56	0.37
L1S2	5.72	37.56	47.45	42.30	39.64	7.72	10.32	10.44	7.62	0.92		0.77	0.58

CHV-R	Elev.	Water content (%)				Organic matter (%)				Dry bulk density (g ·cm^{-3})			
Station	**(m)**	**Yr 1**	**Yr 3**	**Yr 5**	**Yr 7**	**Yr 1**	**Yr 3**	**Yr 5**	**Yr 7**	**Yr 1**	**Yr 3**	**Yr 5**	**Yr 7**
L1S3	4.49	29.43	36.87	37.40	43.58	4.93	6.04	5.50	8.09	1.35	0.72	0.88	0.62
L2FS	6.42	39.27	71.94	69.18	38.92	9.53	27.86	33.79	9.77	0.87	0.28	0.34	0.58
L2S3	5.94	34.39	66.16	56.12	52.32	5.65	19.39	17.91	12.41	0.95	0.39	0.51	0.35
L3FS	6.43	53.57	70.31	63.69	15.00	17.20	23.95	17.48	70.25	0.61	0.34	0.47	0.28
L3S2	6.06	52.65	62.10	55.86	57.49	15.18	14.70	14.18	13.64	0.75		0.41	0.39
L3S3	4.75	49.34	46.56	44.51	45.58	10.23	8.98	7.22	8.33	0.62	0.55	0.86	0.70
L4S1	6.56	27.57	52.76	52.67	57.39	7.15	27.96	18.08	21.43	1.38	0.72	0.83	0.87
L4S2	4.22	41.36	46.68	46.31	44.08	9.20	7.14	7.12	7.53	0.73		0.80	0.61
L5S2	6.48	53.09	68.71	61.10	58.22	13.60	19.08	16.28	16.55	0.57		0.54	0.38
L5S3	6.08	48.87	58.17	57.18	50.72	12.53	14.27	17.24	10.92	0.59	0.45	0.46	0.36
L5S4	6.00	38.57	40.60	42.19	46.49	7.59	7.74	8.30	8.99	0.77	0.67	0.89	0.57
L6S1	6.19	56.20	60.81	60.72	58.71	18.76	23.17	21.76	24.18	0.48	0.37	0.49	0.40
L6S2	6.01	65.72	67.32	61.81	50.82	20.82	17.06	19.99	8.67	0.36	0.28	0.42	0.34
L6S3	5.31	44.58	47.97	44.67	41.70	7.95	9.93	9.02	8.35	0.65	0.62	0.78	0.66
L7S2	6.08	57.12	32.11	58.67	59.20	13.01	4.27	13.91	15.19	0.50	0.36	0.48	2.05
L7S3	5.36	42.01	47.02	48.01	39.74	7.74	8.86	15.43	8.06	0.70	0.50	0.83	4.71
L8S2	5.96	61.81	59.69	61.19	54.73	21.16	13.85	27.56	17.11	0.56	0.41	0.46	
L8S3	5.24	43.35	50.98		44.54	8.19	10.10		10.01	0.70	0.48		0.56

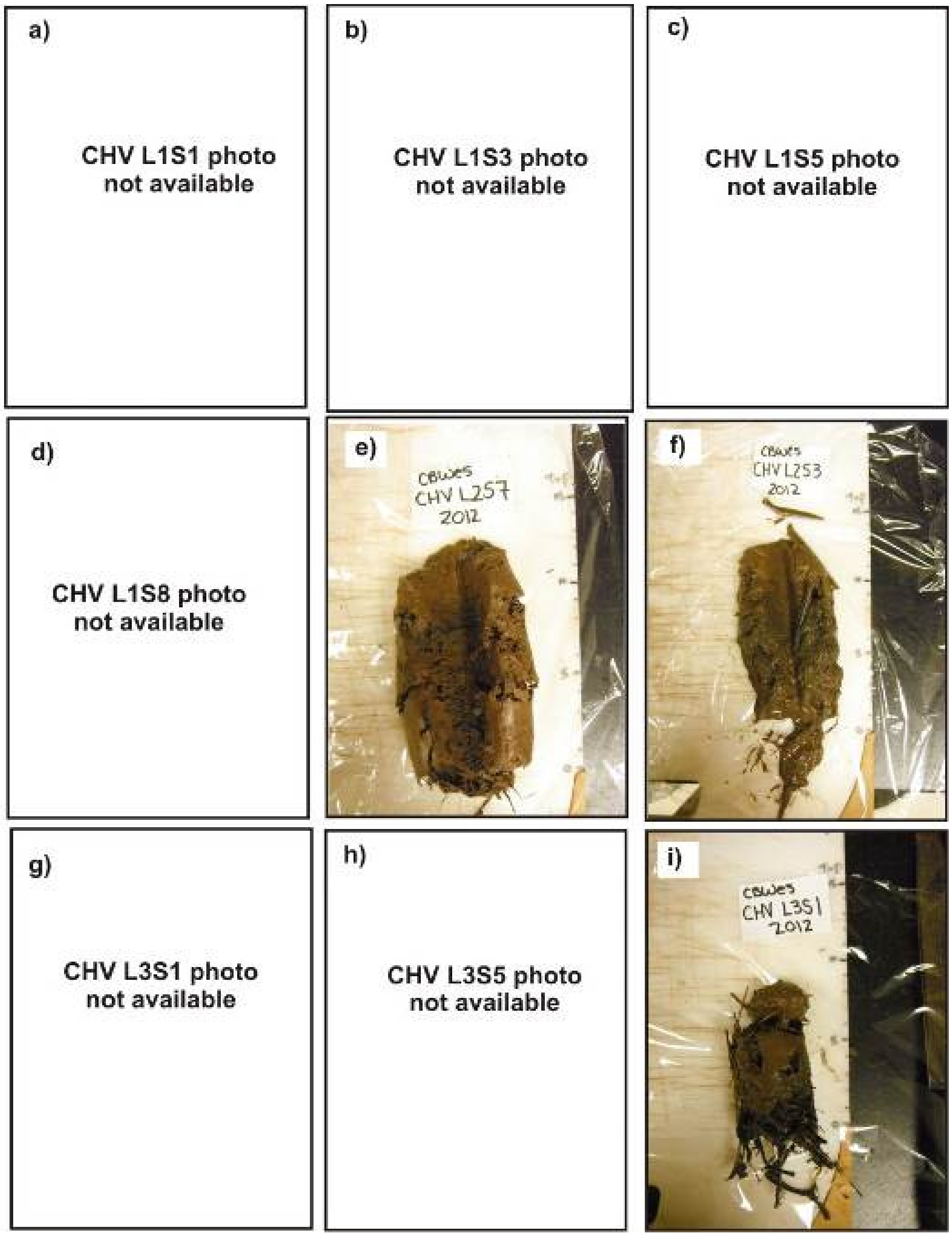


Figure 47 Split core sections for samples collected at CHV in fall 2012 at a) L1S1; b) L1S3; c) L1S5; d) L1BS or L1S8; e) L2S2; f) L2S6; g) L3S1; h) L3S5 and i) L3S7 (note - ignore core photo labels).

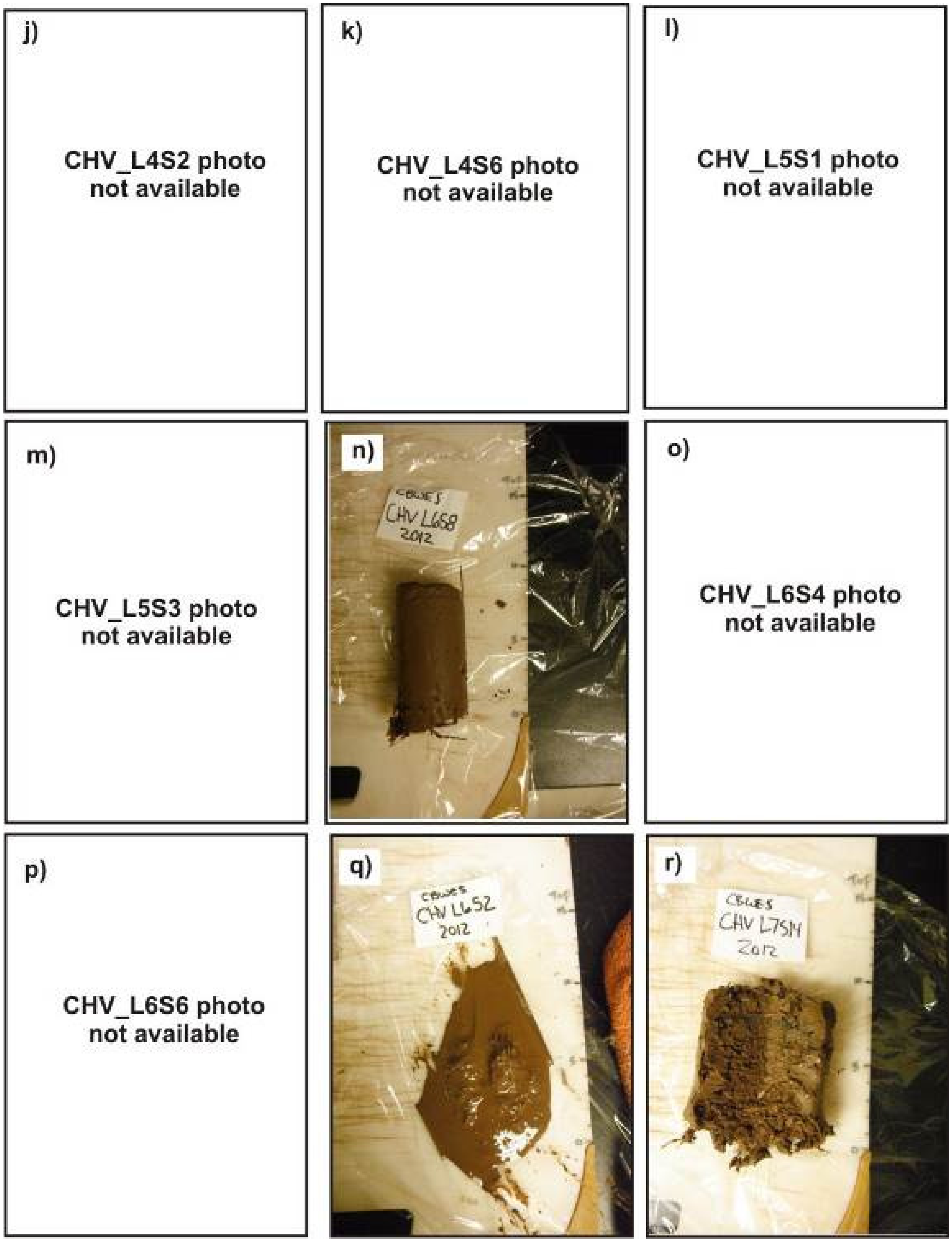


Figure 48 Split core sections for samples collected at CHV in fall 2012 at j) L4S2; k) L4S6; l) L5S1; m) L5S3; n) L6S2; o) L6S4; p) L6S6; q) L6S8 and r) L7S1 (note - ignore photo labels).

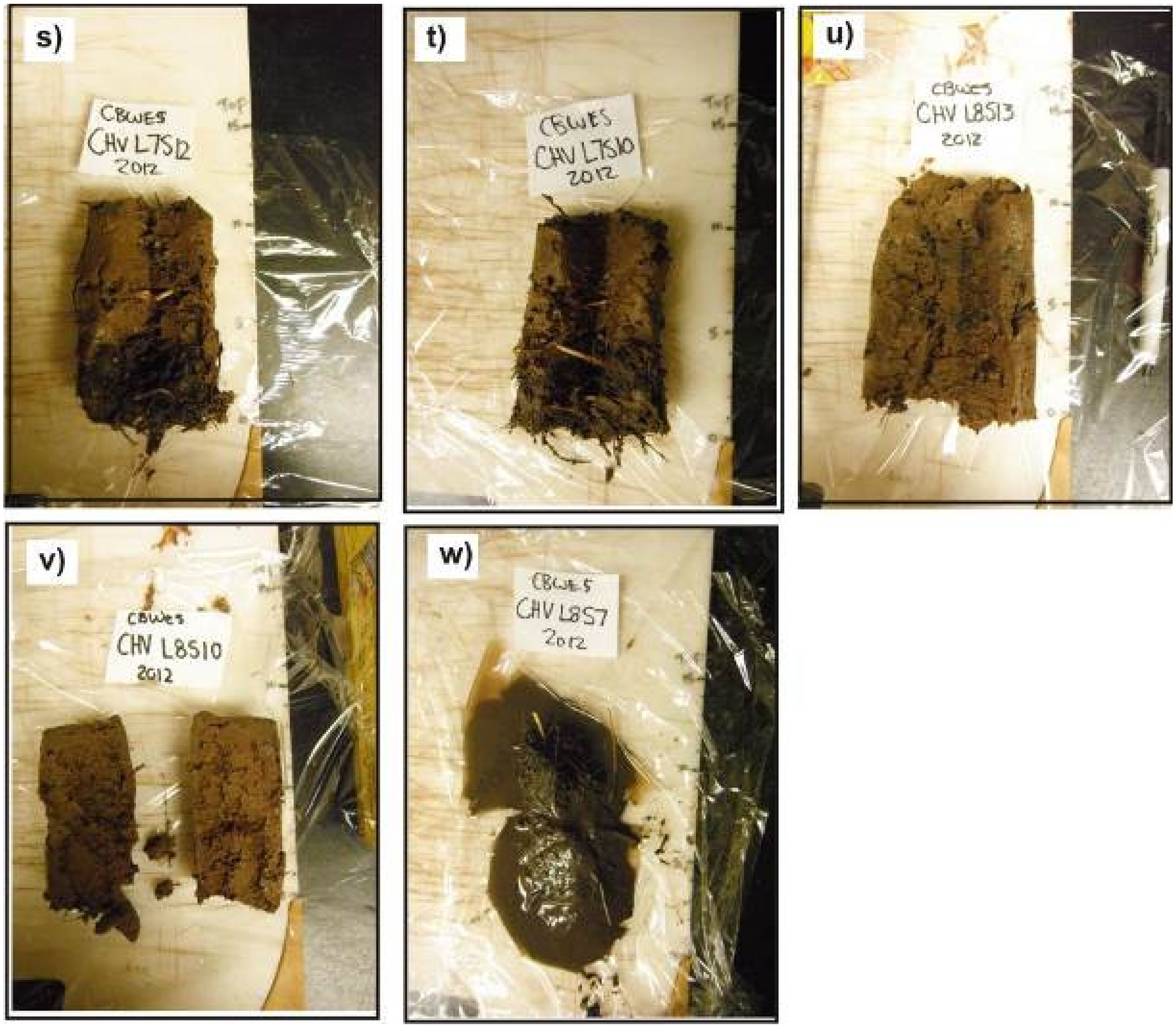


Figure 49 Split core sections for samples collected at CHV in fall 2012 at s) L7S3; t) L7S5; u) L8S2; v) L8S5; and w) L8S8 (note - ignore photo labels).

Figure 50 Split core sections for samples collected at CHV-R in fall 2012 at a) L1S1 or L1FS; b) L1S2; c) L1S3; d) L2S1 or L2FS; e) L2S3; f) L3FS; g) L3S2; h) L3S3 and i) L4S1 or L4FS.

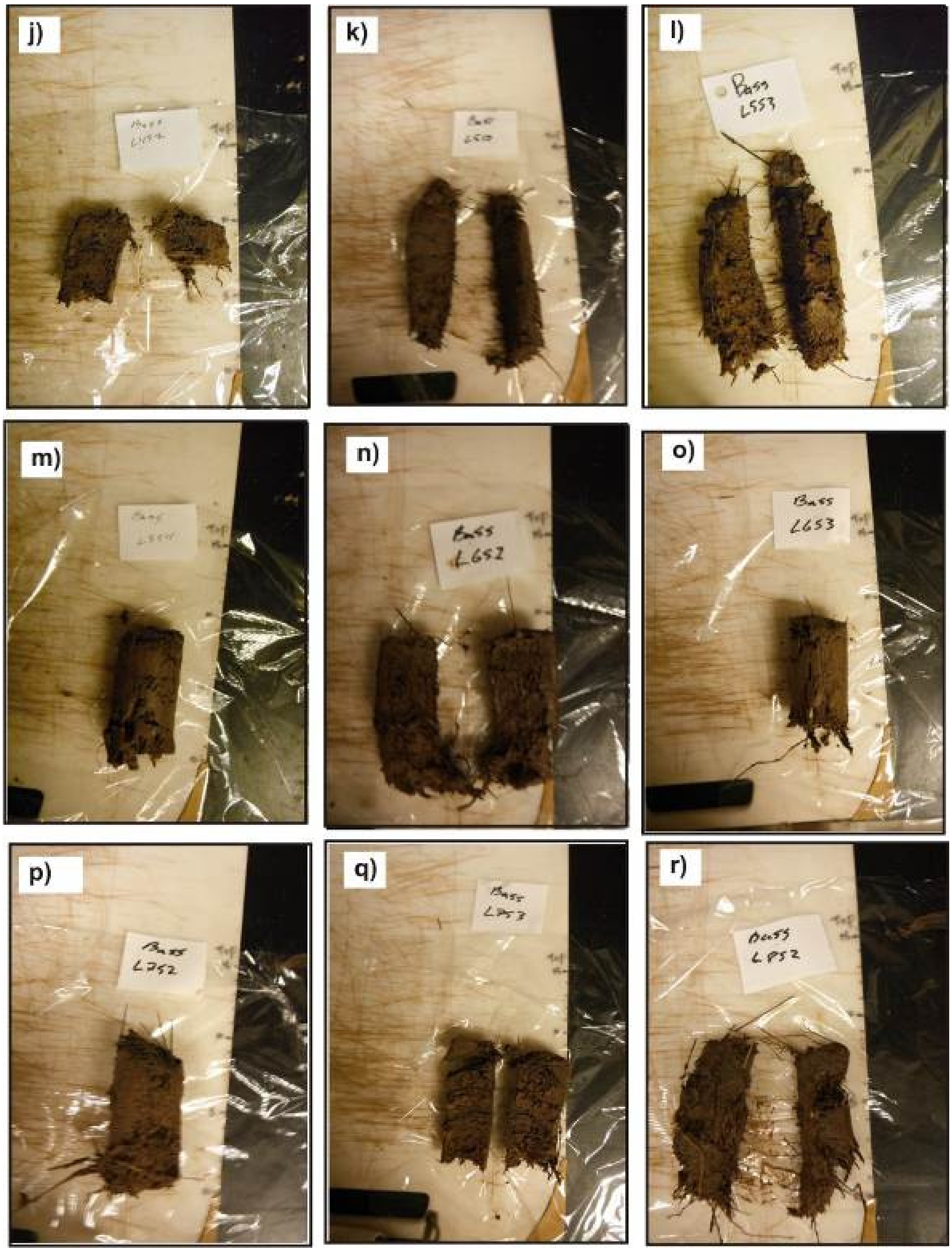


Figure 51 Split core sections for samples collected at CHV-R in fall 2012 at j) L4S2; k) L5S2; l) L5S3; m) L5S4; n) L6S1; o) L6S2; p) L7S2 q) L7S3 and r) L8S2.

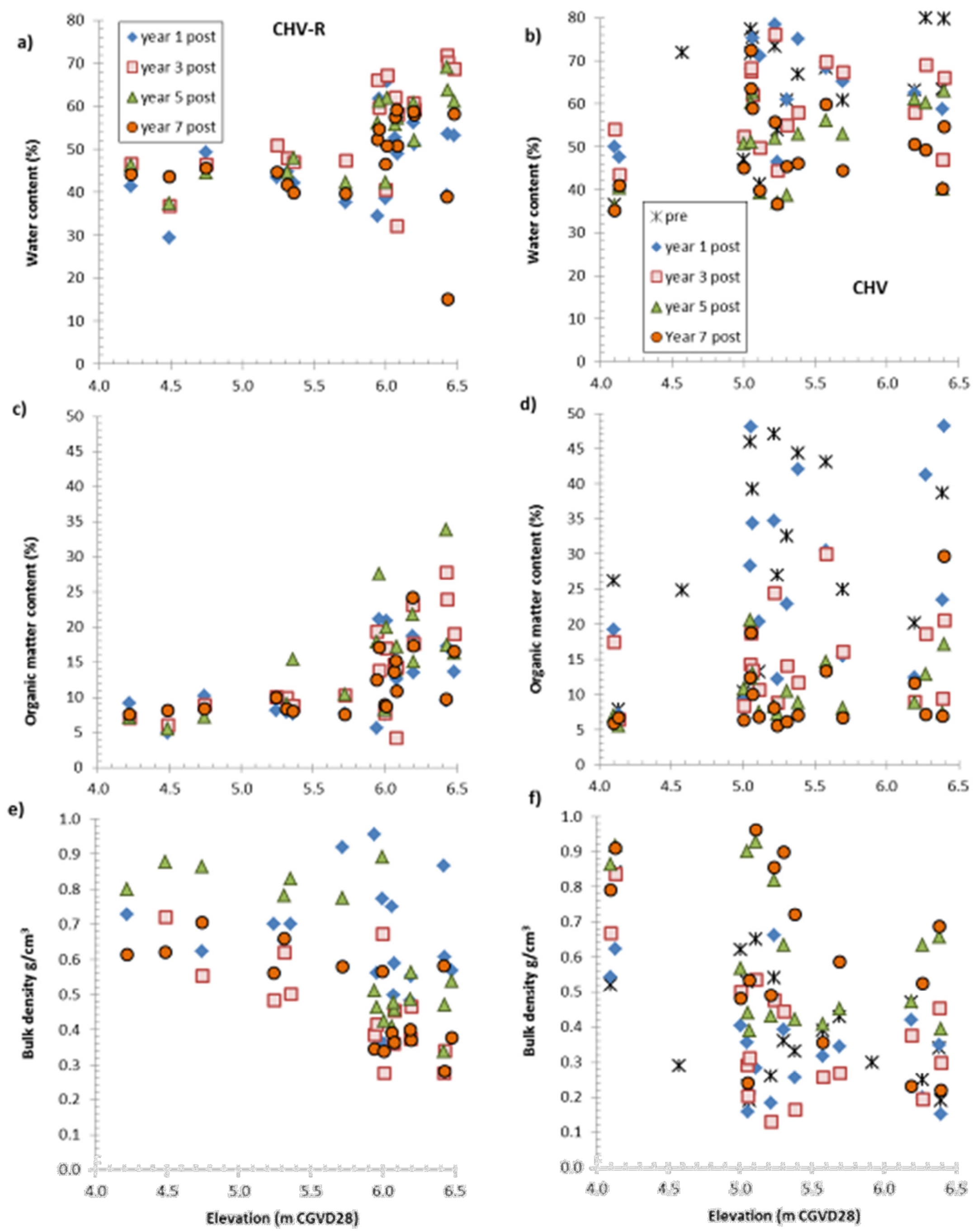


Figure 52 Comparison of variations in percent water content with elevation relative to datum between a) CHV-R and b) CHV for all years. Comparison of variations in organic matter content with elevation between c) CHV-R and d) CHV and comparison of dry bulk density with elevation between e) CHV-R and f) CHV.

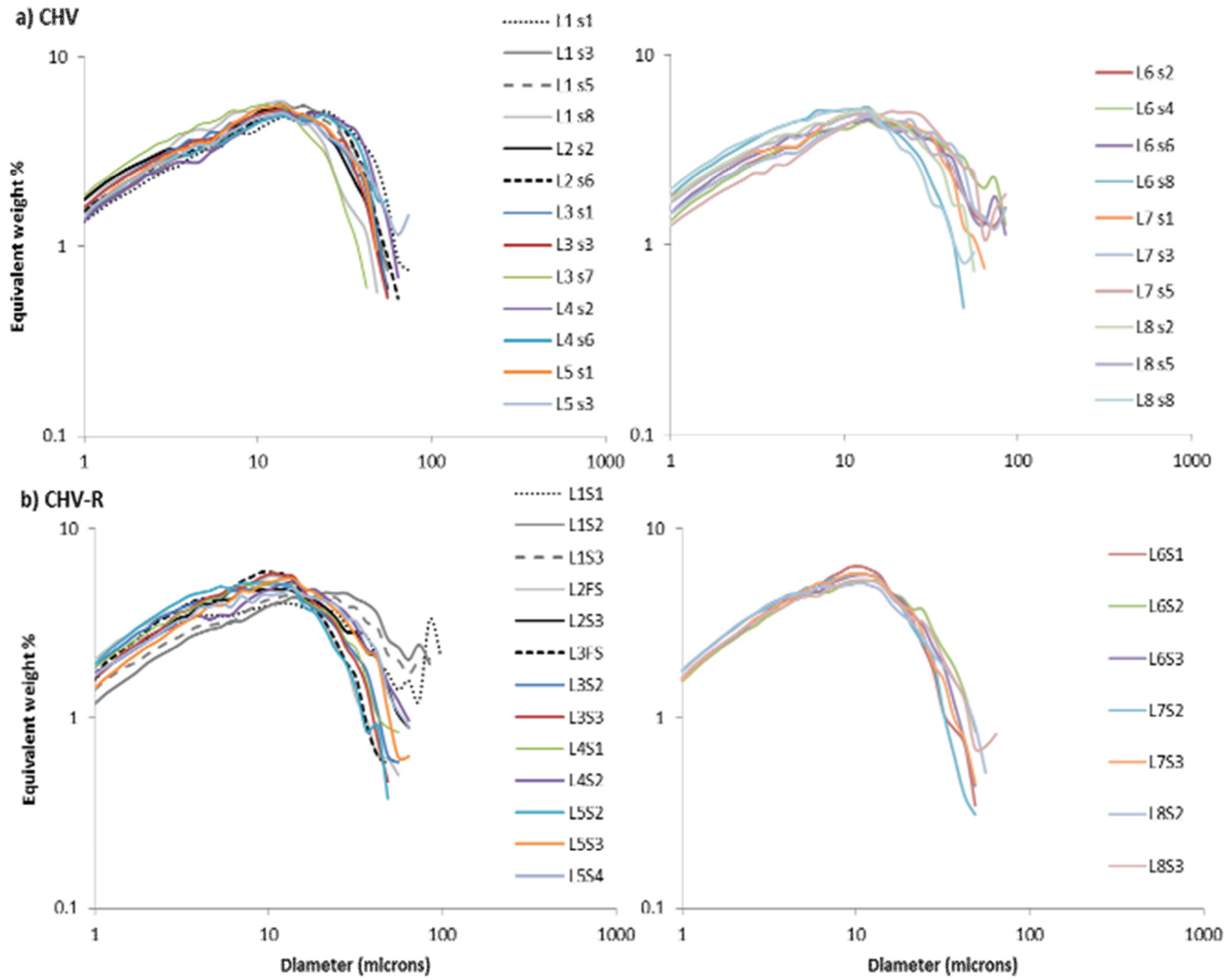


Figure 53 Comparison of the detailed grain size spectra for top 2 cm of core samples collected in 2012 processed with the Coulter Multisizer 3 at a) CHV and b) CHV-R.

Table 15 Variation in grain size characteristic derived from core samples pre- and post- (Years 1, 3, 5 and 7) restoration at CHV. Grain size class determined from modified Udden-Wentworth grain size classification (Blott and Pye, 2001). f.silt = fine silt, m.silt = medium silt, c.silt = coarse silt, vc.silt = very coarse silt, vf.sand = very fine sand, f.sand = fine sand. Note - grain size analysis performed using a Coulter Laser instrument for pre-conditions and Years 1 and 3. A Coulter Multisizer instrument was used for Year 5 (2010) and Year 7 (2012) and will produce smaller size classes.

	Mean grain size (µm)					**Size class**					**Standard deviation (µm)**				
ID	**pre**	**Yr1**	**Yr3**	**Yr5**	**Yr7**	**pre**	**Yr1**	**Yr3**	**Yr5**	**Yr7**	**pre**	**Yr1**	**Yr3**	**Yr5**	**Yr7**
L1s1	54.2	132.8	35.6	8.3	11.2	Vc.silt	f.sand	c.silt	m.silt	m.silt	102.6	78.8	3.2	5.1	3.0
L1s3	31.6	30.4	18.5	9.5	9.9	Vc.silt	c.sit	c. silt	m.silt	m.silt	50.7	20.9	3.5	5.9	2.8
L1s5	35.4	59.8	31.6	9.0	9.5	Vc.silt	Vf. silt	V.c. silt	m.silt	m.silt	56.2	38.0	3.5	6.7	2.9
L1s8	87.4	29.0	**n/a**	7.9	7.9	Vf.sand	C.silt	**n/a**	f.silt	f.silt	124.5	20.4	3.3	5.0	2.6
L2s2	30.3	40.1	24.3	7.6	8.1	C.silt	Vc.silt	C.silt	f.silt	m.silt	49.2	23.4	3.4	4.7	2.9
L2s6	61.6	24.6	15.7	10.9	9.6	Vc.silt	C. silt	m.silt	m.silt	m.silt	114.5	17.1	3.3	7.6	2.9
L3s1	47.6	80.1	25.9	8.7	8.6	Vc.silt	Vf.sand	C.silt	m.silt	m.silt	92.0	28.3	3.8	5.4	2.9
L3s3	72.9	**n/a**	**n/a**	**n/a**	n/a	Vf.sand	**n/a**	**n/a**	**n/a**	n/a	127.8	**n/a**	**n/a**	**n/a**	**n/a**
L3s5	120.4	39.2	16.2	8.9	8.7	Vf.sand	Vc.silt	m.silt	m.silt	m.silt	149.1	29.0	3.3	5.8	2.8
L3s7	80.8	40.0	21.7	8.5	7.0	Vf.sand	V.c.silt	C.silt	m.silt	f.silt	139.8	34.4	3.4	5.2	2.6
L4s2	95.0	87.7	36.4	8.6	10.5	Vf.sand	V.f.sand	V.c. silt	m.silt	m.silt	124.3	64.1	3.4	5.5	2.9
L4s6	111.1	34.7	25.3	8.9	9.7	Vf.sand	V.c.silt	C. silt	m.silt	m.silt	138.7	26.7	3.2	5.9	3.0
L5s1	38.9	41.0	24.0	7.4	8.8	Vc.silt	V.c.silt	C.silt	f.silt	m.silt	67.8	28.0	3.7	4.9	2.8
L5s3	129.4	38.9	19.5	11.2	9.7	f.sand	V.c.silt	C. silt	m.silt	m.silt	174.1	28.3	3.4	7.4	3.0

L5 s5	147.6	**n/a**	**n/a**	**n/a**	n/a	f.sand	**n/a**	**n/a**	**n/a**	n/a	211.2	**n/a**	**n/a**	**n/a**	**n/a**
L6 s2	105.4	43.9	20.5	8.7	10.3	Vf.sand	V.c.silt	C. silt	m.silt	m.silt	153.2	40.0	3.6	5.3	3.2
L6 s4	92.1	31.0	17.9	6.0	11.3	Vf.sand	V.c.silt	C. silt	f.silt	m.silt	138.7	22.2	3.9	3.6	3.2
L6 s6	113.4	45.6	20.5	7.9	10.1	Vf.sand	V.c. silt	C. silt	f.silt	m.silt	144.5	30.7	3.4	5.0	3.3
L6 s8	108.3	33.9	24.6	7.5	7.3	Vf.sand	V.c. silt	C. silt	f.silt	f.silt	131.4	29.3	3.5	4.6	2.7
L7 s1	37.1	31.8	20.2	7.8	8.9	Vc.silt	V.c. silt	C. silt	f.silt	m.silt	59.0	22.9	3.6	4.9	3.0
L7 s3	93.3	33.7	30.5	7.7	10.7	Vf.sand	V.c silt	C. silt	f.silt	m.silt	136.6	27.6	3.2	5.0	3.3
L7 s5	**n/a**	39.2	28.4	9.0	11.8	**n/a**	V.c silt	C. silt	m.silt	m.silt	**n/a**	34.0	3.5	5.5	3.1
L8 s2	91.3	29.9	24.2	11.1	8.5	Vf.sand	C. silt	C. silt	m.silt	m.silt	145.6	20.9	3.3	7.1	2.9
L8 s5	65.2	26.5	23.6	9.5	8.9	Vf.sand	C. silt	C. silt	m.silt	m.silt	126.2	16.4	3.4	0.9	3.0
L8 s8	121.1	28.0	24.0	10.5	7.1	Vf.sand	C.silt	C. silt	m.silt	f.silt	137.2	22.1	3.3	7.0	2.7

Table 16 Variation in grain size characteristic derived from core samples in 2006, 2008, 2010 and 2012 (Years 1, 3, 5 and 7 post-restoration) at CHV-R. Grain size class determined from modified Udden-Wentworth grain size classification (Blott and Pye, 2001). f.silt = fine silt, m.silt = medium silt, c.silt = coarse silt, vc.silt = very coarse silt, vf.sand = very fine sand, f.sand = fine sand. Note - grain size analysis performed using a Coulter Laser instrument for pre-conditions and Years 1 and 3. A Coulter Multisizer instrument was used for Year 5 (2010) and Year 7 (2012) and will produce smaller size classes.

	Mean grain size (µm)				**Size class**				**Standard deviation (µm)**			
Station	**Yr 1**	**Yr 3**	**Yr 5**	**Yr 7**	**Yr 1**	**Yr 3**	**Yr 5**	**Yr 7**	**Yr 1**	**Yr 3**	**Yr 5**	**Yr 7**
L1 s1	28.33	29.91	10.29	9.85	C. silt	c. silt	m.silt	m.silt	**n/a**	3.58	12.57	3.55
L1 s2	30.15	65.12	9.99	12.48	C. silt	V.f sand	m.silt	m.silt	**n/a**	5.85	12.22	3.22
L1 s3	92.44	57.39	9.48	11.20	v.f. sand	V.c. silt	m.silt	m.silt	**n/a**	6.49	11.34	3.24
L2 s1	77.09	40.70	9.06	6.63	v.f.sand	V.c silt	m.silt	f.silt	**n/a**	4.46	10.85	2.56
L2 s3	78.80	38.90	7.96	8.39	v.f.sand	V.c silt	f.silt	m.silt	**n/a**	3.67	9.72	2.94
L3 s1	170.20	**n/a**	9.04	6.82	F.sand	**n/a**	m.silt	f.silt	**n/a**	**n/a**	10.90	2.51

L3 s2	52.580	27.14	8.81	7.16	V.c. silt	C. silt	m.silt	f.silt	**n/a**	3.02	10.77	2.73
L3 s3	51.48	14.50	8.73	7.57	V.c silt	M. silt	m.silt	f.silt	**n/a**	2.47	10.42	2.50
L4 s1	135.6	52.28	9.07	8.80	F. sand	V.c silt	m.silt	m.silt	**n/a**	2.51	11.04	2.98
L4 s2	72.31	76.90	9.00	7.33	V.f.sand	V.f sand	m.silt	f.silt	**n/a**	2.76	10.84	2.74
L5 s2	31.02	23.26	7.82	6.46	V. c. silt	C. silt	f.silt	f.silt	**n/a**	3.53	9.45	2.53
L5 s3	23.56	17.33	8.13	8.70	C. silt	C. silt	m.silt	m.silt	**n/a**	3.30	9.79	2.82
L5 s4	26.95	25.65	8.54	8.67	C. silt	C. silt	m.silt	m.silt	**n/a**	4.90	10.25	2.97
L6 s1	25.31	21.48	8.63	6.89	C. silt	C. silt	m.silt	f.silt	**n/a**	3.32	10.26	2.55
L6 s2	22.85	15.53	9.25	7.84	C. silt	M. silt	m.silt	f.silt	**n/a**	3.27	11.21	2.70
L6 s3	77.53	28.57	7.94	7.51	v.f.sand	C. silt	f.silt	f.silt	**n/a**	4.63	9.54	2.59
L7 s2	34.68	15.32	7.75	6.63	V.c. silt	M. silt	f.silt	f.silt	**n/a**	3.31	9.16	2.48
L7 s3	27.07	16.12	8.19	7.16	C. silt	C. silt	m.silt	f.silt	**n/a**	3.53	9.76	2.56
L8 s2	25.79	16.77	8.99	7.05	C. silt	C. silt	m.silt	f.silt	**n/a**	3.23	10.98	2.71
L8 s3	84.59	11.95	**n/a**	7.71	V.f. sand	M. silt	**n/a**	f.silt	**n/a**	3.41	**n/a**	2.73

Table 17 Inverse floc model statistics for CHV in 2012. Model run by C. Skinner (2012).

a) CHV Station ID	Elev (m)	Floc Fraction (K_f)	Floc Limit (d_f)	Source Slope (m)	Rolloff Diameter (*dhat*)
L1 s1	3.02	0.60	16	0.50	17
L1 s3	5.00	0.61	14	0.46	18
L1 s5	6.71	0.62	14	0.49	15
L1 s8	5.05	0.58	9	0.55	10
L2 s2	3.97	0.66	14	0.38	17
L2 s6	6.19	0.61	14	0.44	16
L3 s1	3.75	0.68	16	0.49	16
L3 s3	4.57	NA			
L3 s5	5.38	0.68	16	0.5	15
L3 s7	5.58	0.67	12	0.52	12
L4 s2	4.10	0.58	14	0.44	17
L4 s6	5.06	0.64	16	0.47	17
L5 s1	3.80	0.59	12	0.52	14
L5 s3	5.22	0.61	14	0.49	15
L5 s5	5.92	NA			
L6 s2	5.24	0.59	14	0.48	15
L6 s4	5.69	0.60	16	0.53	15
L6 s6	6.27	0.63	16	0.50	15
L6 s8	6.40	0.65	12	0.54	12
L7 s1	4.13	0.58	12	0.35	16
L7 s3	6.52	0.57	14	0.42	16
L7 s5	6.39	0.54	14	0.45	18
L8 s2	5.30	0.69	16	0.46	16
L8 s5	5.11	0.66	16	0.48	15
L8 s8	5.05	0.74	16	0.47	14

Table 18 Inverse floc model statistics for CHV-R in 2012. Model run by C. Skinner (2012).

b) CHV-R Station ID	Elev (m)	Floc Fraction (K_f)	Floc Limit (d_f)	Source Slope (m)	Rolloff Diameter (*dhat*)
L1 s1	6.20	0.63	16	0.41	15
L1 s2	5.72	0.57	16	0.52	16
L1 s3	4.49	0.60	16	0.46	16
L2 s1	6.42	0.68	12	0.42	13
L2 s3	5.94	0.66	14	0.55	12
L3 s1	6.43	0.70	14	0.59	13
L3 s2	6.06	0.70	14	0.51	13
L3 s3	4.75	0.70	14	0.60	13
L4 s1	6.56	0.73	16	0.53	14
L4 s2	4.22	0.63	14	0.40	16
L5 s2	6.48	0.74	14	0.54	12
L5 s3	6.08	0.68	16	0.60	15
L5 s4	6.00	0.68	16	0.48	15
L6 s1	6.19	0.67	12	0.65	12
L6 s2	6.01	0.72	16	0.60	14
L6 s3	5.31	0.70	14	0.61	13
L7 s2	6.08	0.73	14	0.60	12
L7 s3	5.36	0.71	14	0.65	12
L8 s2	5.96	0.71	14	0.57	12
L8 s3	5.24	0.68	14	0.57	13

4.4 Vegetation

Species abundance and frequency trends.

There were few notable changes in vegetation at CHV-R, so only results from CHV were shown in Table 19.

At CHV, some species, such as *Atriplex glabriuscula* and *Salicornia europaea*, showed general declines between pre-restoration and 2012, and great fluctuations between years, likely corresponding to the creation of patches of unvegetated areas that were colonized by these early successional or ruderal species (Table 19). Some species associated with brackish conditions or the upper edge of high salt marsh, such as *Carex paleacea* maintained relatively constant frequency and abundances, although it appeared that there was more *C. paleacea* overall compared with pre-restoration (Table 19). Other species inhabiting similar habitats, such as

Juncus gerardii and *Solidago sempervirens* have shown slight declines. Low marsh cordgrass species *Spartina alterniflora* roughly doubled in abundance over the study period and in Year 7 post-restoration occurred in 63 plots versus 41 plots pre-restoration. High marsh cordgrass, or salt meadow hay, *Spartina patens* showed increased abundance and frequency, but the overall change was less dramatic than with *S. alterniflora* (Table 19).

Community Patterns

The ordinations showed a range of communities at both sites from low marsh, dominated by *S. alterniflora* (plots clustered at lower right on Figure 54), high marsh dominated by *S. patens*, (middle-right on Figure 54), to a variety of brackish communities (left side of Figure 54). At the beginning of the study, reference site plots were concentrated in a few clusters (low marsh, high marsh, and brackish with *C. paleacea* and *Juncus gerardii*). CHV had a greater range of communities, and more plots initially in the upper left of Figure 54, which contained upland species. By 2012, it was evident that species composition had shifted at CHV with many plots well within the range of reference site plots across the spectrum of salt marsh communities (Figure 54b). There was more range in reference plots in the 2012 survey, but this likely represented an increased ability by the team to recognize species, thus there may be greater variation attributable to the presence of minor (uncommon) species within the main salt marsh vegetation types. The changes at the study site were consistent with what we might expect from culvert replacement and expansion: shift in communities from upland to salt marsh.

Other Site-level Trends

The average number of species per plot remained largely consistent between years at CHV (Table 20; Figure 55); this was likely due to the replacement of some upland species by salt marsh species. At the reference site, there was a marked increase between 2004 and 2008 (Site x Year interaction; Table 20), and CHV-R generally had greater richness than CHV. This may reflect the team's increased ability to identify non-salt marsh species over time. There were several non-salt marsh species that appeared to be more common at CHV-R compared with CHV, and these may have been detected with greater frequency in later years. It could also imply that CHV-R was also experiencing a degree of change as well.

The average number of halophytic species was consistently greater at the reference site (Figure 56; Table 21). So, even though the main halophytic communities were present at the study site, there was less diversity, on average, at CHV, even seven years post-culvert replacement. The abundance of halophytes was similar at both sites (Table 22; Figure 57). The mean unvegetated area fluctuated greatly between years at CHV, likely due to the formation of pannes, the die-back of vegetation and subsequent re-colonization (Table 23; Figure 58).

Individual Plots at CHV

While the overall patterns showed gradual change or constancy in most species abundances, examination of individual plots over time showed that some plots were highly dynamic and changed substantially over the years. These changes were not captured by only examining site-level trends. Many plots showed low or an absence of coverage of salt marsh cordgrasses *S. alterniflora* and *S. patens* prior to restoration, but became rapidly dominated by one or both post culvert replacement (e.g., CHV L12S4). Some plots showed increased *S. alterniflora* in areas formerly dominated by *S. patens*, possibly indicating increased inundation (e.g., CHV L10S2, CHV L4S2, CHV L7S3, CHV L7S7); this inundation hypothesis was supported by data at other plots previously dominated by *S. patens*, but showed die-back of *S. patens* by 2010, accompanied with greater coverage of standing water and unvegetated area (e.g., CHV L4S3, CHV L4S5, CHV L5S2).

Some plots showed a rapid transition from freshwater wetland or upland vegetation, to a classic salt marsh succession: freshwater/upland vegetation followed by *Salicornia* or *Suaeda* post-culvert replacement, followed by *S. alterniflora* and/or *S. patens* in the later years (e.g., CHV L18S1, CHV L8S3, CHV L4S2S). Other plots showed an even more rapid transition, in this case from upland vegetation to *C. paleacea* dominated communities (e.g., CHV L2S1, CHV L3S1, CHV L4S1, CHV L6S1). Another set of plots began with high coverage of *Juncus gerardii*, which gave way to *S. patens*, *S. alterniflora* or both (e.g., CHV L4S6, CHV L5S2S, CHV L5S4, CHV L5S4S, CHV L7S9, CHV L7S10, CHV L6S2S).

A couple of plots showed another trend: *S. alterniflora* giving way to *S. patens* (e.g., CHV L14S4, CHV L1S2). This would be expected in high marsh areas as succession proceeds with *S. patens* taking longer to colonize and out-compete *S. alterniflora*. in higher elevation areas. While some plots showed little change, overall the main trends were consistent with greater amounts of salt water inundation in many of the plots. This was likely a response to culvert replacement, leading to a wetter marsh and increased soil salinity, which responded by shifts in plant community structure.

Table 19 Abundance patterns for main species at CHV. Columns with "f" indicate frequency (total number of plots in which species was found in that year). "Pre" refers to data collected prior to culvert replacement.

	pre	pre-f	2006	2006 f	2007	2007 f	2008	2008 f	2010	2010 f	2012	2012 f
Agrostis stolonifera			0.04	2	0.16	3	0.20	2				
Ammophila breviligulata			0.22	2								
Ascophyllum nodosum					0.03	1						
Atriplex glabriuscula	0.14	28	0.05	4	0.36	15	0.02	6	0.05	5	0.15	3
Calystegia sepia								1				
Carex hormathodes			0.04	1								
Carex paleacea	0.40	9	0.65	9	1.63	11	0.95	7	1.42	7	1.77	10
Upland vegetation	2.34	27										
Daucus carota	0.02	1										
Distichlis spicata			0.25	3	0.32	7	0.45	4	0.86	7	1.25	12
Elymus trachycaulis			0.01	1								
Euthamia graminifolia												
Festuca rubra					0.14	2	0.04	1			0.07	2
Glaux maritima				2								

	pre	pre-f	2006	2006 f	2007	2007 f	2008	2008 f	2010	2010 f	2012	2012 f
Juncus balticus					0.27	3	0.11	1			0.01	1
Juncus gerardii	2.06	15	4.27	24	2.91	19	2.60	18	2.04	12	0.83	6
Lathyrus maritima		3										
Limonium nashii	0.12	10	0.19	6	0.19	9	0.13	9	0.15	10	0.08	7
Mentha arvensis	0.01	1										
Myosotis laxa		1										
Plantago maritima	0.06	2			0.01	2	0.01	1	0.05	3	0.05	2
Poa palustris						1						
Potentilla simplex	0.06	1										
Rosa virginiana				1								
Rubus strigosus	0.01	1										
Ruppia maritima			0.15	5	0.10	1			0.23	2		
Salicornia europaea	0.78	23	0.01	4	0.17	14	0.58	30	0.09	11	0.08	4
Scutus acutus	0.09	1										
Solidago sempervirens	0.54	10	0.44	12	0.24	12	0.10	5	0.09	3	0.02	2
Spartina alterniflora	5.98	41	8.03	50	8.60	50	8.73	48	10.42	57	10.44	63
Spartina patens	11.29	60	10.81	54	13.10	67	12.87	69	13.46	66	13.28	64
Spartina pectinatas	0.11	1	0.35	2	0.75	6	0.76	6	0.64	4	0.73	5
Suaeda maritima		2			0.21	20	1.02	26	0.04	6	0.12	7
Symphotrichum novi-belgii					0.06	2	0.04	1	0.10	1		
Triglochin maritima			0.02	1	0.03	3			0.01	1	0.01	1
Typha latifolia			0.15	2	0.17	2	0.05	1	0.08	1	0.06	1
Unvegetated	0.09	1	1.38	24	1.45	17	0.15	3	1.06	14	1.19	10

Table 20 Repeated measures ANOVA comparing mean plot species richness at CHV and CHV-R sites over time.

Between plots	Df	Sum Sq	Mean Sq	F	P
Site	1	280.0	280.00	35.39	<0.00001
Residuals	124	981.1	7.91		
Within plots					
	Df	Sum Sq	Mean Sq	F	P
Year	5	29.1	5.821	5.327	<0.00001
Site X Year	5	38.7	7.749	7.091	<0.00001
Residuals	620	677.5	1.093		

Table 21 Repeated measures ANOVA comparing mean plot halophytic species richness at CHV and CHV-R sites over time.

Between plots	Df	Sum Sq	Mean Sq	F	P
Site	1	59.0	59.00	12.57	0.000553
Residuals	124	581.8	4.69		
Within plots					
	Df	Sum Sq	Mean Sq	F	P
Year	5	24.5	4.907	6.153	<00001
Site X Year	5	7.7	1.542	1.933	0.087
Residuals	620	494.4	0.797		

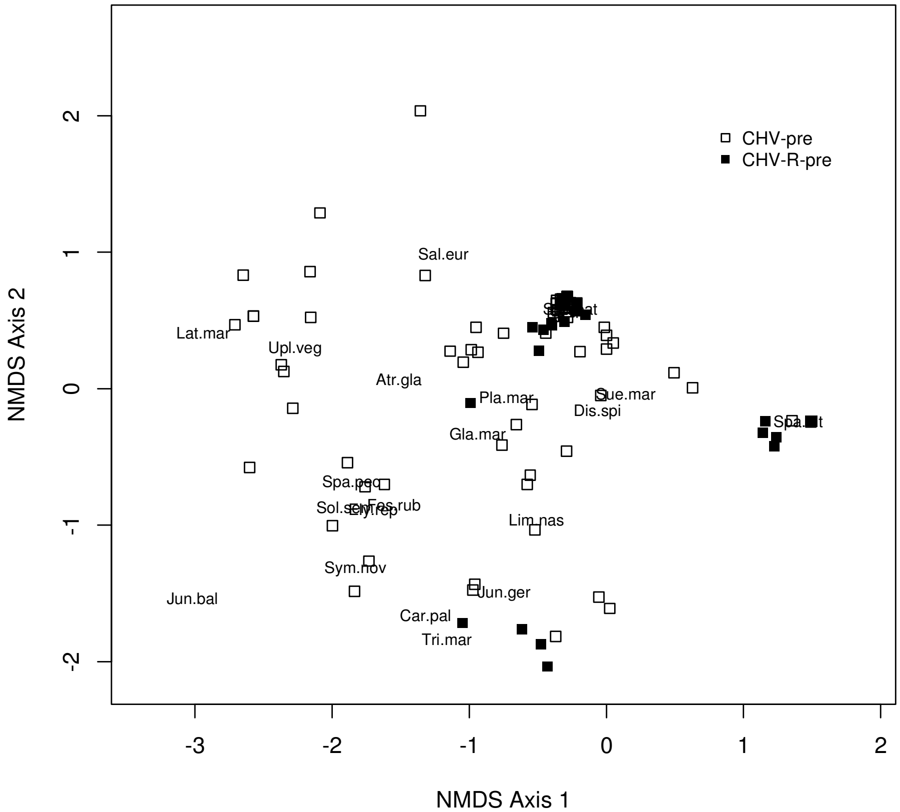
Table 22 Repeated measures ANOVA comparing mean plot halophytic species abundance at CHV and CHV-R sites over time.

Between plots	Df	Sum Sq	Mean Sq	F	P
Site	1	658	657.6	1.945	0.166
Residuals	124	41924	338.1		
Within plots					
	Df	Sum Sq	Mean Sq	F	P
Year	5	9553	1910.6	25.89	<0.00001
Site X Year	5	1406	281.2	3.81	0.002
Residuals	620	45759	73.8		

Table 23 Repeated measures ANOVA comparing mean plot unvegetated area at CHV and CHV-R sites over time.

Between plots	Df	Sum Sq	Mean Sq	F	P
Site	1	22	22.31	0.784	0.378
Residuals	124	3529	28.46		
Within plots					
	Df	Sum Sq	Mean Sq	F	P
Year	5	134	26.878	2.860	0.0145
Site X Year	5	98	19.605	2.086	0.0654
Residuals	620	5826	9.397		

a)


CHV-pre
CHV-R-pre
NMDS Axis 2
NMDS Axis 1
Sal.eur
Lat.mar
Upl.veg
Atr.gla
Pla.mar
Sue.mar
Dis.spi
Gla.mar
Spa.pec
Fes.rub
Lim.nas
Sym.nov
Jun.bal
Jun.ger
Car.pal
Tri.mar

b)

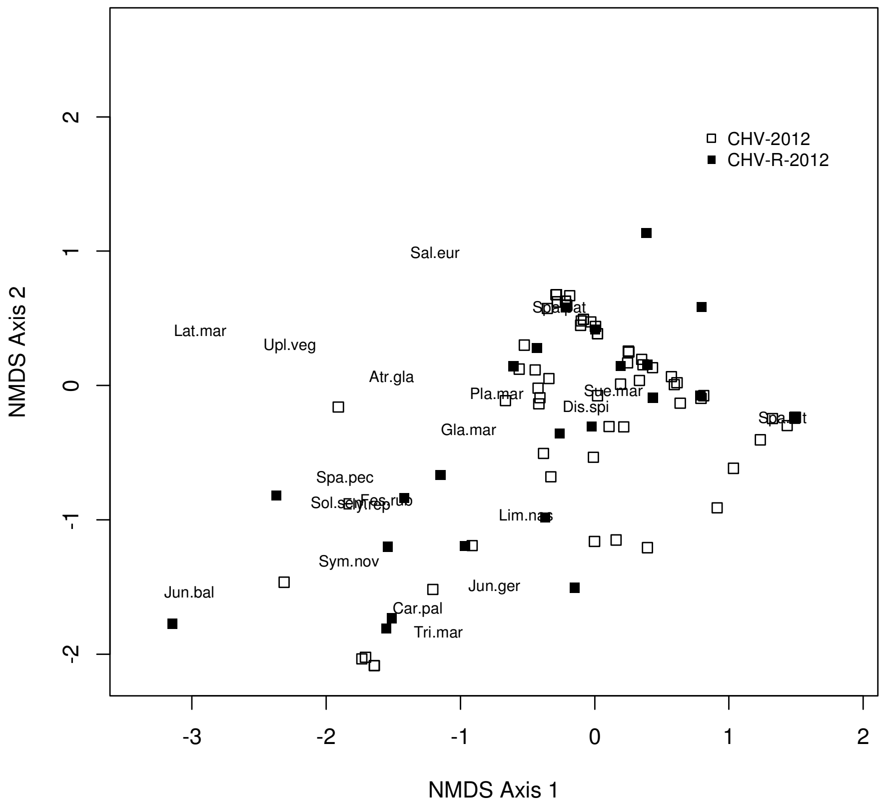


Figure 54 Non-metric multidimensional scaling ordination of plots at CHV and CHV-R sites. a) data from pre-restoration (2002-2004); b) data from 2012.

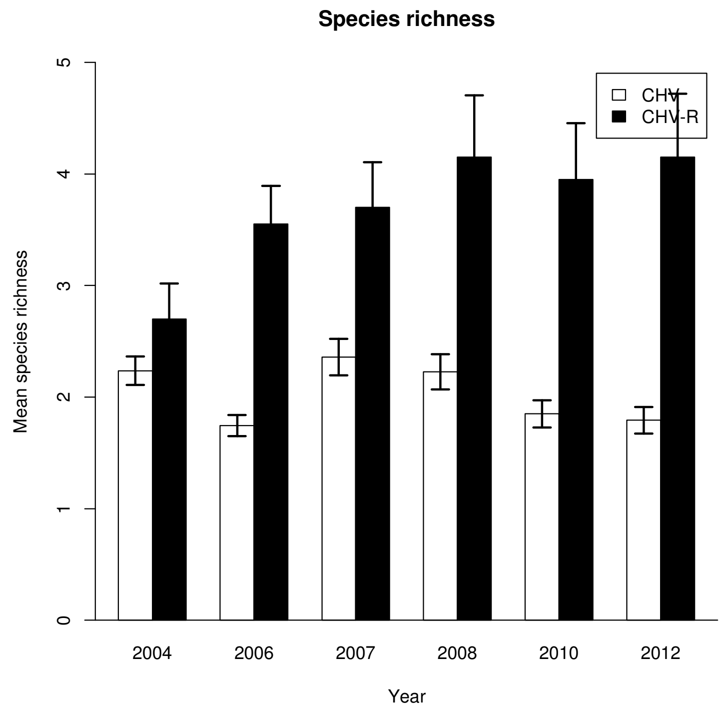


Figure 55 Mean plot species richness at CHV and CHV-R sites over time. 2004 is considered "pre-restoration".

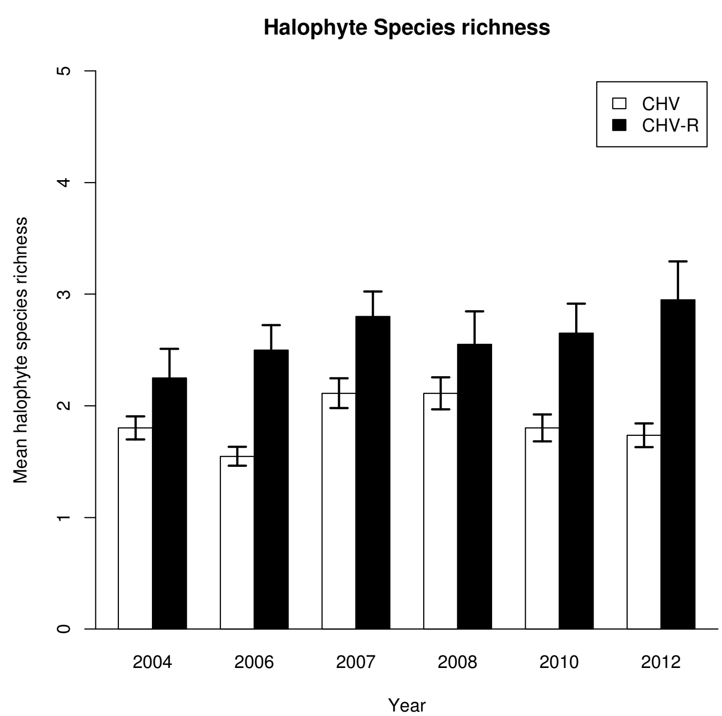


Figure 56 Mean plot halophytic species richness at CHV and CHV-R sites over time. 2004 is considered "pre-restoration".

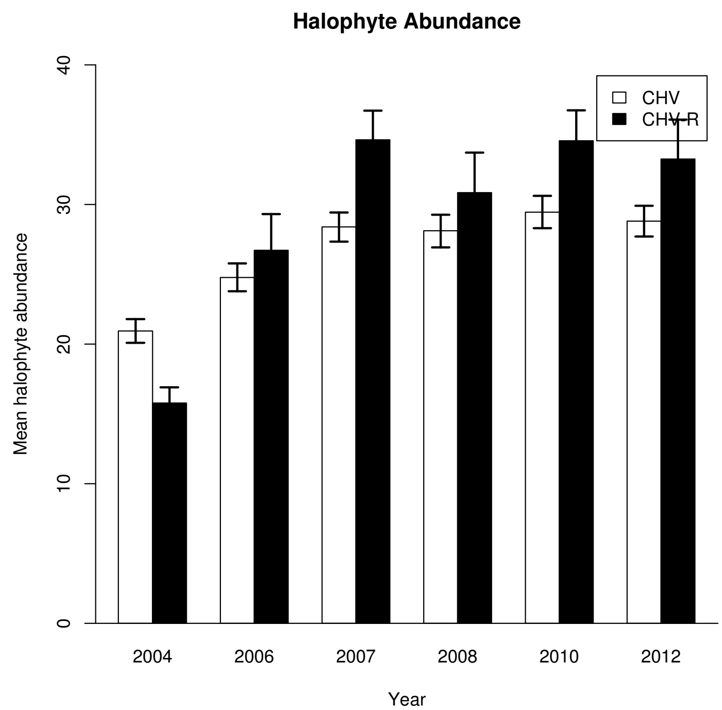


Figure 57 Mean plot halophytic species abundance at CHV and CHV-R sites over time. 2004 is considered "pre-restoration".

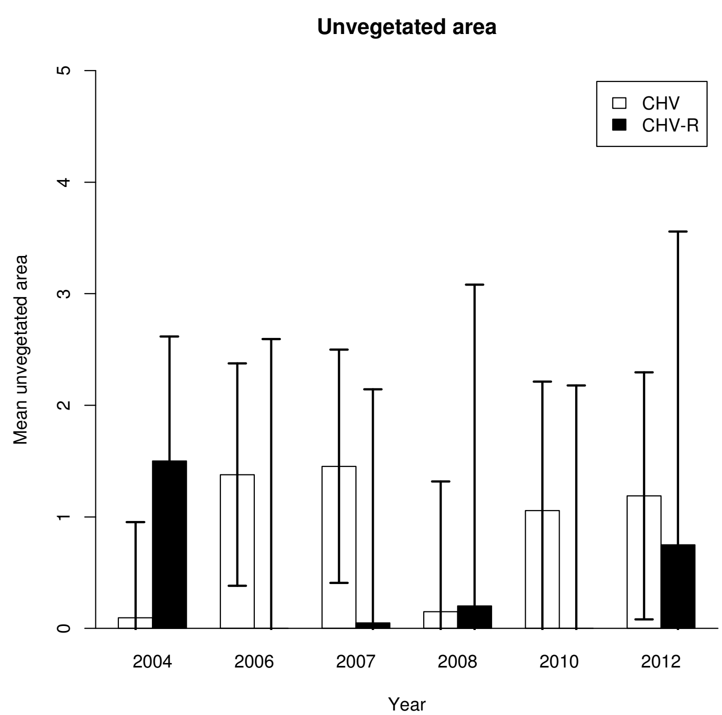


Figure 58 Mean plot unvegetated area at CHV and CHV-R sites over time. 2004 is considered "pre-restoration".

4.5 Nekton

Individuals from twelve species were observed and captured during the 2005-2012 fish survey activities: eight species at CHV and ten species at CHV-R (Table 24; Table 25). No new species were captured during the 2012 surveys, and not all species were encountered in each year (relatively consistent species richness) (Table 25). Years 5 and 7 post-restoration monitoring saw a greater number of large (adult) individuals of several species, most notably *Morone saxatilis* (striped bass) and *Anquilla rostrata* (American eel) (Table 27). These species were, however, encountered at both sites. For pooled data (all methods), *Fundulus heteroclitus* (mummichog) and *Menidia menidia* (Atlantic silverside) were the only species consistently captured at both sites in all years (Table 25). Abundance fluctuated from year to year between the two species at both sites, however, following restoration the mummichog was consistently the most abundant species at CHV, while Atlantic silverside was the most abundant at CHV-R in all but the fifth (2010) year.

Faunal response is dependent on access to the shallow intertidal marsh surface and intertidal and subtidal creeks (Able et al. 2008). The response of fish can be rapid with an increase in density (Roman et al. 2002; Able et al. 2008); however, species richness can decrease following restoration (Roman et al. 2002). At CHV, there was a marked increase in the relative abundance of fish post-restoration, mostly due to the increased panne size, re-activated creek network and improved hydrological conditions. This increased density was most pronounced in year two, which was consistent with findings of other culvert replacement projects in the Gulf of Maine (Konisky et al. 2006). Consistently, more fish were caught at CHV compared to the reference site which may be attributed to the behavior of the dominant species and marked difference in availability of suitable open water habitat (pannes) between the two sites. The lower elevation of marsh platform at CHV means greater water depth and longer inundation period (more habitat and longer availability). At CHV, the catch was dominated by the mummichog, a resident fish, while the Atlantic silverside, a migratory species, occurred with the highest frequency at CHV-R.

This trend of Atlantic silversides being more common on the reference (mature) system has also been observed at the Walton River restoration site (Neatt et al. 2011). The presence of a greater number of Atlantic silversides at CHV-R could be the result of differences in habitat conditions; schooling behavior, a trait not shared by the mummichog; the location of sampling (pulls at CHV-R much closer to the point of tidal entry than those at CHV); and the size of the marsh (populations at CHV may be more dispersed due to the larger marsh area). This last point was supported by the fact that fish density (as measured by catch per unit effort) for almost all years was higher at CHV-R; except for the fyke net sampling (Table 27). In addition, it has also been reported that Atlantic silversides tend to be the most abundant fish species on mature salt marshes (Fay et al. 1983). The low numbers of Atlantic silversides following restoration coupled with the high percentage of mummichogs encountered during this period, which represents a marsh in the early stages of considerable habitat change, could be considered consistent with this finding.

For all years following restoration, the mummichog was the dominant fish species captured at CHV, with the majority of individuals appearing in the minnow traps set within the pannes on the marsh surface. The absence of comparable panne habitat at CHV-R meant that traps had to be set in areas of higher (hydrological) energy and greater exposure (within the main river channel or primary creeks), in other words, areas less favoured by the mummichog. A similar pattern of high numbers of mummichogs captured in minnow traps set in established salt pannes was observed at other reference marsh sites (e.g., Walton River Salt Marsh Restoration reference site; Neatt et al. 2013). The higher percent composition of Atlantic silversides recorded prior to restoration at CHV was because minnow traps were not set in the pannes during that sampling event.

The standard length average and range were calculated for the most common species caught at CHV and CHV-R for each year pre- and post-restoration. The standard length average for the dominant species (mummichogs and Atlantic silversides) at CHV and CHV-R were similar for all years post-restoration (Table 27). For both species, size equates to sexually maturity, with individuals greater than 41 mm considered adults. Although individuals of all age-size classes were encountered, the majority of mummichogs measured were in the upper range of the 41 – 70 mm size class, while the Atlantic silversides measured were in the lower portion of the 71 – 100 mm size class. Particularly for mummichogs, the standard length range for individuals at CHV tended to be greater and encompassed more individuals at the lower size ranges than were recorded for CHV-R.

The presence of American eel, *Microgadus tomcod* (tomcod), and salmonids at both sites (particularly CHV-R) throughout the post-restoration monitoring program is evidence that higher order predators are accessing these sites during high tide events (Figure 59). The higher frequency and abundance of these species at CHV-R is likely the combination of the habitat/hydrology conditions and density.

Table 24 Fish species caught and encountered during fish survey activities at CHV and CHV-R (2005 – 2012), and their important traits.

RES=Resident; TRA=Transient; FRE=Freshwater; BRA=Brackish; MAR=Marine; ANA=Anadromous; CAT=Catadromous.

Common Name	Scientific Name	Species Traits						
		RES	TRA	FRE	BRA	MAR	ANA	CAT
Atlantic silversides	*Menidia menidia*		X			X		
Alewife (Gaspereau)	*Alosa pseudoharengus*		X	X	X	X	X	
Three-spine stickleback	*Gasterosteus aculeatus*		X	X	X	X	X	
Four-spine stickleback	*Apeltes quadracus*	X		X	X	X		
Nine-spine stickleback	*Pungitius pungitius*		X	X	X	X	X	
Mummichog	*Fundulus heteroclitus*	X		X	X	X		
Tomcod	*Microgadus tomcod*		X		X	X		
Rainbow smelt	*Osmerus mordax*		X	X	X	X	X	
American eel	*Anquilla rostrata*		X	X	X	X		X
Striped Bass	*Morone saxatilis*		X	X	X	X	X	
Brook trout	*Salvelinus fontinalis*		X	X	X	X	X	
Rainbow trout	*Oncorhynchus mykiss*		X	X	X	X	X	

Table 25 Percent composition of total catch of fish species for CHV and CHV-R immediately post-restoration and for the additional five years of the sampling program, all sampling methods.

a) Common Name	Pre-restoration (2005)*		Post-restoration									
			Year One (2006)		Year Two (2007)		Year Three (2008)		Year Five (2010)		Year Seven (2012)	
	CHV	CHV-R	CHV	CHV-R	CHV	CHV-R	CHV	CHV-R	CHV	CHV-R	CHV	CHV-R
Atlantic silversides	57	96	6.5	94.0	4.6	72.7	1.0	47.5	3.1	43.8	6.5	54.6
Alewife/Gaspereau	-	-	-	-	-	-	-	-	-	-	0.5	-
Three-spine stickleback	-	-	1.4	-	0.2	-	-	3.3	-	1.1	0.9	0.9
Four-spine stickleback	-	-		-	-	-	-	1.1	-	-	-	-
Nine-spine stickleback	-	-	0.5	-	0.1	-	0.3	0.4	-	-	-	-
Mummichog	43	4	91.5	6.0	95	26.6	98.4	46.4	91.1	51.3	91.7	44
Tomcod	-	-		-	-	-	-	-	-	1.1	-	-
Rainbow Smelt	-	-	-	-	-	-	-	-	-	-	0.2	0.5
American eel	-	-	0.2	-	0.1	-	0.1	1.4	5.8	1.1	1	-
Striped Bass+	-	-	-	-	-	-	0.2	-	-	0.5	-	-
Brook trout		-	-	-	-	0.8	-	-	-	-	-	-
Rainbow trout	-	-	-	-	-	-	-	-	-	1.1	-	-
Abundance	7	375	648	100	3160	128	1766	512	813	187	611	218
Species	2	2	5	2	5	3	5	6	3	7	6	4

*Beach seine only in 2005. Data does not include 2002-2003 minnow trap sampling by the Ecology Action Centre.
+Also observed being caught by local recreational fishermen (hook and line) at the mouth of both systems.

Table 26 Catch per unit effort for each sampling technique.

	CHV			CHV-R		
Year	**Minnow Trap**	**Seine**	**Fyke**	**Minnow Trap**	**Seine**	**Fyke**
2005	--	187.50	--	--	2.33	--
2006	0.50	24.00	--	44.33	14.75	--
2007	0.50	24.40	--	95.67	287.43	--
2008	0.50	68.00	146.00	124.33	42.50	63.67
2010	1.88	22.75	41.00	72.63	32.50	51.00
2012	1.00	--	218.00	62.86	38.67	38.50
Total	**4.38**	**326.65**	**405.00**	**399.82**	**418.18**	**153.17**
Average	**0.73**	**54.44**	**101.25**	**66.64**	**59.74**	**38.29**
n=	43	16	6	51	27	7

Table 27 Standard length average and range for the most common fish species caught at CHV and CHV-R (2005, 2006, 2007, 2008, 2010, 2012) using the measurements of the first 15 individuals for each species caught, all survey methods.

Date	Species	SL Average (mm)		SL Range (mm)	
		CHV	CHV-R	CHV	CHV-R
2006	Mummichog	51	78	10 -95	60 – 90
	Atlantic Silversides	50	46	20 - 80	20 – 80
	Nine-spine stickleback	38	-	30 - 45	-
	Three-spine stickleback	8	-	5 - 10	-
	American Eel	35	-	35 - 35	-
2007	Mummichog	50	46	15 -95	20 – 90
	Atlantic Silversides	68	72	20 -115	50 – 105
	Nine-spine stickleback	27	-	20 - 50	-
	Three-spine stickleback	-	43	-	40 - 45
	American Eel	20	-	10 - 30	-
2008	Mummichog	58	53	5 - 100	30 - 100
	Atlantic Silversides	54	67	30 - 80	40 – 100
	Nine-spine stickleback	54	55	50 - 60	55
	Three-spine stickleback	-	34	-	25 - 40
	American Eel	34	24	22 - 45	15 – 32
2010	Mummichog	61	55	30 - 110	30 - 100
	Atlantic Silversides	77	75	60 - 110	45 – 120
	Three-spine stickleback	-	55	-	40 – 70
	Striped Bass	-	500	-	500-500
	American Eel	171	95	45 - 400	40 - 150
2012	Mummichog	63	65	35-100	45-105
	Atlantic Silversides	80	71	55-100	55-80
	Three-spine stickleback	-	35	-	35
	American Eel	283	-	250 - 300	-

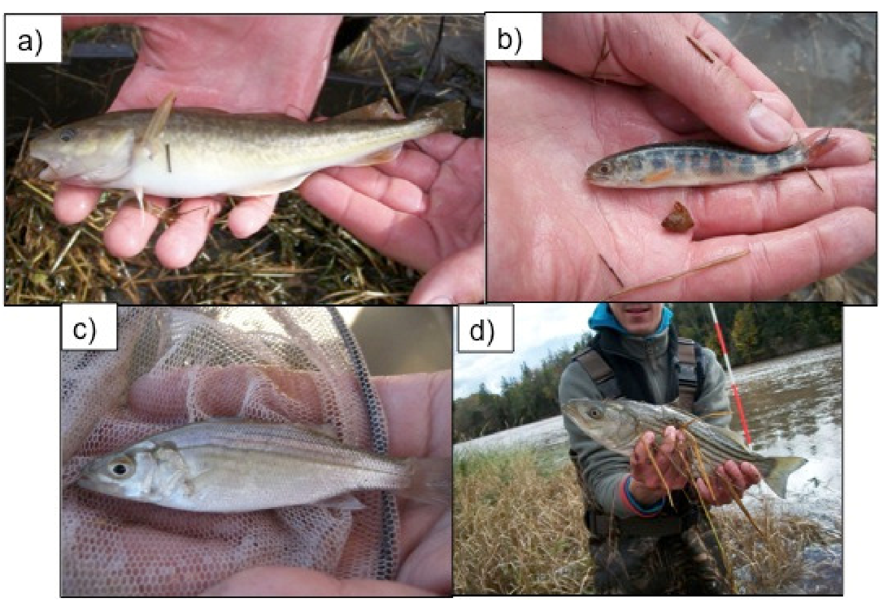


Figure 59 Fish at CHV and CHV-R: a) *Microgadus tomcod*, CHV-R 9/10/10; b) *Salmo trutta*, CHV-R 9/10/10; c) *Morone saxatilis*, CHV 19/9/08; d) *Morone saxatilis*, CHV-R 9/10/10. Photographs by J. Graham and N. Dugandzic.

4.6 Benthic and other Aquatic Invertebrates

Aquatic Invertebrates

Over the course of the monitoring program, sixteen species were collected with the invertebrate activity traps (IAT): CHV (13 species) and CHV-R (10 species) (Table 28; Figure 60). Both sites had an average of six species per sample over all years. Species were a mix of estuarine and freshwater animals.

Corixidae (water boatmen family) and the estuarine snail *Hydrobia totteni* dominated the CHV-R samples, while Corixidae and the amphipod Gammarus mucronatus dominated the CHV samples. A number of copepods (a planktonic crustacean) were collected at both sites, particularly at CHV in panne 1, which was the closest panne to the culvert. Also of note, was the presence of Dipterans (true flies), and *Corophium volutator* (mud shrimp; a keystone species of Bay of Fundy mudflats).

The 2008 and 2010 samples for CHV showed the greatest abundances and diversity of all years; whereas 2012 was the lowest for CHV and highest for CHV-R (Table 28). The variation between years and between sites was to be expected given the small sampling set and the highly variable conditions of pannes, hydrology, and weather conditions. The pannes that were sampled at CHV were larger than those at CHV-R and were located on the front half of the marsh (closer to tidal influence), while the pannes at CHV-R were located towards the back or upstream end of the system. Despite the variation between the two sites (Figure 61), there was no significant difference between the samples from CHV and CHV-R (P-value 0.88).

Table 28 Presence (indicated by checkmark) of individual species per year, in IAT samples for CHV and CHV-R.

Class/Species	CHV 2005	CHV 2007	CHV 2008	CHV 2010	CHV 2012		CHV-R 2007	CHV-R 2008	CHV-R 2010	CHV-R 2012
INSECTS										
Diptera-Chironmidae larvae					✓					
Diptera-Ceratopogonidae-Culicoides sp?	✓							✓	✓	
Hemiptera				✓					✓	✓
Corixidae	✓	✓	✓	✓	✓		✓	✓	✓	✓
Chironmidae				✓						
Coleoptera (unidentified)	✓									
Coleoptera-Dytiscidae	✓									
Thripidae									✓	

MOLLUSCS										
Hydrobia totteni		✓	✓	✓						✓
CRUSTACEANS										
Gastropoda (snails)		✓	✓	✓			✓	✓	✓	
Corophium insidiosum			✓							
Corophium volutator			✓	✓						
Gammarus mucronatus	✓	✓	✓	✓	✓		✓	✓	✓	✓
Ostracoda							✓	✓		
Copepoda-Harpacticoid		✓	✓	✓	✓		✓	✓		✓
HYDRACHNIDIA							✓	✓		
SUMMARY										
ABUNDANCE (#/SAMPLE)	**111**	165	984	579	97		85	348	121	1467
SPECIES/SAMPLE	**5**	5	7	8	4		6	7	6	5

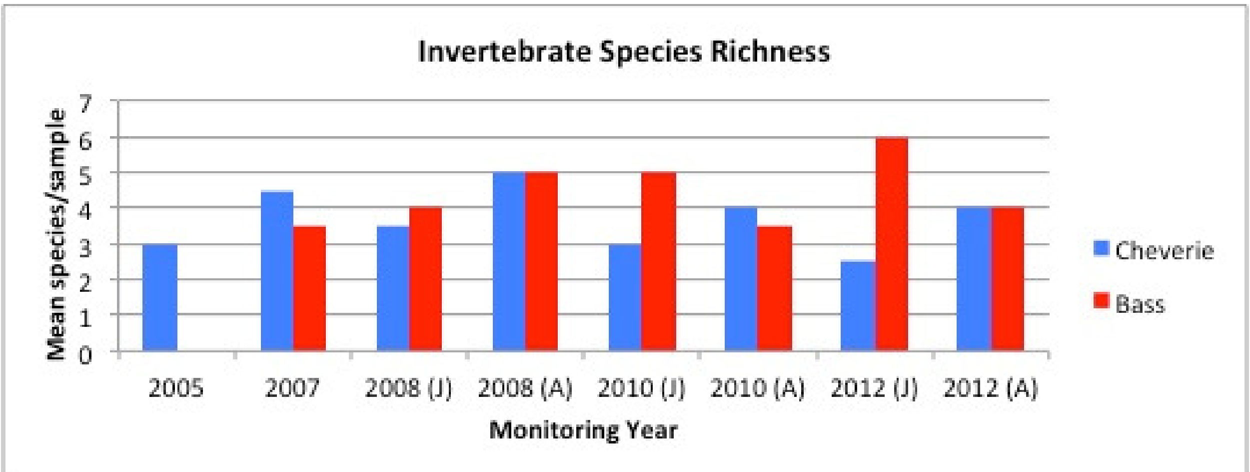


Figure 60 Invertebrate species richness from IAT at CHV and CHV-R (J-July; A-August).

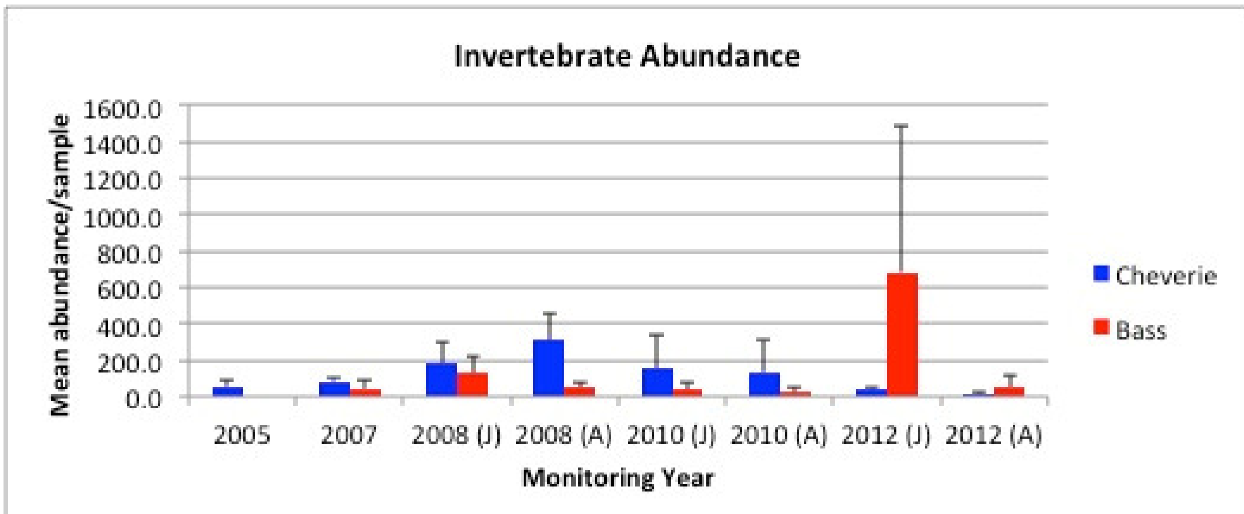


Figure 61 Invertebrate abundance (mean number of individuals/sample) from IAT at CHV and CHV-R (J-July; A-August).

4.7 Structured Winter Walk

Following the warmer than normal winter of 2012, the winter of 2013 experienced an extended cold period that lasted much of January and February. Snow fall and ice development were high throughout much of the winter, but early March saw the onset of warmer conditions and rain, such that by mid-month both CHV and CHV-R were largely ice/snow free. As was observed over the past two years, winter saw more of the trees within the die-back zone broken and fallen. Erosion and bank slumping along the north side of the main river channel in the vicinity of the old dyke continued (Figure 62). There was also erosion occurring around the upstream end of the culvert that was not observed previously (Figure 63).

The larger winter tides and storm events continued to deposit large wrack mats containing dead plant materials and large woody debris along the old dyke and upland edge of the marsh at CHV (Figure 64). Material at CHV-R tended to concentrate on the marsh surface downstream of the causeway-bridge and dispersed over a broader portion of the marsh surface (Figure 65). As in previous years, ice raft deposits at CHV-R were observed to contain more marine (mudflat) derived fine to coarse sediment (rocks) than CHV (Figure 66). This may be indicative of a difference in the origin and transport of ice between the two sites. Given that the culvert at CHV continued to present a barrier to tides larger than 7.1 m (CGVD28), it was likely that the culvert also represented a barrier to the import of the larger marine derived ice materials. Therefore it was likely that much of the ice material at CHV may be locally derived (developed on-site) and thus contained material that was also from within the site (salt marsh sediment and plant materials). The bridge at CHV-R did not represent a barrier to tidal flow, ice or the import/export of materials, and so more materials (estuarine sediment and rock material) from outside the site were able to reach and be deposited within.

The deterioration along the entire length of the seaward side of the causeway adjacent to the culvert (DNR crown land) continues to be a concern. The larger tides and storms of the fall of 2012 and winter of 2013 continue to cause considerable erosion. First noted in the 2010 monitoring report (Bowron et al. 2010), damage to the causeway has increased over the past two years, with considerable damage (loss of armour rock and fill) having occurred since the fall of 2010 (Figure 67).

A selection of landscape photographs from the CHV and CHV-R winter walks are provided in Appendix C.

Figure 62 Bank slumping and erosion along the main channel at the toe of the dyke. Photograph by T. Bowron, 15 March 2011.

Figure 63 Erosion around the upstream end of the culvert. Photograph by T. Bowron, 6 March 2013 (NB: NSTIR added additional armour stone in Summer 2013).

Figure 64 Vegetative material and large woody debris along downstream side of dyke at CHV. The dyke itself has suffered much erosion and subsidence over the past several years. Photograph by T. Bowron, 15 March 2011.

Figure 65 Vegetative material, ice and large woody debris downstream of causeway-bridge at CHV-R. Photograph by T. Bowron, 6 March 2013.

Figure 66 Suspected marine derived coarse material deposited on the marsh surface at CHV-R by winter ice. The skeleton was not part of the deposited material as it was present at this location in fall. Photograph by T. Bowron, 6 March 2013.

Figure 67 Loss of armour stone and erosion of fill along seaward side of causeway. Photograph taken at mid-causeway looking north away from culvert. Photograph by T. Bowron, 6 March 2013.

5.0 Summary and Implications

Monitoring of a range of physical and biological indicators of tidal wetland habitat condition, as part of the CHV salt marsh restoration project, extended from prior to culvert replacement in 2005 until seven years post-restoration (2012). The tidal wetland monitoring protocol that this program was based on outlines monitoring activities over a five year post-restoration period (Konisky et al. 2002). However, the monitoring program was modified (reduced monitoring activities in year four and a year seven added) in order to document the longer-term changes in physical and biological components of the system as a result of culvert replacement.

The results of monitoring activities prior to 2012 were presented in a series of reports by CBWES (Bowron and Chiasson 2006; Bowron and Neatt 2007; Bowron et al. 2008; Bowron et al. 2009; Bowron et al. 2010, Bowron et al. 2011a). The seventh year (2012) of post-restoration monitoring saw the implementation of the full monitoring program at both CHV and CHV-R, the results of which were presented in this report. The monitoring and research activities that have taken place as part of this restoration project have provided a comprehensive record of biotic and abiotic habitat conditions at both the restoration and reference sites and have documented the change in conditions at CHV following restoration.

The installation of a more appropriately sized culvert in the causeway that crosses the mouth of the CHV system in 2005 resulted in the restoration of a more natural hydrological regime to the tidal river and marsh. The new hydrological regime was found to be sufficient to flood the entire marsh surface (~43 ha) with tidal waters on spring high tide events (15% of high tides). This increase in extent, duration and frequency of tidal flooding has improved wetland conditions at the site as well as availability and accessibility of the marsh surface for fish. The increase in tidal wetland area is fulfilling the mandate of the HADDs project to increase and improve the overall availability and accessibility of fish habitat.

Over the course of monitoring activities spanning the first seven years following restoration, positive change was observed in the physical (extent and frequency of flooding; increased and improved salt panne habitat conditions; sediment accretion; and elevation) and the biological (expansion of halophytic vegetation community and fish usage) components of the CHV system as a result of culvert replacement. Similar changes were not observed at the reference site.

As with most salt marsh restoration projects (e.g. Onaindia et al. 2001; Hinkle and Mitsch 2005; Wolters et al. 2005, van Proosdij et al. 2010), the variables driving the ecosystem response were hydrology and surface topography (elevation). While the expansion of halophytic vegetation at CHV was rapid following culvert replacement, differences continued to persist between the two sites (e.g. vegetation composition). This may indicate a lack of dispersal or differences in environmental conditions between the study and reference site. In particular, the smaller size of the marsh platform at CHV-R, the lower elevation of the marsh platform at CHV, and the inclusion of a number of higher elevation vegetation sampling plots at CHV-R are each potential contributing factors to the higher vegetation diversity at CHV-R (greater number of high marsh and upland species represented at CHV-R). Fitting environmental variables to the species composition ordinations supports the idea that environmental differences may prevent convergence in community structure.

The data collected for geospatial attributes, hydrology, soils and sediment, vegetation and fish during the 2012 field season continue to support the conclusion that the CHV system continues to respond positively to restoration. Although parity with conditions at the reference site has not been reached for some of the parameters, the differences that remain are less likely the result of a failure of the restoration treatment, but rather a combination of insufficient time for site to achieve maturation, sampling design and natural variability.

Overall this project demonstrates that it is possible to successfully restore a tidally restricted salt marsh ecosystem through culvert replacement and with minimal manipulation of the geomorphology and biota in a hypertidal environment. The success of this restoration project can likely be attributed to the determination and installation of a sufficiently sized culvert to re-establish a more natural tidal regime, the presence of a local source of colonists (on-site), and the presence of relict creek, ditch and panne network allowing the re-establishment of hydraulic connectivity within the site. This project has and will continue to help guide future attempts at salt marsh restoration within macro-tidal systems such as the Bay of Fundy.

Implications for restoration:

- The availability of high-resolution elevation data such as LiDAR and low altitude photogrammetry early in the restoration process can significantly assist with restoration design, monitoring program design, the placement of sampling stations and accurate tidal flood modeling.

- Monitoring programs need to consider the spatial variability of sedimentary processes such as sediment accretion within their sampling strategy.

- Vegetation recovery can be rapid (two years) when shifts in abiotic conditions result in mortality of terrestrial vegetation and sources for re-colonization are nearby.

- Simple indicators such as species richness may not be useful indicators of restoration success, when restoration and reference sites occupy different positions within the tidal frame or have significantly different ranges in elevation relative to mean high water.

- The timing and type of trap used to sample fish can exert a strong influence on the type and abundance of nekton species captured and comparisons to a reference site.

- Pre- and post-restoration monitoring is critical, and a comprehensive monitoring program such as the GPAC Protocol, when modified to be more responsive to local conditions, can be an effective tool for determining project success.

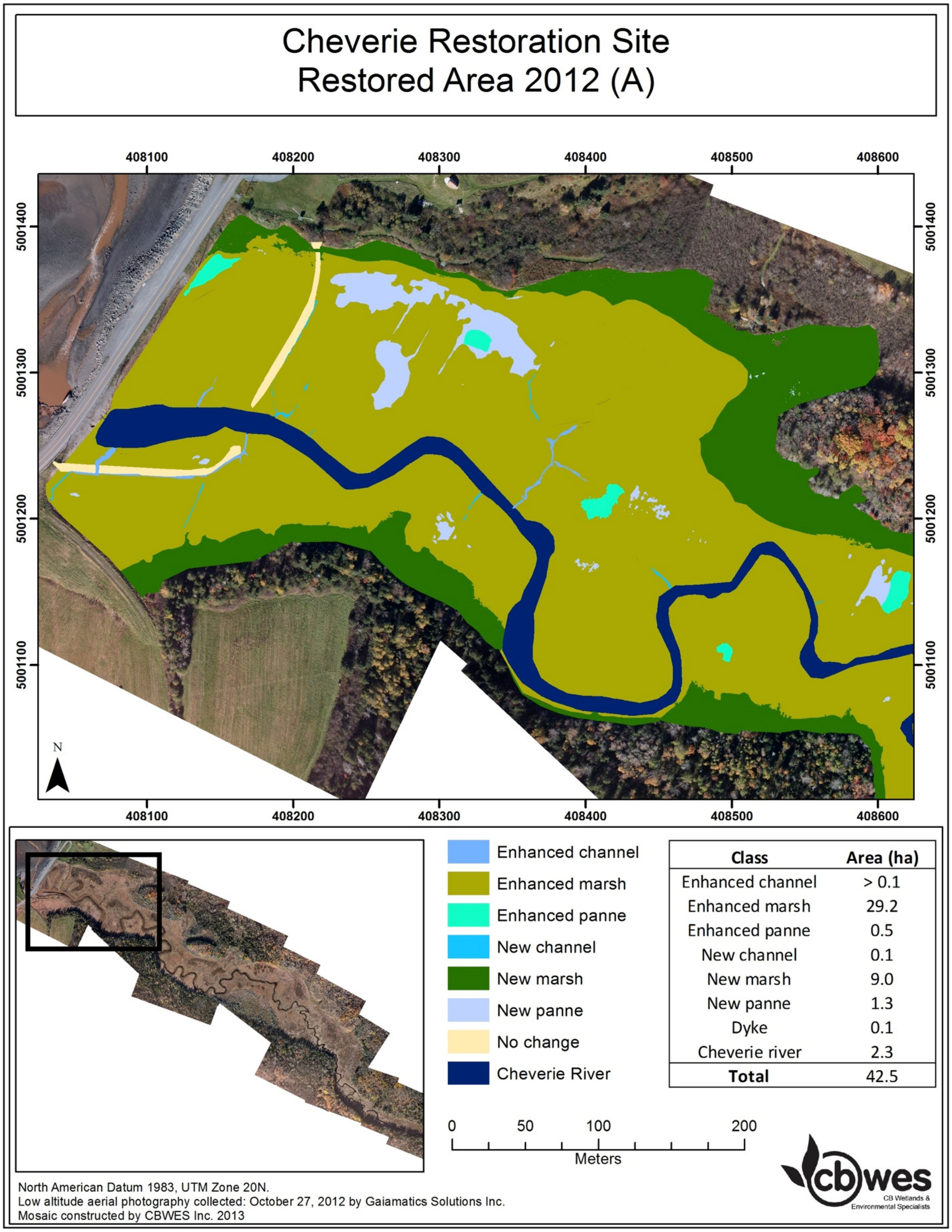
- Culvert replacement (barrier removal) projects can be an effective restoration technique in macro-tidal environments as long as they are properly designed – new culverts or breaches are sufficiently sized to allow the majority of spring tides to pass freely.

Restored Area

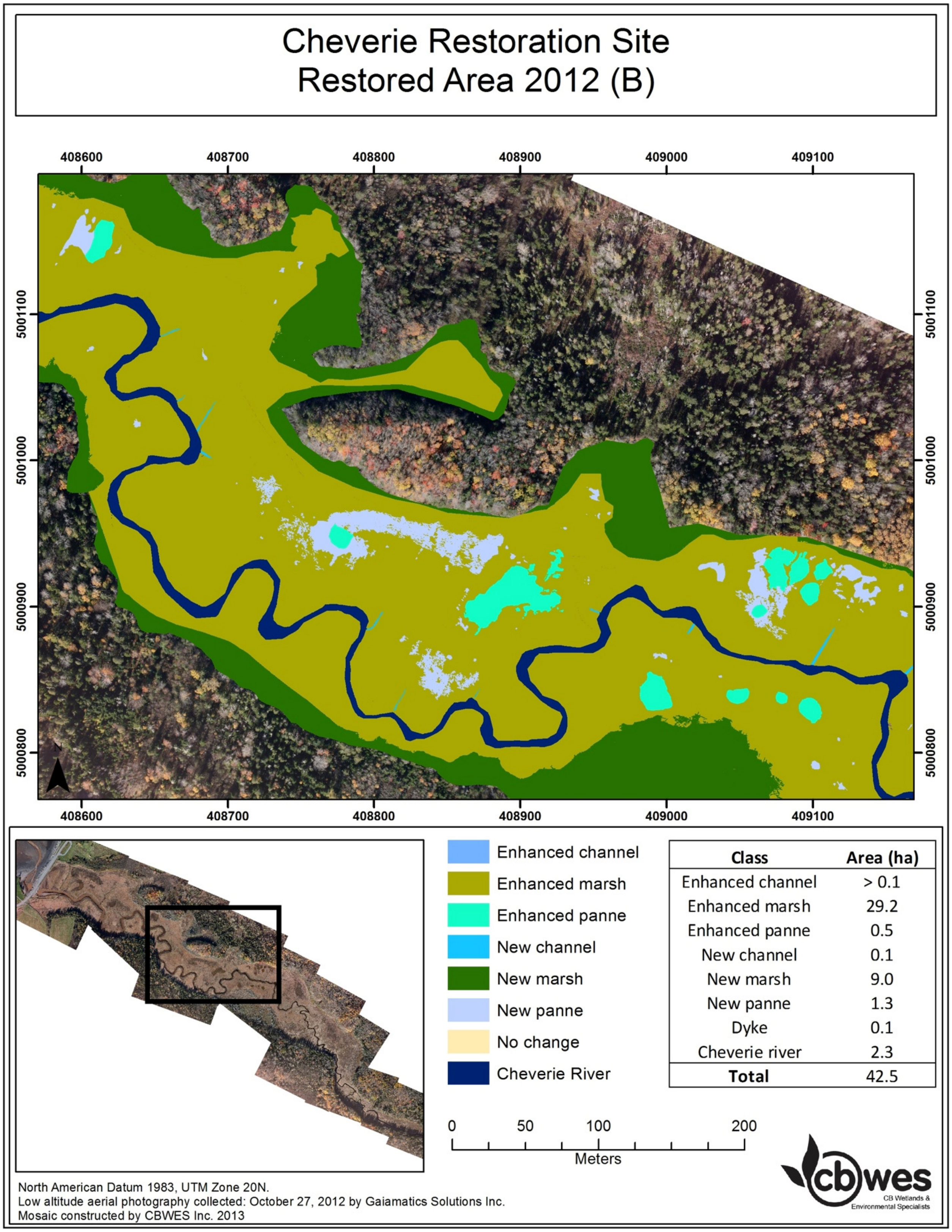
The results of the seven years of post-restoration monitoring indicate that the CHV system has responded in a positive and acceptable manner to the original intervention. Aside from the damage (erosion) sustained by the causeway on its seaward side, which is external to the restoration project, no unanticipated or undesirable conditions emerged during this period.

To illustrate the changes in wetland habitat conditions that occurred following the re-establishment of a more natural hydrological regime to CHV, the following series of maps (Figure 68 a - e) were created. The maps were created by comparing the 2002 provincial aerial photograph with the 2012 low-altitude aerial photographs and incorporating the 2012 vegetation survey. The wetland boundary was determined by visually interpreting the aerial photographs as well as the 2012 hydrological data (observed water levels). Based on the 2012 DEM, hydrology, and comparison of aerial photography, the estimated area of recovering tidal wetland at CHV was determined to be approximately 42.5 ha (Figure 68). By comparing aerial photographs, a series of habitat classifications were created within the 43 ha of total restored wetland habitat. Enhanced channel, enhanced marsh and enhanced panne reflect better defined boundaries for pre-existing classes. New channel, new marsh, and new panne classes were features that were present in the 2012 aerial photographs, but not in the pre-restoration image.

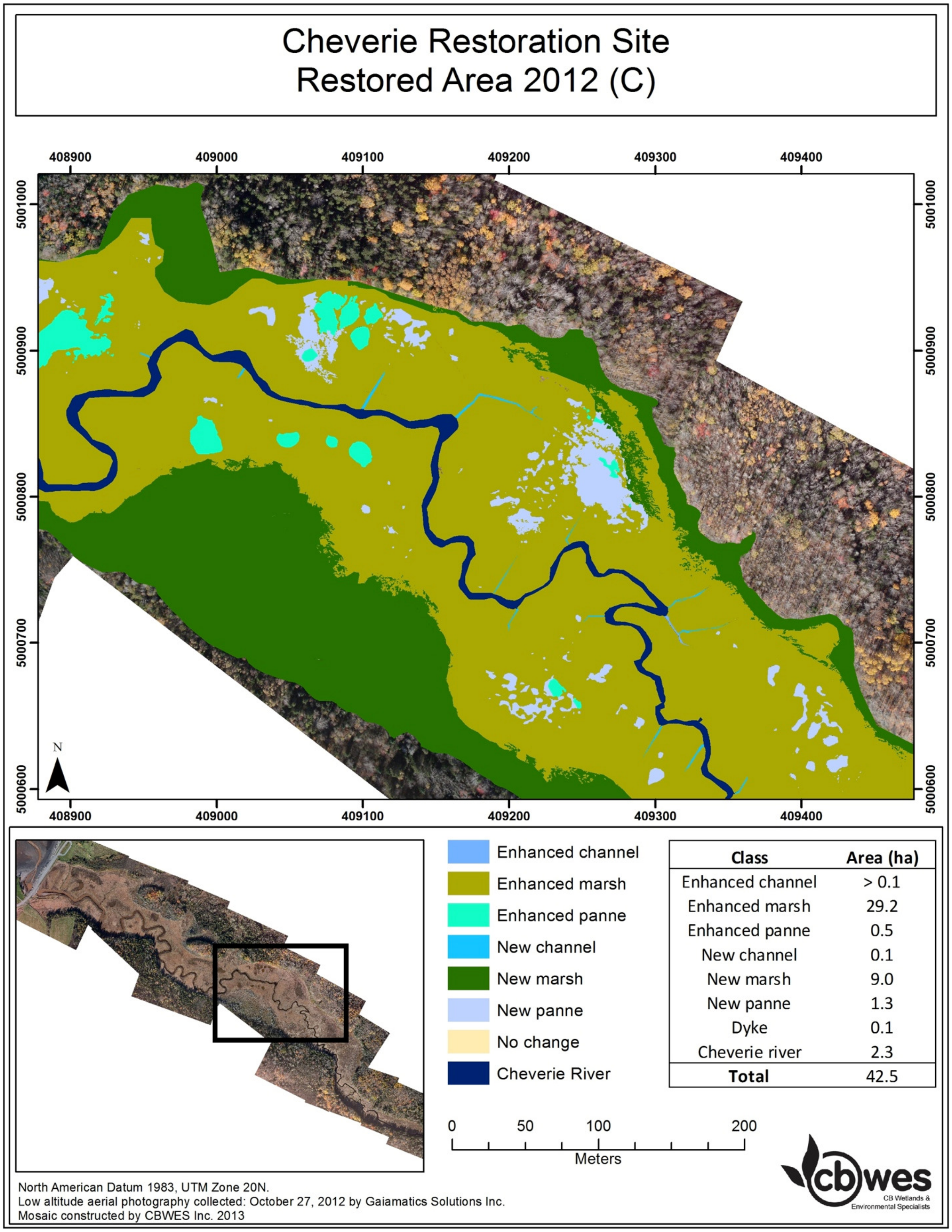
While it is difficult to predict how successful this restoration will be in the long term, it is clear that the major objectives (significantly reduce the tidal restriction caused by the Highway 215 crossing; re-establishment of a more natural hydrological regime to the site; improve fish passage; increase the extent, distribution and abundance of halophytic vegetation) were achieved. Despite the continued differences between habitat conditions observed at the restoration site compared to the reference, attributable in large part to the natural variability between sites, the restoration activities undertaken at CHV in 2005 have resulted in the restoration of a self-sustaining and resilient salt marsh and tidal wetland system.



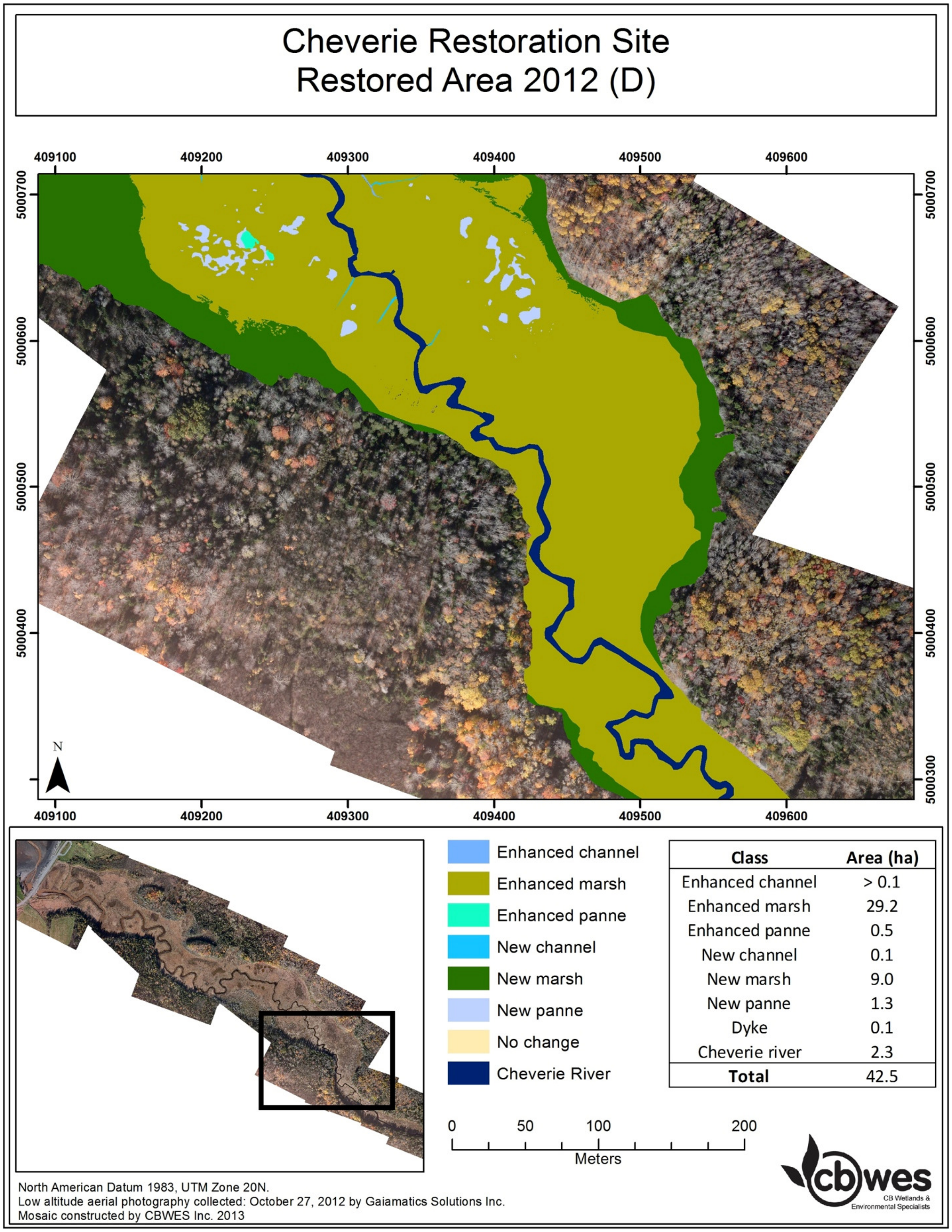
Class	Area (ha)
Enhanced channel	> 0.1
Enhanced marsh	29.2
Enhanced panne	0.5
New channel	0.1
New marsh	9.0
New panne	1.3
Dyke	0.1
Cheverie river	2.3
Total	42.5



Class	Area (ha)
Enhanced channel	> 0.1
Enhanced marsh	29.2
Enhanced panne	0.5
New channel	0.1
New marsh	9.0
New panne	1.3
Dyke	0.1
Cheverie river	2.3
Total	42.5



Class	Area (ha)
Enhanced channel	> 0.1
Enhanced marsh	29.2
Enhanced panne	0.5
New channel	0.1
New marsh	9.0
New panne	1.3
Dyke	0.1
Cheverie river	2.3
Total	42.5


Cheverie Restoration Site
Restored Area 2012 (D)
409100
409200
409300
409400
409500
409600
5000700
5000600
5000500
5000400
5000300
N
Enhanced channel
Enhanced marsh
Enhanced panne
New channel
New marsh
New panne
No change
Cheverie River
Class | Area (ha)
Enhanced channel | > 0.1
Enhanced marsh | 29.2
Enhanced panne | 0.5
New channel | 0.1
New marsh | 9.0
New panne | 1.3
Dyke | 0.1
Cheverie river | 2.3
Total | 42.5
0
50
100
200
Meters
cbwes
CB Wetlands & Environmental Specialists
North American Datum 1983, UTM Zone 20N.
Low altitude aerial photography collected: October 27, 2012 by Gaiamatics Solutions Inc.
Mosaic constructed by CBWES Inc. 2013

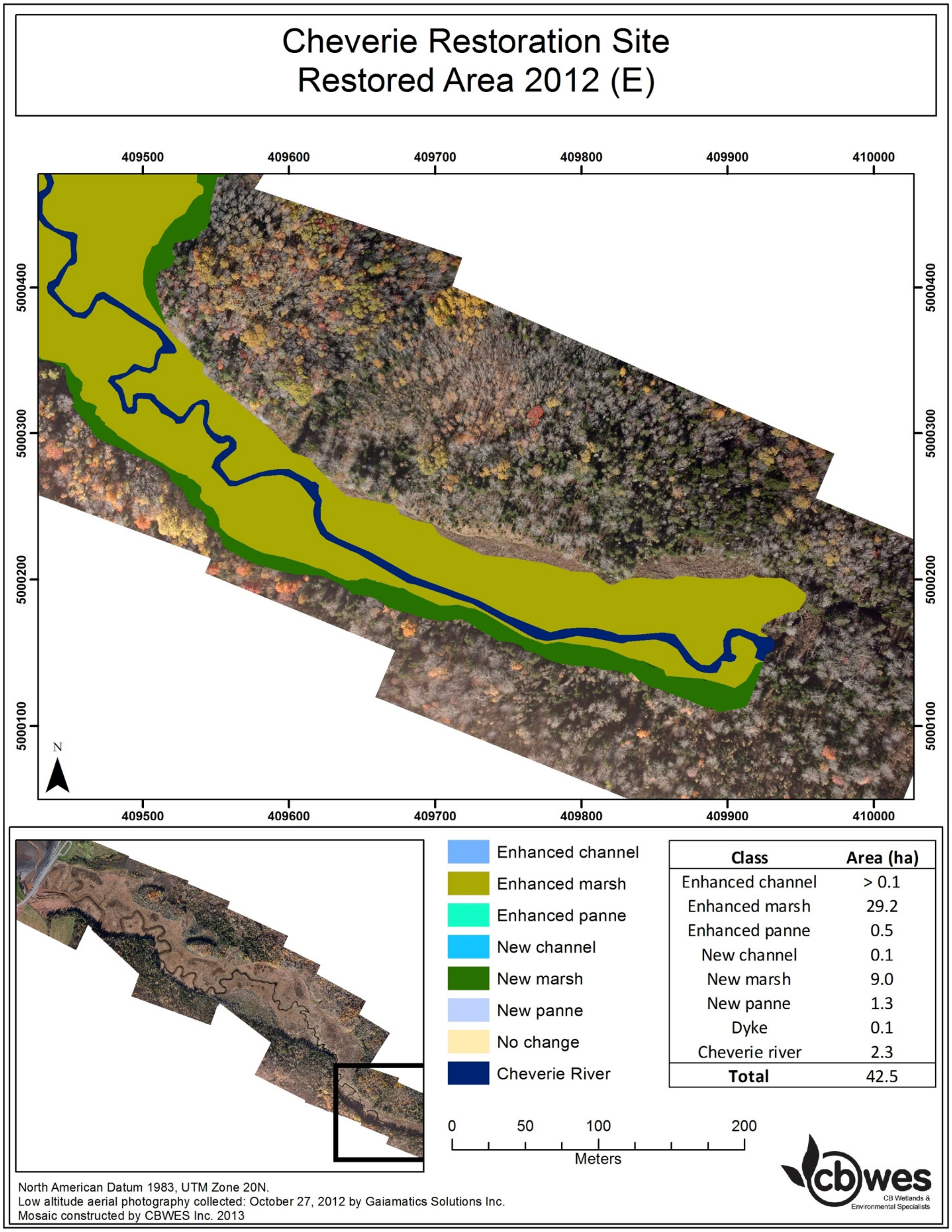


Figure 68 (a – e) Estimated area of recovering tidal wetland habitat at CHV based on seven years of hydrology, elevation and vegetation data.

6.0 Recommendations for Future Post-Restoration Monitoring Activities

The monitoring program developed for the Cheverie Creek 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 program was modified following the third year of post-restoration monitoring from a consecutive five year post program to a seven year program. This was accomplished by greatly reducing the monitoring activities conducted during the fourth year post-restoration (2009) in favour of the addition of a seventh year (2012).

Annual monitoring during the first three years following restoration is critical because it is during these initial years that the greatest and most rapid change are likely to occur. Monitoring beyond the first three years following restoration allow a greater period of time for change to occur and for the documentation of these longer term, often more gradual, changes in response to restoration. For most restoration projects, it is important that monitoring activities, like those looked at for this project, be conducted over at least the first five years following restoration. Depending on the scale and type of the individual restoration project, it may be necessary to conduct monitoring beyond the post five year point, as it has been shown that wetland habitats often need longer periods of time to mature (Able et al. 2008; Burden et al. 2013; Garbutt and Wolters 2008; Mitsch et al. 2012; Neatt et al. 2013).

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 damage (erosion) sustained by the causeway along its seaward side and around the culvert, no new problems have emerged within this period. That the objectives for the project have been met and that the CHV site has been returned to a self-sustaining and resilient salt marsh and tidal river system.

Additionally:

- The long term monitoring program associated with the CHV restoration project represents one of the longest and most comprehensive salt marsh restoration monitoring programs in the region. The resulting data set has, and continues to, provide new insights into the form and function of tidal wetland systems in NS and their response to restoration efforts. One of the important lessons learned from 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; and replacement of non-halophytic vegetation by halophytes) were only evident in the data at and beyond the five-year post-restoration point in the monitoring program. When the experiences with this restoration site are combined with those of other sites in NS (Walton, Cogmagun, St. Croix), it is confirmed that monitoring as part of any restoration project is crucial; that documentation of baseline habitat conditions must be conducted before restoration activities are undertaken; and that monitoring changes in habitat conditions post-restoration requires a period of at least five years.

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

- It is highly recommended that the damage to the causeway be repaired and that complimentary and/or alternative shoreline protection options be explored beyond replacing the materials that were lost.

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

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Appendix A – Summary of CBWES Supported Student Research

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

Current Projects:

Peer-review Publication

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

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

Vegetation in tidal marshes of eastern North America shows conspicuous zonation attributable to biotic interactions between plant species and differential tolerance of salinity and flooding. Tidal marshes are a conspicuous feature of the coastline in Nova Scotia, and previous descriptions suggest that many of the plant communities are similar to those found in New England, which have been extensively studied. The goal of this study was to perform a numerical classification of tidal marsh vegetation in Nova Scotia, and to determine the relationships between variation in plant species composition and environmental factors. We sampled tidal marsh vegetation in six sites designated as reference (intact) sites for salt marsh restoration projects. Cluster analysis revealed seven distinct plant communities related to gradients of inundation duration and salinity. Plant community types were usually dominated by a single graminoid species. Communities detected are similar to those found farther south in Maine and New England, but we also describe three brackish communities of which the *Juncus balticus/Festuca rub*ra and *Spartina pectinata* communities have not been previously described. Redundancy analysis shows continuous variation among these community types and highlights key environmental variables related to plant community patterns. These analyses provide a baseline for further restoration work and identify environmental correlates of plant communities, allowing for better predictions of ecological restoration trajectories in tidal marshes.

Undergraduate Honours

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

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

Completed Projects:

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

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

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

Masters of Applied Science

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

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

CBWES Inc. has been engaged in tidal wetland restoration and monitoring projects in Nova Scotia since 2005. In 2009, CBWES Inc. developed the project design and undertook restoration at two former tidal wetland systems in the Bay of Fundy; a 8 ha site on the Cogmagun River (COG) and a 19 ha site on the St. Croix River (SC). Both projects involved the breaching of an existing dyke in one or more locations and the excavation and recreation of historical tidal channel networks. The restoration designs put forward the problem of identifying appropriate locations for dyke breaches and excavated tidal channels in order to restore a more natural hydrological regime to the systems including the re-activation of relict creek systems while avoiding excessive erosion. During the restoration design phase of the SC project (Graham et al. 2008) a set of preliminary hydraulic equations were established for the Bay of Fundy region using the methods laid out by Williams et al. (2002). These equations were used to determine width and depth of excavated creeks and were further tested and refined through observations and application to a previously restored salt marsh (Walton River; van Proosdij et al. 2010).
The results of this preliminary work brought up several questions which would be addressed in this research project by:

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

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

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

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

Phragmites australis at Cogmagun Restoration Site

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

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

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

Undergraduate Honours

Department of Environmental Science
Dalhousie University
Rachel Deloughery
2010

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

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

Undergraduate Honours

Department of Biology
Saint Mary's University
Ben Lemieux
NSERC Industrial Undergraduate Student Research Awards
2009

The influence of soil seed bank on the colonization and restoration of a macro-tidal marsh

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

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

Undergraduate Honours

Department of Biology
Saint Mary's University
Emile Colpron
2008

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

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

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

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

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Appendix B – Comparison of the original and revised sampling station labeling system for Cheverie Creek

Veg = vegetation; Sed = Sediment Sample; SP = Sediment plate

New Label	Old Label	Dist (m) from FS	Transect	Easting	Northing	Elevation	Station Type*
CHV L1S0_BS		Back Stake	1				Sed
CHV L1S1_5.7m	CHV L1S8	5.7	1	408166.85	5001397.74	5.05	Veg/SP
CHV L1S2_25.7m	CHV L1S7	25.7	1	408156.39	5001380.99	4.36	Veg
CHV L1S3_45.7m	CHV L1S6	45.7	1	408145.88	5001364.16	4.77	Veg/SP
CHV L1S4_65.7m	CHV L1S5	65.7	1	408136.05	5001344.07	6.71	Veg/Sed
CHV L1S5_85.7m	CHV L1S4	85.7	1	408125.14	5001330.19	5.47	Veg/SP
CHV L1S6_105.7m	CHV L1S3	105.7	1	408114.91	5001312.89	5	Veg/Sed
CHV L1S7_125.7m	CHV L1S2	125.7	1	408105.35	5001295.02	4.35	Veg/SP
CHV L1S8_C.5m	CHV L1S1	0.5	1	408095.38	5001277.61	3.02	Veg/Sed
CHV L1S1s_C.5m	CHV L1S1(s)	0.5	1	408133.13	5001277.85	2.36	Veg
CHV L2S1_-7.5m	CHV L2S8	-7.5	2	408200.93	5001395.59	6.14	Veg
CHV L2S2_12.5m	CHV L2S7	12.5	2	408192.08	5001378.98	5.4	Veg
CHV L2S3_32.5m	CHV L2S6	32.5	2	408181.95	5001360.86	6.19	Veg/Sed/SP
CHV L2S4_52.5m	CHV L2S5	52.5	2	408171.8	5001344.16	5.31	Veg
CHV L2S5_72.5m	CHV L2S4	72.5	2	408162	5001326.3	5.9	Veg
CHV L2S6_92.5m	CHV L2S3	92.5	2	408151.89	5001309.23	5.04	Veg/SP
CHV L2S7_112.5m	CHV L2S2	112.5	2	408142.31	5001291.96	3.97	Veg/Sed
CHV L2S8_C.5m	CHV L2S1	0.5	2	408133.13	5001277.85	2.36	Veg
CHV L2S1s_C.5m	CHV L2S1(s)	0.5	2	408128.06	5001269.18	2.69	Veg
CHV L2S2s_20m	CHV L2S2(s)	20	2	408117.82	5001250.65	4.38	Veg
CHV L3S1_-3.8m	CHV L3S7	-3.8	3	408228.49	5001371.76	5.58	Veg/Sed
CHV L3S2_16.2m	CHV L3S6	16.2	3	408225.4	5001356.13	5.53	Veg
CHV L3S3_36.2m	CHV L3S5	36.2	3	408221.55	5001336.24	5.38	Veg/Sed
CHV L3S4_56.2m	CHV L3S4	56.2	3	408217.78	5001316.66	5.19	Veg/SP
CHV L3S5_76.2m	CHV L3S3	76.2	3	408214.25	5001296.97	4.57	Veg
CHV L3S6_96.2m	CHV L3S2	96.2	3	408210.53	5001277.15	4.21	Veg/SP
CHV L3S7_C.5m	CHV L3S1	0.5	3	408206.76	5001257.25	3.75	Veg/Sed
CHV L3S1s_C.5m	CHV L3S1(s)	0.5	3	408206.37	5001247.74	4.17	Veg
CHV L3S2s_20m	CHV L3S2(s)	20	3	408202.37	5001228.89	6.28	Veg/SP
CHV L3S3s_40m	CHV L3S3(s)	40	3	408198.89	5001209.63	6.25	Veg
CHV L3S4s_60m	CHV L3S4(s)	60	3	408195.28	5001189.97	6.68	Veg
CHV L4S1_-9.7m	CHV L4S8	-9.7	4	408279.59	5001370.96	5.77	Veg
CHV L4S2_10.3m	CHV L4S7	10.3	4	408275.77	5001351.76	5.7	Veg
CHV L4S3_30.3m	CHV L4S6	30.3	4	408272.17	5001331.96	5.06	Veg/Sed
CHV L4S4_50.3m	CHV L4S5	50.3	4	408268.27	5001312.45	4.65	Veg
CHV L4S5_70.3m	CHV L4S4	70.3	4	408264.5	5001292.29	4.51	Veg
CHV L4S6_90.3m	CHV L4S3	90.3	4	408260.67	5001272.08	4.4	Veg
CHV L4S7_110.3m	CHV L4S2	110.3	4	408256.97	5001252.68	4.05	Veg/Sed
CHV L4S8_C.5m	CHV L4S1	0.5	4	408256.53	5001233.66	2.79	Veg
CHV L4S1s_C.5m	CHV L4S1(s)	0.5	4	408250.63	5001221.59	4.1	Veg
CHV L4S2s_20m	CHV L4S2(s)	20	4	408246.43	5001202.32	6.22	Veg
CHV L5S1_2.7m	CHV L5S6	2.7	5	408325.82	5001350.71	6.02	Veg/SP

New Label	Old Label	Dist (m) from FS	Transect	Easting	Northing	Elevation	Station Type*
CHV L5S2_22.7m	CHV L5S5	22.7	5	408322.08	5001331.08	5.92	Veg
CHV L5S3_42.7m	CHV L5S4	42.7	5	408317.92	5001311.54	5.64	Veg/SP
CHV L5S4_62.7m	CHV L5S3	62.7	5	408313.93	5001291.67	5.22	Veg/Sed
CHV L5S5_82.7m	CHV L5S2	82.7	5	408309.86	5001272.05	4.62	Veg/SP
CHV L5S6_C.5m	CHV L5S1	0.5	5	408305.43	5001252.58	3.8	Veg/Sed
CHV L5S1s_C.5m	CHV L5S1(S)	0.5	5	408304.04	5001243.77	4.21	Veg
CHV L5S2s_20m	CHV L5S2(S)	20	5	408300.32	5001224.58	6.09	Veg/SP
CHV L5S3s_40m	CHV L5S3(S)	40	5	408295.69	5001206.08	5.58	Veg
CHV L5S4s_60m	CHV L5S4(S)	60	5	408291.49	5001186.46	5.8	Veg
CHV L6S1_-19.5m	CHV L6S9	-19.5	6	408377.19	5001363.47	7.36	Veg
CHV L6S2_0.5m	CHV L6S8	0.5	6	408374.23	5001344.12	6.4	Veg/Sed
CHV L6S3_20.5m	CHV L6S7	20.5	6	408371.94	5001323.75	6.52	Veg
CHV L6S4_40.5m	CHV L6S6	40.5	6	408368.98	5001304.29	6.27	Veg/Sed
CHV L6S5_60.5m	CHV L6S5	60.5	6	408365.64	5001284.96	6.2	Veg
CHV L6S6_80.5m	CHV L6S4	80.5	6	408362.28	5001264.66	5.69	Veg/Sed
CHV L6S7_100.5m	CHV L6S3	100.5	6	408358.84	5001245.94	6.32	Veg
CHV L6S8_120.5m	CHV L6S2	120.5	6	408355.86	5001225.99	5.24	Veg/Sed
CHV L6S9_C.5m	CHV L6S1	0.5	6	408352.41	5001206.93	3.91	Veg
CHV L6S1s_C.5m	CHV L6S1(S)	0.5	6	408350.93	5001194.61	3.94	Veg
CHV L6S2s_20m	CHV L6S2(S)	20	6	408347.63	5001175.53	5.5	Veg
CHV L6S3s_40m	CHV L6S3(S)	40	6	408344.35	5001155.29	5.8	Veg
CHV L6S4s_60m	CHV L6S4(S)	60	6	408340.89	5001135.85	5.61	Veg
CHV L7S0_-22.35m	CHV L7S15	-22.35	7				Veg
CHV L7S1_-2.35m	CHV L7S14	-2.35	7	408424.52	5001338.33	7.12	Veg/SP
CHV L7S2_17.65m	CHV L7S13	17.65	7	408421.46	5001318.66	6.67	Veg
CHV L7S3_37.65m	CHV L7S12	37.65	7	408418.44	5001299.08	6.78	Veg
CHV L7S4_57.65m	CHV L7S11	57.65	7	408415.67	5001279.51	6.48	Veg/SP
CHV L7S5_77.65m	CHV L7S10	77.65	7	408412.17	5001259.06	7.23	Veg
CHV L7S6_97.65m	CHV L7S9	97.65	7	408408.98	5001239.81	6.45	Veg
CHV L7S7_117.65m	CHV L7S8	117.65	7	408406.2	5001219.96	6.18	Veg/SP
CHV L7S8_137.65m	CHV L7S7	137.65	7	408403.04	5001200.06	6.32	Veg
CHV L7S9_C.5m	CHV L7S6	157.65	7	408399.86	5001180.28	6.84	Veg
CHV L7S10_177.65m	CHV L7S5	177.65	7	408396.84	5001160.52	6.39	Veg/Sed/SP
CHV L7S11_197.65m	CHV L7S4	197.65	7	408393.81	5001141	6.5	Veg
CHV L7S12_217.65m	CHV L7S3	217.65	7	408390.66	5001121.51	6.52	Veg/Sed
CHV L7S13_237.65m	CHV L7S2	237.65	7	408387.37	5001101.43	5.63	Veg/SP
CHV L7S14_C.5m	CHV L7S1	0.5	7	408384.5	5001082.3	4.13	Veg/Sed
CHV L7S1s_C.5m	CHV L7S1(S)	0.5	7				Veg
CHV L8S1_-7.1m	CHV L8S14	-7.1	8	408474.43	5001335.5	6.7	Veg
CHV L8S2_12.9m	CHV L8S13	12.9	8	408471.71	5001315.5	6.23	Veg
CHV L8S3_32.9m	CHV L8S12	32.9	8	408468.93	5001295.44	6.46	Veg
CHV L8S4_52.9m	CHV L8S11	52.9	8	408466.12	5001275.68	6.56	Veg
CHV L8S5_72.9m	CHV L8S10	72.9	8	408463.33	5001255.93	6.75	Veg
CHV L8S6_92.9m	CHV L8S9	92.9	8	408460.86	5001236.3	6.91	Veg
CHV L8S7_112.9m	CHV L8S8	112.9	8	408457.5	5001215.77	5.05	Veg/Sed
CHV L8S8_132.9m	CHV L8S7	132.9	8	408454.75	5001196.08	4.81	Veg/SP
CHV L8S9_152.9m	CHV L8S6	152.9	8	408451.94	5001176.04	4.56	Veg
CHV L8S10_172.9m	CHV L8S5	172.9	8	408446.15	5001136.71	5.11	Veg/Sed/SP

New Label	Old Label	Dist (m) from FS	Transect	Easting	Northing	Elevation	Station Type*
CHV L8S11_192.9m	CHV L8S4	192.9	8	408449.24	5001156.04	4.7	Veg
CHV L8S12_232.9m	CHV L8S3	232.9	8	408443.94	5001116.14	4.81	Veg/SP
CHV L8S13_252.9m	CHV L8S2	252.9	8	408441.27	5001096.72	5.3	Veg/Sed
CHV L8S14_272.9m	CHV L8S1	0.5	8	408438.51	5001077.22	4.63	Veg
CHV L8S1s_C.5m	CHV L8S1(S)	0.5	8				Veg
CHV L10S1_FS	CHV L10S3	0	10	408553.013	5001181.664	6.282	Veg
CHV L10S2_20m	CHV L10S2	20	10	408548.778	5001172.139	5.866	Veg
CHV L10S3_C.5m	CHV L10S1	0.5	10	408548.686	5001162.194	4.748	Veg
CHV L12S1_FS	CHV L12S4	0	12	408650.165	5001131.889	6.216	Veg
CHV L12S2_20m	CHV L12S3	20	12	408648.6	5001111.881	6.077	Veg
CHV L12S3_60m	CHV L12S2	0.5	12	408645.6	5001071.39		Veg
CHV L12S4_C.5m	CHV L12S1	0.5	12	408643.41	5001051.94		Veg
CHV L14S1_FS	CHV L14S4	0	14	408739.362	5001001.622	6.165	Veg
CHV L14S2_20m	CHV L14S3	20	14	408736.329	5000981.819	6.12	Veg
CHV L14S3_60m	CHV L14S2	60	14	408730.034	5000942.417	6.089	Veg
CHV L14S4_C.5m	CHV L14S1	0.5	14	408728.478	5000932.528	5.546	Veg
CHV L16S1_FS	CHV L16S5	0	16	408835.238	5000959.755	6.07	Veg
CHV L16S2_20m	CHV L16S4	20	16	408830.392	5000940.555	6.067	Veg
CHV L16S3_60m	CHV L16S3	60	16	408820.61	5000901.9	6.039	Veg
CHV L16S4_100m	CHV L16S2	100	16	408810.676	5000863.203	6.01	Veg
CHV L16S5_C.5m	CHV L16S1	0.5	16	408804.24	5000836.72		Veg
CHV L18S1_FS	CHV L18S4	0	18	408934.778	5000941.79	6.105	Veg
CHV L18S2_20m	CHV L18S3	20	18	408930.963	5000922.227	6.1	Veg
CHV L18S3_60m	CHV L18S2	0.5	18	408922.903	5000883.215	6.066	Veg
CHV L18S4_C.5m	CHV L18S1	0.5	18	408921.039	5000873.629	5.1	Veg
CHV L20S1_FS	CHV L20S3	0	20	409034.19	5000929.2	5.886	Veg
CHV L20S2_20m	CHV L20S2	20	20	409032.025	5000909.316	6.098	Veg
CHV L20S3_C.5m	CHV L20S1	0.5	20	409029.442	5000885.603	5.386	Veg
CHV L22S1_FS	CHV L22S3	0	22	409131.282	5000912.356	5.786	Veg
CHV L22S2_20m	CHV L22S2	20	22	409126.87	5000892.889	5.873	Veg
CHV L22S3_C.5m	CHV L22S1	0.5	22	409119.573	5000860.118	5.289	Veg
CHV L24S1_FS	CHV L24S6	0	24	409230.129	5000885.014	6.022	Veg
CHV L24S2_20m	CHV L24S5	20	24	409225.354	5000865.728	5.878	Veg
CHV L24S3_60m	CHV L24S4	0.5	24	409215.962	5000826.873	5.793	Veg
CHV L24S4_100m	CHV L24S3	0	24	409206.696	5000787.964	5.897	Veg
CHV L24S5_140m	CHV L24S2	20	24	409197.504	5000749.081	5.725	Veg
CHV L24S6_C.5m	CHV L24S1	0.5	24	409193.839	5000733.531	5.405	Veg
CHV L26S1_FS	CHV L26S3	0	26	409314.126	5000756.512	6.002	Veg
CHV L26S2_20m	CHV L26S2	20	26	409311.989	5000736.827	5.917	Veg
CHV L26S3_C.5m	CHV L26S1	0.5	26	409310.529	5000725.43	5.466	Veg

Appendix C – Winter Conditions: Cheverie Creek and Bass Creek

Select images from the vegetation survey (August 2012) and structure winter walk conducted at CHV & CHV-R on 6 March 2013.

STRUCTURED WALK PHOTOGRAPHS CHV (left – summer 2012; right – winter 2013):

Figure 1 Transect one.

Figure 2 Transect three.

Figure 3 Transect five.

Figure 4 Transect seven.

Figure 5 Transect eight.

Figure 6 View upstream from transect nine.

Figure 7 Cheverie Creek culvert, upstream end, as viewed from the dyke.

Figure 8 Downstream end of culvert, coastal berm and channel.

STRUCTURED WALK PHOTOGRAPHS CHV-R (left – summer 2012; right – winter 2012):

Figure 1 Transect one.

Figure 2 Transect three.

Figure 3 Transect five, high marsh.

Figure 4 Transect seven.


Figure 5 Bass Creek landscape upstream of transect eight (back of marsh).


Figure 6 Mouth of the Bass Creek system (downstream of transect one).

Appendix D – Waterfowl Monitoring Report by Ducks Unlimited Canada

Ducks Unlimited Canada
Conserving Canada's Wetlands

2005 - 2010 Post Construction Monitoring of Waterfowl at the Cheverie Creek Salt Marsh

Introduction

Cheverie Creek was a small, tidally-restricted watercourse located in the community of Cheverie, Hants County, along the southern shore of the Minas Basin in the upper Bay of Fundy. In 2005, TPW designed a salt marsh restoration project to restore a more natural tidal regime that would flood approximately 30 ha of upstream marsh, the original, pre-development size of the salt marsh. As part of the long-term monitoring program for the Cheverie Creek Salt Marsh Restoration Project, the Nova Scotia Department of Transportation and Public Works (TPW) commissioned Ducks Unlimited Canada (DUC) to carry out waterfowl surveys before and for 5 years after the installation of a new culvert in Route 215 (November-December 2005). An experienced birder carried out surveys at dawn and dusk from the old agricultural dyke (parallel to the road, running east to west) looking out over the marsh. The surveyor walked the length of the dyke and reported any waterfowl observed. This survey methodology is based on protocols developed for the Musquash Estuary Marine Protected Area and other DUC wetlands in Atlantic Canada. These surveys were conducted 3 times annually during key waterfowl life stages: 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. This past field season (2010) was the final year of monitoring; this report presents waterfowl survey data collected over the last 6 years and highlights trends observed over this period.

Results

Since 2005 there have been 7 species of water birds, including 4 species of waterfowl, observed at Cheverie Creek during seasonal monitoring (Table 1). Of these the most prevalent is the American black duck, both pre and post restoration. Since the restoration there have been 8 waterfowl broods observed (5 ABDU and 3 AGWT). No waterfowl broods were observed in 2005, prior to the salt marsh restoration. Additionally, 2 shorebird species, semi-palmated sandpiper and greater yellowlegs, were observed regularly.

Table 1 – Total birds counted during seasonal monitoring at Cheverie Creek Salt Marsh

Year	*Date*	*ABDU*	*GBHE*	*GRYE*	*SESA*	*AGWT*	*MALL*	*AMWI*
2005	July	1	0	0	0	0	0	0
	August	0	0	0	0	0	0	0

Year	*Date*	*ABDU*	*GBHE*	*GRYE*	*SESA*	*AGWT*	*MALL*	*AMWI*
	Sept	0	0	0	0	0	0	0
	Oct	6	0	0	0	0	0	0
2006	May	18	0	0	0	0	0	0
	Aug	12	0	3	4	5	0	0
	Oct	10	0	0	0	0	2	0
2007	May	20	0	0	0	1	3	0
	July	28	0	2	2	0	0	0
	Oct	0	0	0	0	0	0	0
	Nov**	5	0	2	0	0	0	0
2008	May	21	5	9	0	0	0	0
	June	23	0	3	0	8	0	0
	Oct	24	0	0	0	12	0	0
2009	May	3	1	0	0	0	0	2
	July	9	0	0	0	9	0	0
	Oct	12	1	0	0	1	0	0
2010	April*	3	0	0	0	0	0	0
	Aug*	0	1	1	18	0	0	0
	Totals	195	8	20	24	36	5	2

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.
**Dawn survey only.

Table 2 - 4-letter codes for bird species

ABDU – American black duck
GBHE – great blue heron
GRYE – greater yellowlegs
AGWT – American green-winged teal
MALL – mallard
AMWI – American wigeon
SESA – Semi-palmated sandpiper

Discussion

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

Direct observations (Figure 1) suggest that Cheverie was successfully reverted back to its historical salt marsh state. This is most evident by the re-establishment of salt marsh vegetation (*Spartina sp.*) and the creation of salt pannes. The monitoring results suggest that there has been an increase in waterfowl use both for breeding and staging habitat since the salt marsh restoration. This can likely be attributed to the increase in waterfowl habitat through the increased availability of salt marsh and open water. Observation of semipalmated sandpipers, in August, suggests that this salt marsh may also play an important role as fielding/staging habitat during their migration through the Upper Bay of Fundy.

Figure 1 **–** Cheverie Creek salt marsh August, 2010.