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

By
Christa Skinner

A Thesis Submitted to
Saint Mary's University, Halifax, Nova Scotia
in Partial Fulfillment of the Requirements for
the Degree of Bachelor of Science (Honours) in Environmental Science

April, 2013, Halifax, Nova Scotia

Approved: Dr. Danika van Proosdij, Supervisor
Department of Geography
Saint Mary's University

Approved: Dr. Jeremy Lundholm, Reader
Department of Biology and
Environmental Science
Saint Mary's University

Date: April 2013

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

By: Christa Skinner

Abstract

Monitoring 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 compensation projects. Dominant vegetation and geodetic elevation were 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 included *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 length of time since beginning of restoration.

April, 2013

ACKNOWLEDGEMENTS

In completing this research project, I have realized that it would not have been possible without the support, encouragement, patience and knowledge of Dr. Danika van Proosdij. Her support and understanding has enabled me to grow as a person not only in my academic life but also given me the confidence to complete this work. Thank you to Dr. Jeremy Lundholm for his statistics expertise as well as taking the time to read through and critique my thesis. This project would not have been able to be completed without the data being compiled by the CBWES crew, Tony Bowron, Nancy Neatt, Ben Lemieux and Jennie Graham. Would also like to thank Casey O'Laughlin, Emma Poirier and Carly Wrathall of the InCoaST crew for giving me the support I needed to follow through with this project. Thank you to Greg Baker for his GIS expertise. A big thank you to all of those who have been there to support me and encourage me to keep going, Sam, Niccole, Liz, Ellen, Michelle, and all others. Without the support of my partner, Steph, and my family, mom, dad, Matt and Sarah, I would have been unable to follow this project through to the end. Thank you to my fellow ENVS 4599 classmates, Alisha, Brenden and Liam. We've done it!

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Salt marshes are found at the interface between the land and ocean which creates unique habitats for a variety of species and provides numerous free benefits. These free benefits include providing protection from storm surges, filtering out wastes from water, and providing habitat for fish, wildlife and plants. Salt marshes have been altered since the 1700s onward leading to the loss of an estimated 85% of salt marshes in the Bay of Fundy (Byers and Chmura, 2007; Ganong 1903) and 50% of salt marshes province wide (Nova Scotia Government, 2011). The damage caused by human activities has left few surviving marshes to ensure protection from coastal flooding and storms which has led to an increased need to restore these valuable ecosystems (Fagherazzi et al., 2004). Salt marsh restoration activities require extensive monitoring pre and post-restoration to ensure activities undertaken were appropriate for the success of the project which will assist in the development of future projects. One of the indicators used in monitoring salt marsh restoration activities is assessing the dominant vegetation. Re-colonization of the marsh surface by vegetation occurs after hydrology has been restored (Sullivan, 2001). Comparing the vegetation found within the restoration site and a paired reference site will determine if the restoration site is tending towards conditions experienced at the reference site. This research examines the relationship between geodetic elevation and vegetative community structure at three restoration projects in Bay of Fundy, Nova Scotia, Canada. The research will add to the growing knowledge of vegetation community structure within macrotidal salt marshes. This chapter examines salt marsh biogeography, formation of salt marshes and the processes which occur to shape them. The physiology of plants and the structure of plant communities will be investigated. Lastly, this paper will examine salt marsh restoration within the Bay of Fundy and the restoration and monitoring activities being used today.

1.2 Salt Marsh Biogeography

Salt marshes are found around the world in low lying areas that are in proper position with the current sea level to allow sea water to enter and inundate the marsh (Blum and Christian, 2004). Salt marshes develop within the intertidal zone with an increase in sediment deposition rates which in turn causes an increase in topographic elevation, which leads to less frequent flooding enabling the marsh surface to be colonized by pioneer vascular plants (Silvestri and Marani, 2004). These environments depend on a delicate balance between erosional and depositional processes within the marsh system in order to remain alive (Aspden et al. 2004, Fagherazzi et al. 2004, and Silvestri and Marani, 2004). The marsh is influenced by topography, tide, salinity and biology which in turn influences the way in which vegetation grows on the marsh. By understanding the geomorphological processes and ecosystem structure of an area, also known as ecogeomorphology, one is able to understand the interactions and processes occurring within the marsh system (Fagherazzi, et al., 2004).

1.2.1 Salt Marsh Morphology

Salt marshes, from a geomorphological point of view, are comprised of a gently sloping vegetated platform which is divided by networks of channels which increase in width and depth towards the sea (Allen, 2000; Davidson-Arnott et al., 2002; Lawrence et al., 2004; Pethick, 1992). The platform lies at the highest point in the tidal frame in which only a portion of the tides are high enough to over-top. The channels act as passageways for the tidal water to enter and exit into the marsh system allowing sediment to be deposited (Allen, 2000; Davidson-Arnott et al., 2002). The tidal network is stable after initial development and is further stabilized by vegetation. Tidal marshes are stabilized by the marsh morphology and hydrodynamics in which the morphology consists of the vegetative growth and sedimentary features (Leonard and Reed, 2002; Freidrichs and Perry 2001). The morphology of salt marshes is determined by climate, shoreline configuration, wave climate, tidal range, sediment sources, volume of sediment input, depositional processes, sea level history and vegetation characteristics (Mudd et al., 2004; Davidson-Arnott et al., 2002; Jacobson and Jacobson, 1987; Allen and Pye, 1992; Chmura et al., 1997; Allen, 2000).

Salt marshes form within the upper intertidal zone in latitudes ranging from the Arctic to subtropics where the wave energy is sufficiently low to allow fine sediments to be deposited and for vegetation to establish (Davidson-Arnott et al., 2002; Freidrichs and Perry, 2001; Reed, 1990; Allen and Pye, 1992; Broome et al., 1988). The areas in which salt marshes develop include river mouths, estuaries and deltas, natural embayments, sheltered areas behind islands and reefs, back barrier lagoons and bays (Davidson-Arnott et al., 2002; Jacobson and Jacobson, 1987; Allen and Pye, 1992). Salt marshes occur in areas of net sediment accumulation which allows them to grow both vertically and horizontally. The marshes which accrete organic matter develop a flat platform due to below ground production that allows for steady deposition rate across the marsh surface whereas those who accrete through sediment trapping develop a platform that slopes away from the tidal creek due to decreased suspended sediment farther away from the creek (Mudd et al., 2004).

The first stage of salt marsh development is the colonization of intertidal sands and mudflats by vascular plants which are able to survive in the water or are able to tolerate being submerged for periods of time (Davidson-Arnott et al., 2002). The establishment of plants encourages deposition of fine sediment and organic matter due to a decrease in the tidal flow by vegetation. This sediment deposited is further consolidated by the plant roots (Silvestri and Marani, 2004). In combination, these deposits add to the vertical growth of the marsh surface and the development of channel networks throughout the marsh system. Some sediment may be eroded from the channels which is deposited on the platform, channels or taken out to sea (Allen, 2000). Deeper channels are created within salt marshes by erosional forces aided by vegetation and cohesive fine sediments (Townend et al., 2011). Sometimes a barrier to the flow of open water, such as a spit or island, is needed to decrease the speed of the flow and allow sediment deposition and vegetation to colonize (Freidrichs and Perry, 2001).

1.2.2 Salt Marsh Plants and Physiology

Vegetation that is found within salt marshes must endure harsh conditions as well as competition from other plant species in order to survive. The lifecycle of plants consists of reproduction, germination and growth, all of which are important to the survival of the plant. These key elements depend upon a number of physiological needs that include energy input, vital resources and limitation of stressing factors brought on in a saline environment (Silvestri and Marani, 2004). Plants which are called halophytes have evolved to be able to live their whole lifecycle within saline environments but may not require saline environments to survive (Fagherazzi et al., 2004; Silvestri and Marani, 2004). Those plants which fall into the obligate halophyte category require saline environments throughout their whole lifecycle to survive (Fagherazzi et al., 2004; Silvestri and Marani, 2004). Glycophytes are another plant group that may be found on the marsh, develop and germinate in non-saline environments enabling them to be better adapted to areas of low saline concentration (Silvestri and Marani, 2004). The competition between the halophytes and glycophytes limits the area in which the halophytes are able to colonize. The colonization of salt marshes by vegetation is important for the stabilization and growth of salt marshes. Pioneer species require a flat shoreline which is sheltered from waves to ensure seeds are able to germinate (Freidrichs and Perry, 2001). The frequency and duration of inundation will influence whether or not the seeds will be able to germinate and establish.

The distribution of plants across the marsh is organized into zones of similar species which is influenced by environmental stress. Several studies have been conducted which look at the processes that influence vegetative zonation on the marsh (e.g. Crain et al., 2004; Bertness, 1992; Bertness, 1987; Bertness, 1991). The results of the studies point to an interconnected relationship between abiotic conditions and biotic competition. It has been found that in New England salt marshes, plants are zoned in areas correlating to the degree of tidal flooding (Bertness, 1991; Nixon 1982). The abiotic condition identified which had the highest influence on zonation was the salinity gradient from highest concentration closest to the source of the tidal water and lowest by the upland which sees infrequent tidal waters. The differences in geodetic elevation, distance to creek, and frequency and duration of inundation vary from creek banks to the upper limit of tidal inundation which influences soil salinity across the marsh (Blum and Christian, 2004). Geodetic elevation is the height of a point on land above geodetic datum which is the elevation at sea level (ESRI, 2010). In Canada, this is referenced to the Canadian Geodetic Vertical Datum of 1928 (CGVD 28). The use of geodetic elevation enables comparison between marsh systems. Bertness et al. (1992) identified that as salinity decreased, both species evenness and richness increased significantly. An important factor in the distribution of plants across the marsh is inundation frequency (Mudd et al., 2004). The plants within the low marsh are inundated by every tide whereas the plants within the high marsh on the platform are only inundated during the highest tides. The competition between plant species has shown that those species which are not able to compete with top competitors are displaced to lower elevations with harsher physical stress but are not found below mean high tide (Bertness et al., 1992; Freidrichs and Perry, 2001). Biotic competition is seen between halophytic species within the saline environment and between halophytes and glycophytes in less saline environments.

In order for plants to survive and flourish, it is necessary for them to uptake oxygen. Within tidal environments there are periods of time in which the marsh is under water which creates anerobic conditions. Anerobic conditions occur when oxygen is limited by water saturation and what oxygen remains is used up by bacteria to breakdown organic matter. Once the oxygen is depleted, the bacteria move onto different elements which cause a buildup of elements such as sulphur. Due to the decreased oxygen levels in the soil, plants had to develop a method of up taking oxygen from other sources. The way in which plants deal with the lack of oxygen due to the frequent inundation is the development of aerenchyma. The aerenchyma is a network of intercellular pore spaces which diffuse air into the root tissues from above ground sources (Silvestri and Marani, 2004; Aspden et al., 2004). The aeration of the soil is dependent upon the conductivity of the hydraulic network, topography of the marsh and position within the tidal frame. The aeration is also dependent upon the size of the particles and how tightly the particles are packed together. The *Spartina spp*. have developed an extensive network of aerenchyma which has enabled them to grow in these soils (Silvestri and Marani, 2004).

The marshes along the Eastern North American Coast are dominated by *Spartina spp*. as well as those found within the *Juncus* family (Weis and Butler, 2009). The vegetation found within the restoration and reference marshes with the upper Bay of Fundy are found with Table 1.1 and 1.2 respectively. The common salt marsh species found within the reference sites going from low marsh to high marsh are: *Spartina alterniflora*, *Carex paleacea*, *Distichlis spicata*, *Juncus gerardii*, and *Spartina patens*. Some of the salt marshes being studied have dominant brackish species, these are: *Juncus balticus* and *Spartina pectinata*.

Table 1.1 Species Found at Restoration Sites (Data provided by CBWES Inc. from vegetation surveys completed in 2010).

Location on Marsh	**Vegetation Species**
Low Marsh	*Spartina alterniflora*
High Marsh	*Carex paleacea*
	Agrostis stolonifera
	Juncus gerardii
	Spartina patens
Brackish	*Alopecurus geniculatus*
	Spartina pectinata
	Typha latifolia
	Alopecurus pratensis
	Scirpus atrovirens
	Scirpus cyperinus
	Elymus repens
Fresh	*Poa pratensis*
	Calamagrostis canadensis
Upland	*Bromus inermis*
	Lolium perenne

Table 1.2 Species Found at Reference Sites (Data provided by CBWES Inc. from vegetation surveys completed in 2010).

Location on Marsh	**Vegetation Species**
Low Marsh	*Spartina alterniflora*
High Marsh	*Carex paleacea*
	Distichlis spicata
	Juncus gerardii
	Spartina patens
Brackish	*Juncus balticus*
	Spartina pectinata

1.2.3 Processes within a Salt Marsh

Several processes and factors affect salt marsh growth and survival. These include subsidence, plant processes, sedimentation, elevation, tidal flooding, rising sea level, soil volume, compaction/decomposition and ground water as seen in Figure 1.1 (Cahoon et al., 1999). A delicate balance between all of these factors will allow marshes to remain healthy and stable (Silvestri and Marani, 2004; Aspden et al., 2004). The deposition, accretion and erosion of sediment may be threatened by climate change and consequently a rise in sea level and storm frequency (Aspden et al., 2004).

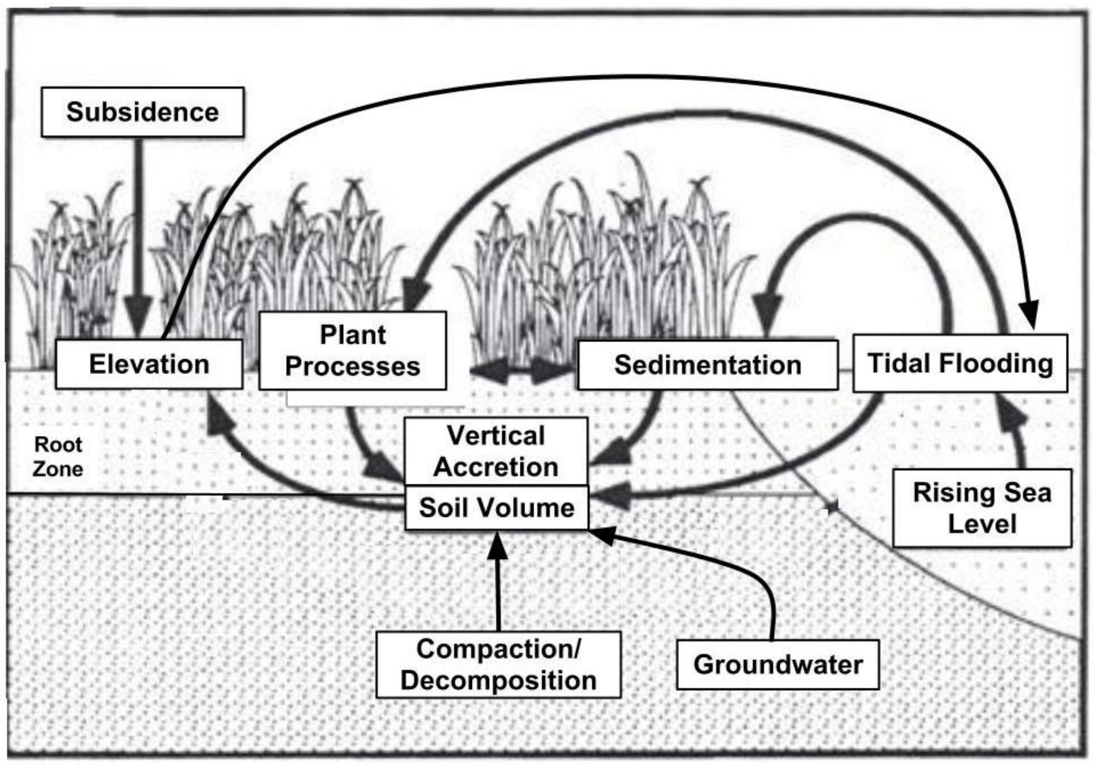

Figure 1.1 Conceptual diagram of relationship between hydrology, biotic and geologic processes affecting marsh elevation (Modified from Cahoon et al. 1999).

The ever increasing sea level rise is one of the main threats to the survival of salt marshes (Fagherazzi et al., 2004). A rising sea level will cause accretion of both sediment and organic matter but the sustainability of the marsh will depend on a balance between rising sea level and inorganic sediment accretion (Keusenkothen and Christian, 2004; Aspden et al., 2004; Cahoon et al. 1999). The steady sediment supply ensures the marsh will keep pace with sea level change but any change or decrease in this supply will allow erosion processes to dominate and degrade the marsh further. The gain in elevation is affected by the degree of compaction the marsh surface experiences. The compaction of the sediment is shown in the decrease in water content and consolidation within the first 1m of the marsh surface (Cahoon et al. 1999).

The dominant factor in the development of a salt marsh has been found to be vertical accretion (Townend et al., 2011; Cahoon et al, 2004; Nyman et al., 2006). The surface elevation change within the marsh may be dominantly organogenic, which is the belowground organic accumulation, or dominantly minerogenic, which is the accumulation of fine sediments on the marsh surface (Davidson-Arnott et al., 2002; Allen, 2000). The rate of vertical growth of a marsh is dependent on the tidal range under stable sea level. Within minerogenic salt marshes, the rate of vertical growth is rapid during the early phases of development but begin to decrease as the marsh surface matures at or above mean high tide level because fewer tides are able to over top the developing marsh surface (Davidson-Arnott et al., 2002; Allen, 1990; French and Spencer, 1993; Jennings et al., 1993). Thick deposits accumulate during rising sea levels which ensures the marsh can keep pace with rising sea levels (Davidson-Arnott et al., 2002; Allen, 1990; Jennings et al., 1995).

Each salt marsh experiences a degree of subsidence throughout time. Those within deltas and wide coastal plains which have thick deposits and small or nonexistent stable geologic formations have higher degrees of subsidence (Cahoon et al., 1999). Subsidence may also occur in areas where a growth fault has developed or further compaction of deep sediments. It is also important to understand that activities conducted on the site will enhance subsidence. If the subsidence is greater than the sediment accretion, the marsh will be susceptible to sea level rise and further degradation.

The vertical accretion on the marsh is influenced by the frequency, duration and depth of flooding as this affects the amount of sedimentation on the marsh surface (Cahoon et al., 1999). The availability of sediment and the way in which it travels to the marsh also affects the amount of sedimentation. The sedimentation then affects the growth of the vegetation by altering the elevation of the marsh as well as being the source of valuable nutrients (Cahoon et al., 2004). The vegetation dampens the tidal flow which enhances sedimentation and consolidates the particles on the marsh surface (Silvestri et al., 2004; Leonard and Croft, 2006; Leonard, 1997; Nepf et al., 1997; Christiansen et al., 2000). The root growth and sedimentation affect the soil volume which affects elevation. The percentage of time that water is over the marsh, also called hydroperiod (Townend et al., 2011; Reed 1990), affects the pore water storage which affects the elevation of the marsh (Cahoon et al., 1999). The hydroperiod has also been found to affect sedimentation and decrease the plant productivity due to increased stress on the plants (Townend et al., 2011). The elevation of the marsh within the tidal frame ultimately determines the hydroperiod. The connection between all of these factors is complex and must be evaluated closely to ensure proper management of the marsh.

1.2.4 Controls on Sediment Deposition

The key to the distribution of sediment across the marsh is the movement of water and suspended sediment (Allen, 2000). The way in which sediment reaches the marsh depends on where it lies in the tidal frame. The marshes which are located along open coasts receive sediment laden tidal water from direct paths whereas those which lie in estuaries or inlets receive the sediment through indirect paths (Davidson-Arnott et al., 2002). Generally, the sedimentation which occurs on the marsh surface is dominantly from an inorganic source rather than organic matter. The inorganic source is primarily fine sediments from an estuarine source which depends on the interaction of the concentration at the marsh edge, the amount of time the water is over the marsh, the flow over the marsh vegetation, settling and trapping processes and distance from the source (Townend et al., 2011). Salt marsh plants have been identified as being able to trap and bind mineral sediment as well as provide organic matter to the sediment that is deposited (Allen, 2000; Townend et al., 2011). A significant decrease in suspended sediment occurs the farther away from the sediment source due to the enhanced settling of sediment caused by drag created by the presence of vegetation (Townend et al., 2011; Leonard and Croft, 2006; Nepf, 2004; Reed et al., 1999; Friedrichs and Perry, 2001). This causes the banks of the creeks to accrete at a faster rate as compared to the interior of the marsh. The lower marsh is dominated by inorganic sedimentation whereas the high marsh is dominated by organic matter deposition due to the decrease in sediment within the water column farther away from the source. The decrease in flow and increased sedimentation is correlated back to the size and density of the vegetation. *Spartina alterniflora* has been identified as having the ability to collect sediment on their stems and leaves whereas *Juncus* and *Salicornia* are unable to (Townend et al., 2011; French and Spencer 1993). Studies conducted by Leonard and Luther 1995 and Christiansen et al. 2000 in the field and those conducted by Burke, 1982; Shi et al. 1996 demonstrated reduction in flow velocity within the vegetation canopy as compared to open areas (Friedrichs and Perry, 2001). Along with enhancing sediment settling, damping the flow also decreases the ability for erosion processes to act on the marsh surface allowing sediment accretion to dominate (Townend et al., 2011).

1.3 Salt Marsh Restoration in the Bay of Fundy

Throughout history, vast coastal marshes have been altered for other purposes as they have been viewed as wastelands and those which remain are under pressure from coastal development. As previously mention, within the Bay of Fundy since the 17th century, it has been estimated that 85% of estuaries have been lost to agricultural dyking (Byers and Chmura, 2007; Ganong 1903). In order to combat these losses, salt marsh restoration activities have begun to return tidal flow to previously altered marshes. There are several goals which can be achieved through restoration activities can include: repair of biotic communities; re-establishment of communities if they have been destroyed; and construction of synthetic communities if the original community is no longer available (Keddy, 1999). Ultimately, the goal of salt marsh restoration is to return natural ecosystem functions to a damaged area (Broome et al., 1988; Weis and Butler, 2009). Restoration of any ecosystem is complex especially those within salt marsh ecosystems. In order for a project to be successful, an understanding of both the biotic and abiotic factors and their interactions is needed. Six restoration projects within Nova Scotia have been overseen by CB Wetlands and Environmental Specialists Inc. (CBWES) since 2005 (Bowron, et al. 2011a). These projects have been a collaboration between CBWES, the Nova Scotia Department of Transportation and Infrastructure Renewal and Saint Mary's University (Bowron, et al. 2011a).

1.3.1 Methods of Salt Marsh Restoration and Monitoring

The key abiotic factor in salt marsh restoration is the return of the natural hydrology to the site. The hydrology affects the sediment dynamics, soil development, plant dispersal, plant growth, and access for aquatic life (Callaway, 2001). In order to return the proper hydrology to the site, several options can be used on their own or in combination. These options include excavating fill from a dredge wetland, reintroducing species that were previously on the site, breaching dykes and opening tide gates to return tidal flow (Sullivan, 2001). A breach in a dyke can occur through human intervention which requires human involvement throughout the duration of the project or may occur during storm events in which the marsh would develop without human intervention (Byers and Chmura, 2007). The next step in the restoration process is to allow the establishment of vegetation (Sullivan, 2001). There are two ways in which vegetation may be reintroduced to the site. The first option is by designing the wetland and planting the vegetation according to the plans established. The second option is to allow the wetland vegetation to establish without human intervention and allow nature to decide which plants are best suited around the marsh.

Once the restoration activities have been completed, it is important to assess the success of the project to address further human intervention if necessary. One of the ways to assess the progress and success is to determine the difference between the vegetation cover and biomass at the restoration and reference sites (Byers and Chmura, 2007; Warren et al. 2002). Vegetation plays an important role in ecosystem functions as well as particle trapping (Nepf, 2004). Other variables influencing restoration success include hydrology and topography, water quality, soils, fish and invertebrates (Callaway et al., 2001). Hydrology and topography are used to determine the tidal inundation across the site and to evaluate the changes in morphology, erosion and sedimentation (Callaway et al., 2001). Water quality identifies the physical and chemical conditions at the restored site which can identify poor circulation or impaired tidal flushing (Callaway et al., 2001). Monitoring of soils helps to identify constraints on plant growth including porosity, nutrient levels and pore water salinity. Fish require several wetland habitats throughout their life span and by measuring the density and occurrence of the fish, it will give an understanding of what habitat requirements the wetland has and if these requirement should be changed to allow opportunity for larger abundance (Callaway et al., 2001). Invertebrates are part of the food web by being food for a variety of organism and therefore important to assess the health of the ecosystem (Callaway et al., 2001).

1.4 Rationale

The distribution of vegetation across the marsh surface is highly influenced by salinity of the sediment, duration of tidal flooding and competition between plant species. Studies have been conducted to understand how these factors affect the distribution of plants across the marsh surface (e.g. Crain et al., 2004; Bertness, 1992; Bertness, 1987; Bertness, 1991). Geodetic elevation and duration of tidal flooding have been found to influence soil salinity across the marsh (e.g. Blum and Christian, 2004). Elevation and duration of tidal flooding have been found to influence the vegetation community structure on an island within the North Sea (e.g. Bockelmann et al., 2002).

Within the Bay of Fundy, focus has been placed on vegetation regeneration in post restoration activities (e.g. Byers and Chmura, 2007) and the role vegetation plays in sediment deposition (e.g. Davidson-Arnott et al., 2002; van Proosdij et al., 2006). 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.

Many more salt marsh restoration projects are being undertaken throughout the Bay of Fundy. These projects require the development of monitoring programs specific to the marsh environment. With the development of a predictive model for the vegetative community structure within restoration salt marshes in the Bay of Fundy, more efficient monitoring programs can be developed for future projects.

1.5 Purpose and Objectives

The purpose of this project was to analyze the relationship between vegetation community structure and geodetic elevation within restoration and reference macrotidal salt marshes in the Bay of Fundy. This relationship is part of research leading to the ultimate goal of developing a predictive model for the potential range of vegetation species within future restoration salt marshes. The variables evaluated were geodetic elevation and dominant plant species. It was hypothesized that similar dominant vegetation would be found at similar ranges of elevation within reference and restoration sites. The objectives of this project were to:

1. Determine relationship between vegetation communities and geodetic elevation within restoration and reference salt marshes;

2. Compare range of geodetic elevation for similar species between restoration and reference salt marshes.

CHAPTER TWO

STUDY AREA

2.1 The Bay of Fundy

The Bay of Fundy is a macrotidal estuary located between New Brunswick and Nova Scotia on the East Coast of Canada (Figure 2.1) (van Proosdij et al., 2010; Davidson-Arnott et al., 2002). The Bay emerged during the Appalachin orogeny approximately 286-360 million years ago (Desplanque and Mossman, 2001). Today's boundaries of the Bay of Fundy were the result of the development of a rift valley that ultimately formed the Atlantic Ocean (Desplanque and Mossman, 2001). At the upper reaches of the Bay of Fundy, lies the Minas Basin which is a semi-enclosed remnant of a 200 million year old rift valley (Figure 2.1) (Hinch, 2004).

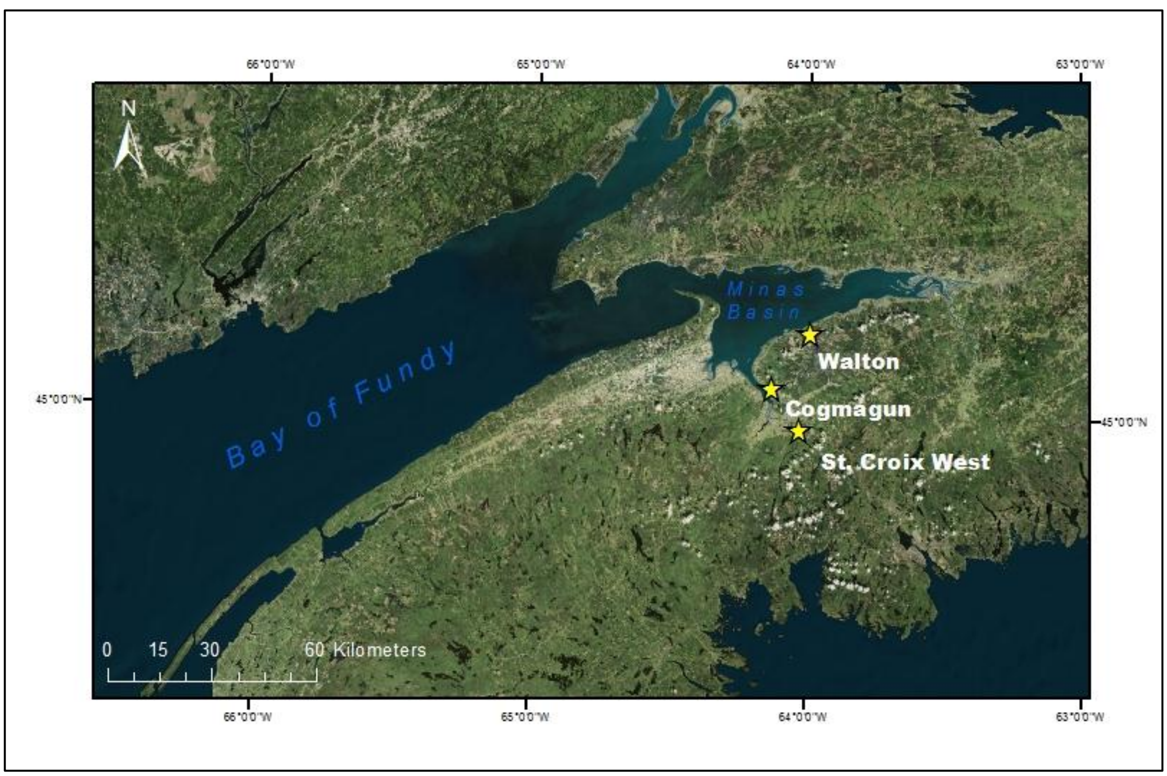

Figure 2.1 The Bay of Fundy and Minas Basin (Bing Aerial 2010).

The tides experienced in the area range from 4m at the entrance of the Bay (Davidson-Arnott et al., 2002) and reaches 13 to 16 m in the Minas Basin (Hinch, 2004). The suspended sediment concentrations within the Bay range from 150 mgl^{-1} on the marsh surface to 4000 mgl^{-1} in the upper reaches of the Minas Basin (Proosdij et al., 2010). The high level of sediment deposition and expansive low intertidal area within the Bay have facilitated extensive areas of tidal marshes to develop. Prior to European settlement, it was estimated that the marshes surrounding the Bay of Fundy was 395 km^2 (Davidson-Arnott et al., 2002). Due to dyking, the area that is still natural tidally flooded marshes has decreased to 65 km^2 (Davidson-Arnott et al., 2002).

The Minas Basin, approximately 190,000 hectares, consists of four distinct sections (Hinch, 2004). The Minas Channel at the mouth of the Basin, central Minas Basin, Southern Bight on the southward side and Cobequid Bay at the inner extremity (Hinch, 2004). Along the extensive mudflats lies approximately 1330 hectares of low salt marsh (Hinch, 2004). Approximately 80% of salt marshes are found along the Southern Bight and along with the extensive tidal mudflats, provide important habitat for micro-organisms and shore birds (Hinch, 3004). The sites used in this research lie along rivers which are fed by the waters of the Minas Basin (Figure 2.2).

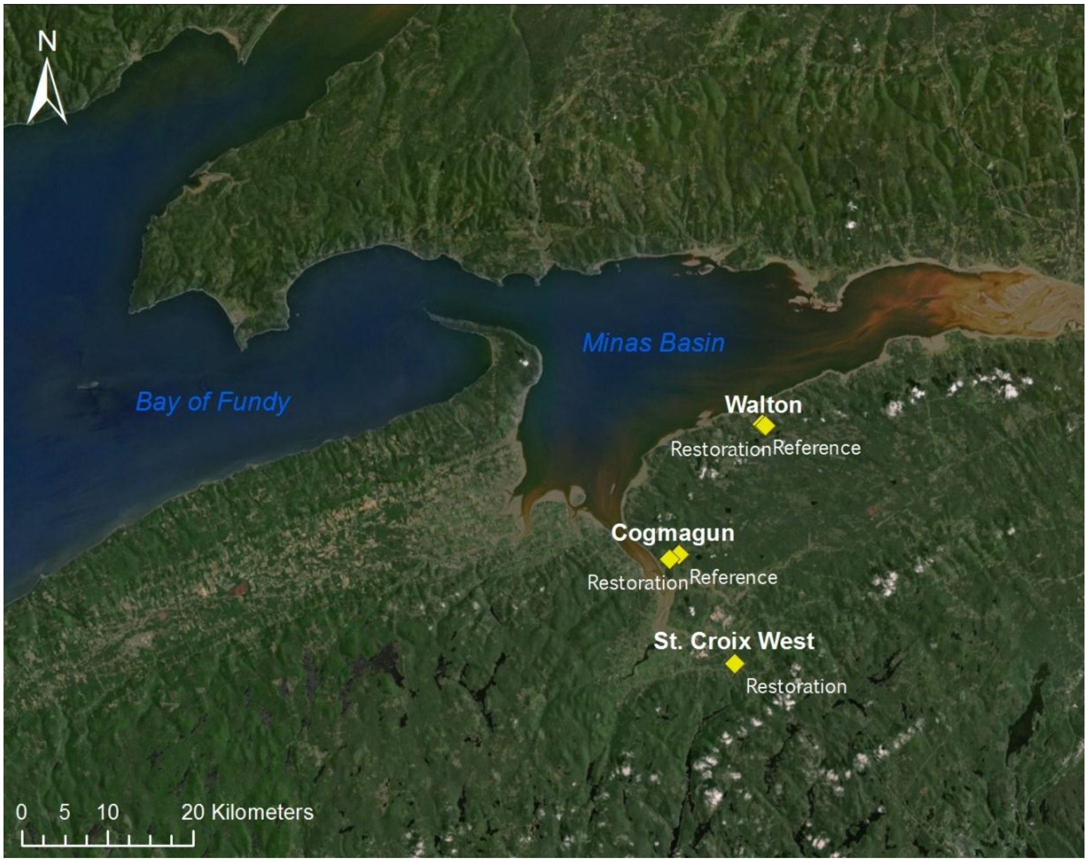

Figure 2.2 The research sites within the Minas Basin (Bing Aerial 2010).

For this research it was determined that the study sites used would all have dyke breaches completed to restore tidal flow and paired reference sites for two of the restoration sites. It was essential to keep the restoration method the same as the environmental conditions at the sites would be the similar and able to be compared to one another.

2.2 Cogmagun River Restoration Site

The 6.9 ha Cogmagun River restoration site is located along the Cogmagun River in Hants County, Nova Scotia (Figure 2.3). The site was a freshwater impoundment shut off from tidal water by a dyke prior to restoration and was created to establish habitat for waterfowl and other wildlife (Bowron et al., 2011a). An enclosed channel, also known as a burrow pit, was found at the inside of the dyke structure and was used to construct the original dyke. A water control structure was installed to ensure water level was kept at a constant elevated level. The dyke and water control structure were built by Ducks Unlimited Canada (DUC) in 1991 (Bowron et al., 2011a). The cost required to ensure salt water did not enter into the impoundment became too great. In 2003, DUC decided to cease maintenance on the structures and to allow the site to regenerate on its own. The site in March of 2009 was put forward by Nova Scotia Department of Transportation and Infrastructural Renewal (NSTIR) as a compensation project. Legislation requires mitigation or compensation when a wetland or wetland functions are damaged during a project (Hanson et al., 2008). On September 22, 2009, restoration activities began to create a 60m breach in the dyke, remove the water control structure and connect the internal borrow pit to the outside fringe marsh (Bowron et al., 2011a). The reference site for the Cogmagun restoration project is located approximately 1.5km upstream from the restoration site and is 6.1 hectares in size (Figure 2.4) (Bowron et al., 2011a). The reference is similar to the restoration site in spatial scale and has evidence of similar ecological and social history (Bowron et al., 2011a).

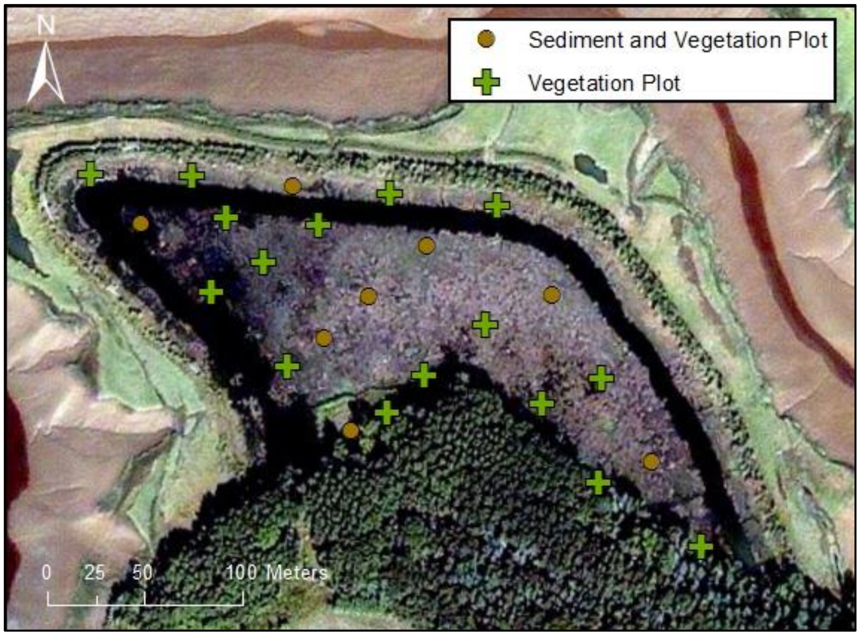

Figure 2.3 Cogmagun Restoration site (Basemap Imagery from ArcMap 2012).

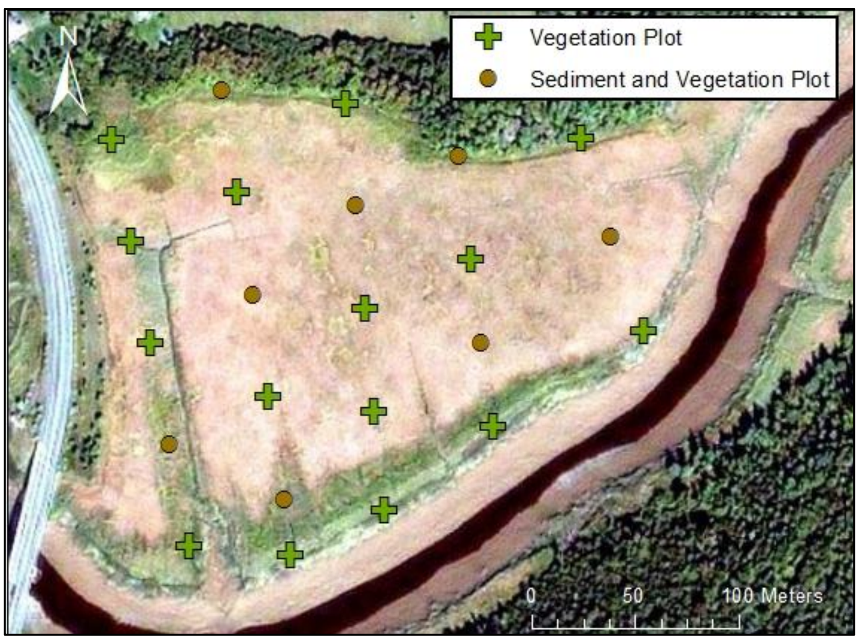

Figure 2.4 Cogmagun Reference (Basemap Imagery from ArcMap 2012).

The Cogmagun site is an asset to this research project as the site is in its first year since restoration. As well, the site has one breach as compared to several at other sites. The monitoring program initiated by CBWES included permanent sampling locations which allows for repeated sampling at each point and can be compared over several years. As well, the permanent sampling locations allow for addressing any potential sampling issues such as insufficient number of sampling locations within areas of the marsh or too many sampling locations in other areas of the marsh. Although things would not be able to be changed on this project, it would enable the determination of adequate sampling plots in future projects and assist in decreasing costs.

2.3 St. Croix River Restoration Site

The St. Croix River Restoration site is located at the upper reaches of the St. Croix River where it is intersected by Highway 101 (Figure 2.5). The site consists of four separate salt marshes which were dyked for agricultural purposes. Many of these dykes have been in place for 200 years but due to economic pressures and changing land uses, many of the sites have since been left fallow (Bowron et al., 2011b). The restoration of these areas came to a front when the twinning of Highway 101 was in the planning phase. The twinning was going to result in the damage and loss of several wetlands which required compensation. The compensation project was purposed to NSTIR by the Nova Scotia Department of Agricultural, who are in charge of the agricultural dyke lands around the province (Bowron et al., 2011b). The size of all four sites equates to 19.29 ha in which St. Croix West is the largest section of the restoration (Bowron et al., 2011b). The site is 10.65 ha (Bowron et al., 2011b) and is the only section of this site used in the research. St. Croix West was mainly pastureland for cattle which contained a network of agricultural drainage ditches and two higher elevation areas (Bowron et al., 2011b). The restoration plan for the site was to partially or completely remove the agricultural dykes to allow tidal waters to return to the site.

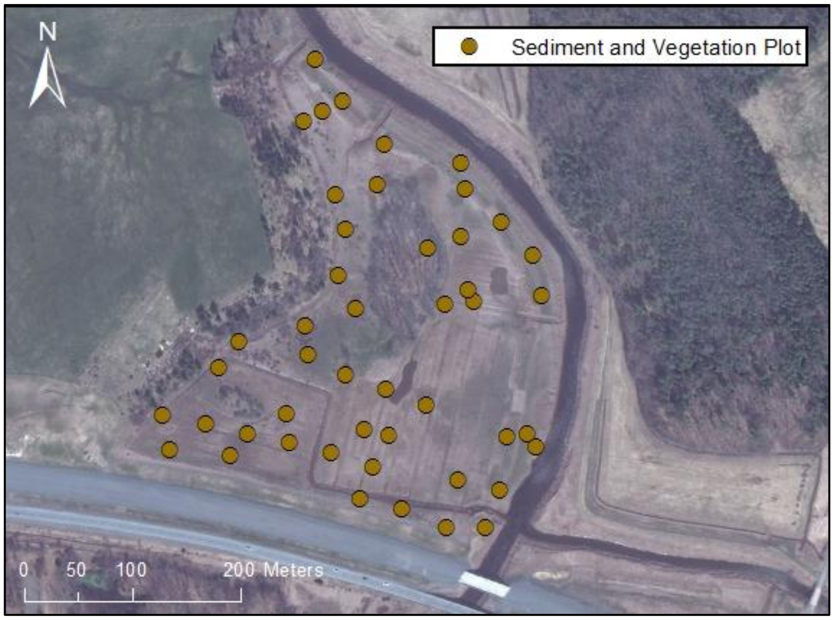

Figure 2.5 St. Croix River Restoration Site (Bing Aerial 2010).

The St. Croix West site is an access to the research as it lies at the upper reaches of the St. Croix River at a transition zone between fresh water and salt water. Therefore, the site is not only influenced by the tidal water but the fresh water inputs allowing for both salt tolerant and freshwater plants to flourish on the site. As well, the site experiences a large amount of deposition during each high spring tide which is important to analyze the grain size and other sediment characteristics across the marsh. The restoration project consisted of creating a few breaches in the dykes surrounding the site as compared to one breach at the Cogmagun site. The permanent sampling locations were set up by CBWES Inc. during the development of the monitoring program. These permanent locations enable sampling to be completed at the same location over periods of years as well as addressing any potential issues as explained in the Cogmagun site section.

2.4 Walton River Restoration

The Walton River is located along the south shore of the Minas Basin within Hants County, Nova Scotia (Figure 2.6). Approximately 1.2 km upstream from the mouth of the river, approximately 1.2 km, lies the 12 ha Walton River salt marsh restoration site. In 1990, Duck Unlimited Canada (DUC) decided to place a dyke and water control structure on the site to create a freshwater impoundment (Bowron et al., 2011c). The water control structure was used to keep the water within the impoundment at a raised level. Along the inside of the dyke was a burrow pit which was created during the construction of the dyke system. DUC found the costs required to keep the dyke system and water control structure maintained was too great. The site was purposed as a restoration site to the Nova Scotia Department of Transportation and Infrastructure Renewal as a compensation project for alteration of wetlands during construction projects across the province. The restoration of the Walton River salt marsh was the first project of its kind in Nova Scotia in 2005 (Bowron et al., 2011c). The restoration activities, which began on August 29 to September 9, 2005 by DUC, included breaching the dyke in five locations, removing the water control and creating a tidal channel into the interior of the impoundment (Bowron et al., 2011c). The reference site for the Walton site was located directly downstream from the restoration site (Figure 2.7). The site is 4.95 ha in size as compared to the 12 ha restoration site (Bowron et al., 2011c). The reference site was an appropriate choice as it has similar social and ecological history to the restoration site.

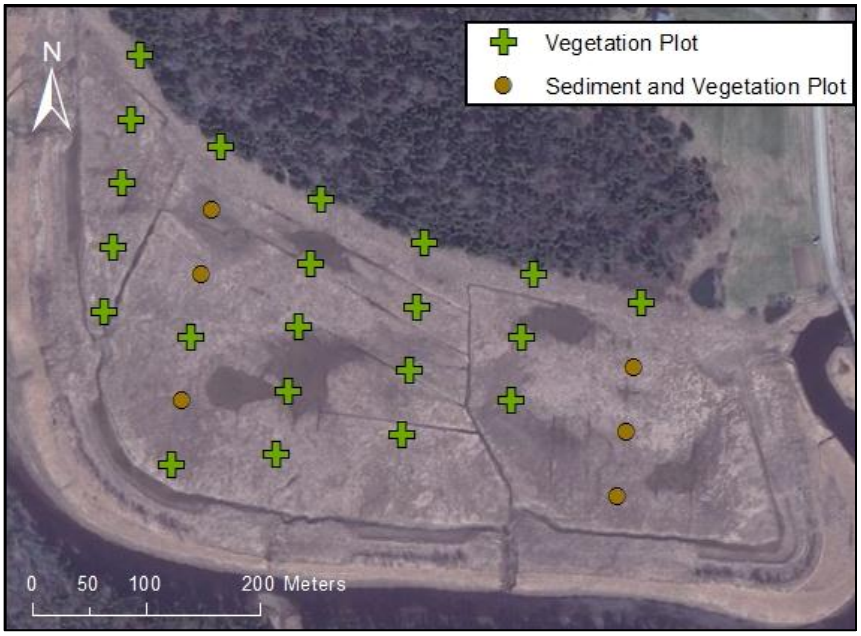

Figure 2. 6 Walton River Restoration site (Bing Aerial 2010).

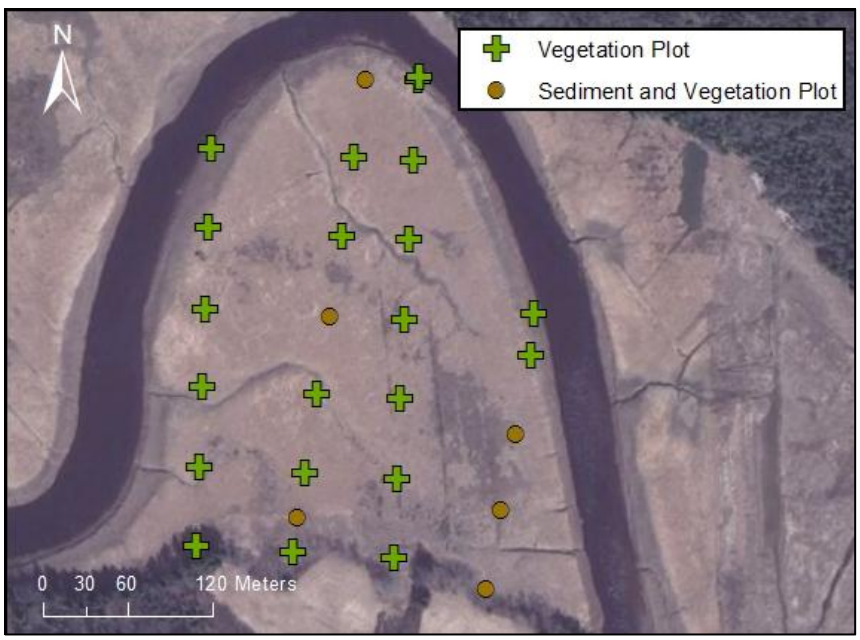

Figure 2.7 Walton River Reference site (Bing Aerial 2010).

The Walton restoration and reference sites are a great asset to this research project. The Walton site is the most progressed site as compared to the other sites being analyzed. This project is in the fifth year of monitoring post-restoration which may be more similar to the reference sites than the marshes which were only recently restored. The site also has several breaches as compared to one at the Cogmagun site. The site was a previous freshwater impoundment which allows for a unique opportunity to understand how the characteristics change over the marsh when several breaches are made. The monitoring program developed by CBWES includes permanent sampling locations which allow for repeated sampling in the same location over periods of years.

2.5 Summary of Study Site Characteristics

The restoration sites used for this research were all dyke breaches and ranged in size from 6.9 to 12 hectares (Table 2.1). The reference sites used for this research were both stable salt marshes and ranged in size from 4.95 to 6.1 hectares. Both the Cogmagun and St. Croix West restoration sites were only 1 year post restoration whereas the Walton restoration site was 5 years post restoration. The Cogmagun and Walton restoration sites were both previously fresh water impoundments whereas the St. Croix West restoration site was previously agricultural lands.

Table 2.1 Summary of site characteristics for Cogmagun, Walton and St. Croix restoration and reference sites.

Marsh	Type of Restoration	Year of restoration	Size (hectares)	Elevation Range (m CGVD 28)	Previous Use
Cogmagun Restoration	Dyke breach	2009	6.9	3.8 – 8.5	Freshwater impoundment
St. Croix West Restoration	Dyke breach	2009	10.65	3.0 – 13.8	Agricultural lands
Walton Restoration	Dyke breach	2005	12	3.5 – 10.0	Freshwater impoundment
Cogmagun Reference	N/A	N/A	6.1	1.5 – 12.3	Stable salt marsh
Walton Reference	N/A	N/A	4.95	3.5 – 9.3	Stable salt marsh

2.5.2 Sediment Characteristics

Sediment characteristics are an important variable to consider during the monitoring of salt marsh restoration activities. The majority of the sediment within the oceans consists of mud which has approximately equal proportions of material in all size classes (clay, silt and sand) (Krank and Milligan,1991; Curran et al., 2004). Salt marshes within the Bay of Fundy are highly influenced by the large volume of sediment supplied through erosion of fine sediments or rocks (Davidson-Arnott et al., 2002). Within the Bay of Fundy, suspended sediment concentrations are typically high, ranging from 50 $mg \cdot l^{-1}$ to up to 6,000 $mg \cdot l^{-1}$ in some areas (van Proosdij et al. 2006; Desplanque and Mossman, 2004) which can provide a significant supply of sediment into Fundy marshes. Once the hydrology is returned to a salt marsh undergoing restoration, sediment is brought along to allow for marsh development and growth. Important sediment and soil properties to monitor during salt marsh restoration monitoring activities, include bulk density, organic matter and grain size. Bulk density measures the mass to volume relationship for the given sample and takes into account the solid spaces as well as the pore spaces (Bowron, et al., 2011a). The grain size of the sample influences the how large or small the bulk density value will be. Clay sized particles decrease the value and sand sized particles increase the value. A high bulk density leads to low pore space that indicates compaction or large amount of cohesive particles packing closely together, removing water and creating a low permeability bed (Bowron, et al., 2011a; Aspden et al., 2004). Organic matter measures the percentage of organic matter content in a given sample. This can help identify if the marsh is organogenic or minerogenic. The availability of organic matter is influenced by the aboveground and belowground productivity (Cahoon et al., 2004) as this leads to more waste biomass and decomposition.

Grain size characteristics are the most important physical property of oceanic particles and can affect the environment, transport and deposition of each particle (Krank and Milligan, 1991; Blott and Pye, 2001). The knowledge gained by analyzing these particles can help to piece together the puzzle of the processes and environments of deposition. The size of the particle governs where it will fall out of suspension, if it will be re-suspended and in what form it falls out of suspension. The hydrodynamics throughout the marsh and available geologic material control the particle size distribution that will form the marsh bed (Aspden et al., 2004). Fine particles tend to remain in suspension for longer periods of time as compared to coarser sediments thus being able to be brought further into the estuary. The fine grained mineral sediments come from four different sources which include: discharges from river catchments, retreating coastal cliffs, sedimentary formations and other exposed rocks, and hard shelled organisms which live in the surrounding area (Allen, 2000).

The particles which are held in suspension consist of single grains and flocs. Flocs are aggregates of fine particles which form with the assistance of organic matter. These aggregates are large and thus will sink faster than the individual particles in which they are made up of (Curran et al., 2004). Within the water column there is constant give and take between the single grains and the flocs until they are deposited onto the sea bed where they lose their integrity and become part of the sea bed (Curran et al., 2004, Krank and Milligan, 1991). Due to the size of the flocs and the ability to come fall out of suspension quicker, which leads to more deposition, marsh development occurs quicker.

Sediment cores and bulk density syringes were collected by members of the CB Wetlands and Environmental Specialists Inc. team at each restoration and corresponding reference marsh in August and September 2010.

The water content at the Cogmagun restoration site ranged from 31.76% to 76.88% whereas at the reference site it ranged from 32.56% to 70.96%. The organic matter at the restoration site ranged from 7.32% to 36.37% and at the reference site it ranged from 2.05% to 32.85%. The bulk density at the restoration site ranged from 0.22 g/cm^3 to 0.97 g/cm^3 and at the reference site, it ranged from 0.22 g/cm^3 to 1.14 g/cm^3. The mean grain size for both the restoration and reference site was found to be fine silt and medium silt determined from using modified Udden-Wentworth scale. The source slope ranged from 0.19 to 0.65 at the restoration site and ranged from 0.16 to 0.62 at the reference site. The rolloff diameter ranged from 13µm to 18µm at the restoration site and ranged 11µm to 18µm at the reference site. The floc limit ranged from 12 µm to 15 µm at the restoration and 9 µm to 15 µm at the reference site. The floc fraction for the restoration site ranged from 0.57 to 0.74 and ranged from 0.49 to 0.76 at the reference site. A summary of the sediment characteristics determined at the Cogmagun restoration and reference sites is shown in Appendix A.

The water content at the St. Croix West restoration site ranged from 18.36% to 51.55%. The organic matter at the restoration site ranged from 2.78% to 31.05%. The bulk density at the restoration site ranged from 0.64 g/cm^3 to 1.35 g/cm^3. The mean grain size for the restoration site was found to be fine silt and medium silt determined from using modified Udden-Wentworth scale. The source slope ranged from 0.17 to 0.73 at the restoration site. The rolloff diameter ranged from 9µm to 40µm at the restoration site. The floc limit ranged from 6 µm to 14 µm at the restoration. The floc fraction for the restoration site ranged from 0.43 to 0.70. A summary of the sediment characteristics determined at the St. Croix West restoration site is shown in Appendix A.

The water content at the Walton restoration site ranged from 43.86% to 59.98% whereas at the reference site it ranged from 41.47% to 63.10%. The organic matter at the restoration site ranged from 7.19% to 13.32% and at the reference site it ranged from 7.33% to 21.70%. The bulk density at the restoration site ranged from 0.70 g/cm^3 to 0.81 g/cm^3 and at the reference site, it ranged from 0.44 g/cm^3 to 0.84 g/cm^3. The mean grain size for both the restoration and reference site was found to be fine silt and medium silt determined from using modified Udden-Wentworth scale. The source slope ranged from 0.36 to 0.54 at the restoration site and ranged from 0.38 to 0.67 at the reference site. The rolloff diameter ranged from 11µm to 15µm at the restoration site and ranged 12µm to 15µm at the reference site. The floc limit ranged from 9 µm to 12 µm at the restoration and 12 µm to 14 µm at the reference site. The floc fraction for the restoration site ranged from 0.55 to 0.66 and ranged from 0.64 to 0.70 at the reference site. A summary of the sediment characteristics determined at the Walton restoration and reference sites is shown in Appendix A.

CHAPTER THREE

METHODS

3.1 Site Set-Up

The data used for this research are part of a larger monitoring program developed by CBWES Inc. prior to restoration at each site. The monitoring program includes hydrology, sediment analysis, vegetation, nekton (fish), benthic and other aquatic invertebrates, and winter conditions (Bowron, et al., 2011a). The data collected during the vegetation surveys in the summer of 2010 were used for this research. The vegetation surveys were completed at selected stations throughout each marsh. This was done using transects leading from the upland towards the main tidal creek. The location of the vegetation survey locations are shown in Figure 3.1 for Cogmagun river restoration site; Figure 3.2 for Cogmagun river reference site; Figure 3.3 for St. Croix West restoration site; and Figure 3.4 for Walton River restoration and reference sites. One year of data was selected for the research because each of the sites would experience the same environmental conditions and could be compared to one another.

Upon close examination of the data, sample points along the fringe marsh outside of the dyke on the creek side were not included. The data may have been lost or were not gathered during sampling.

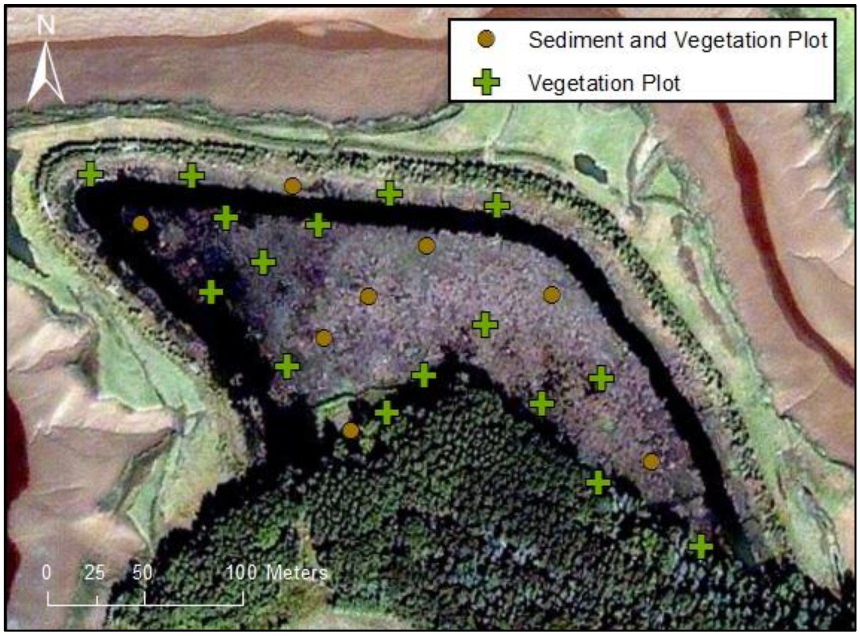

Figure 3.1 Sample survey locations for Cogmagun Restoration site (Basemap Imagery from ArcMap 2012).

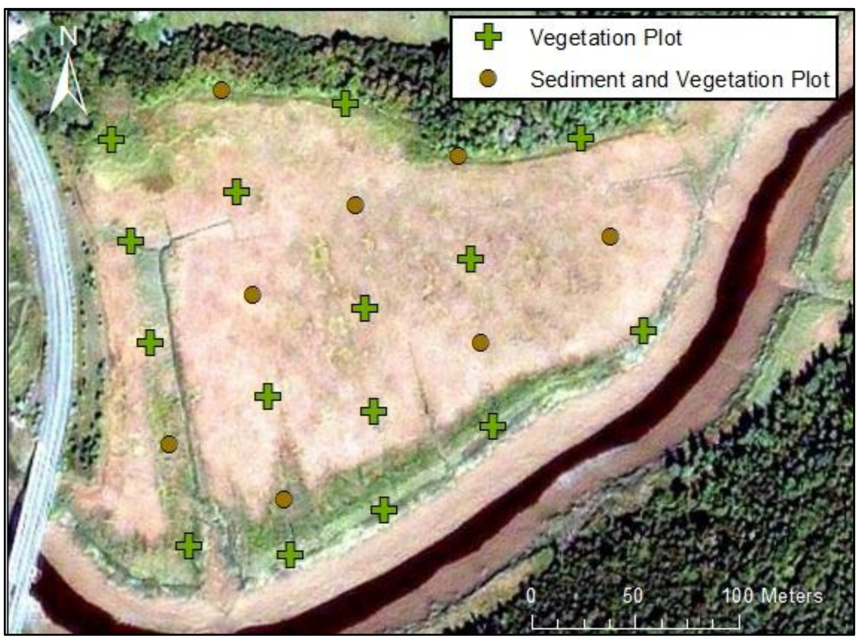

Figure 3.2 Sample survey locations for Cogmagun River Reference site (Basemap Imagery from ArcMap 2012).

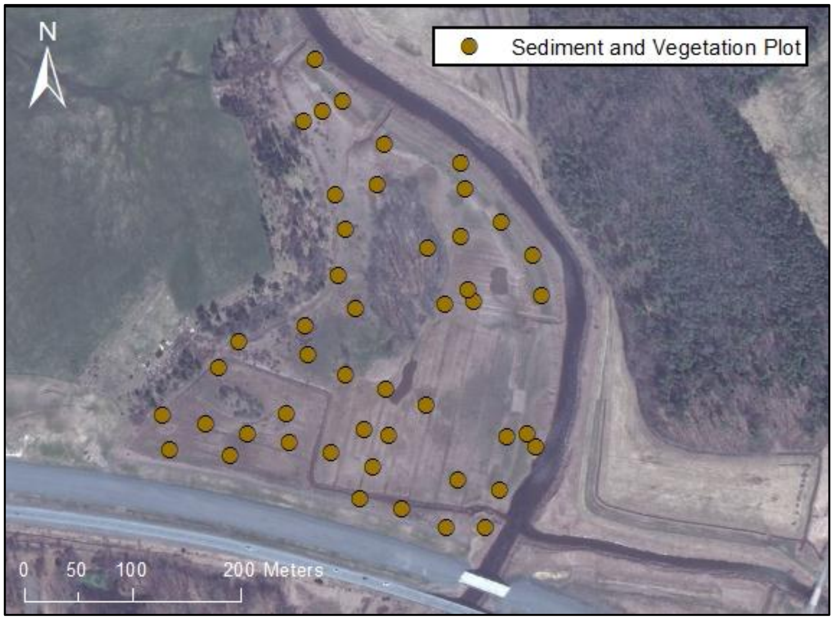

Figure 3.3 Sample survey locations for St. Croix West Restoration Site (Bing Aerial 2010).

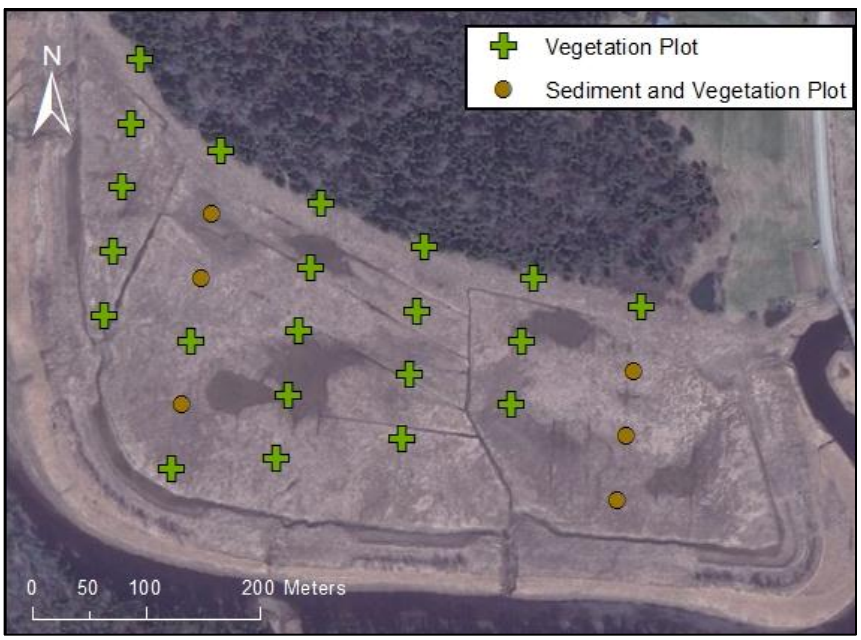

Figure 3.4 Sample survey locations for Walton River Restoration site (Bing Aerial 2010).

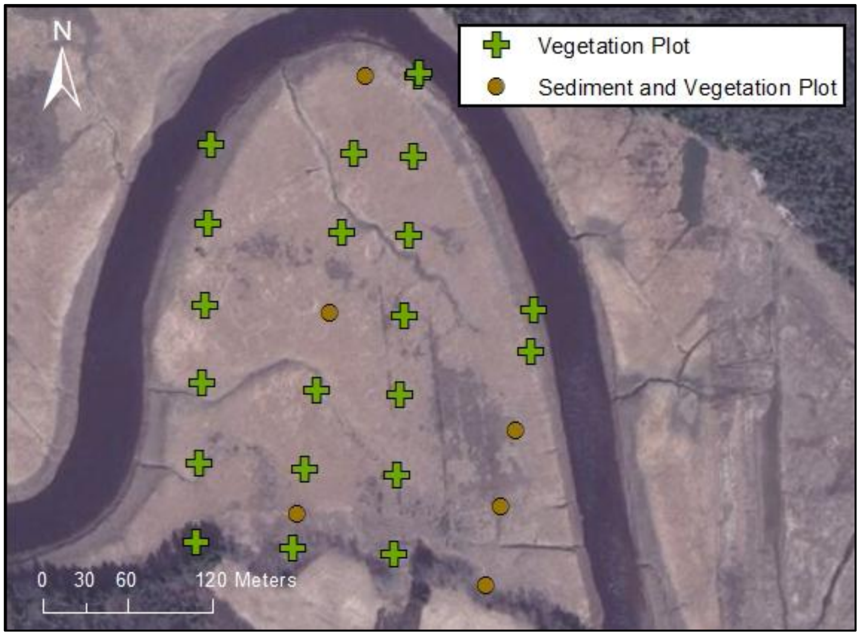

Figure 3.5 Sample survey locations for Walton River Reference site (Bing Aerial 2010).

3.2 Determination of Geodetic Elevation

The geodetic elevation was determined with the use of a differential global positioning system (DGPS) and a Total Station (Bowron, 2011a). Permanent benchmarks were established on each of the sites using the DGPS which allowed the Total Station to complete the survey. The Total Station determines horizontal and vertical angles and distance to the prism target pole with the use of a laser (Bowron, 2011a). The X, Y, and Z coordinates of the sample stations are computed automatically from the known location of the Total Station and trigonometry functions (Bowron, 2011a). The Total Station is accurate to within 5 seconds of a measured arc and 2 mm + 2 parts per million for distances (Bowron, 2011a).

3.3 Vegetation Survey

A vegetation survey was completed by members of the CB Wetlands and Environmental Specialists Inc. team at each of the restoration sites and the corresponding reference marsh during July and August 2010. The survey stations for Cogmagun restoration/reference, St. Croix West restoration and Walton restoration/reference are shown in Figure 3.1, 3.2, 3.3, 3.4 respectively. A 1m quadrat split into 25 squares and a wooden dowel was used to complete the survey at each of the stations within the study area (Figure 3.6). At the first station, the quadrat was placed next to the station and was then flipped 1m to the left of the station (facing the main creek). It was critical to keep the main creek in front to ensure each vegetation survey was taken in the exact same way. The vegetation within the quadrat is identified and a tally sheet with 1 – 25 was created. The wooden dowel was placed in the square in the top left facing the creek of the quadrat in the bottom right of the first square. The vegetation which touches the wooden dowel was described as a "hit" and was recorded within the tally sheet. The dowel was the placed into the second square and the vegetation which touched the dowel was recorded. The same process was completed for the rest of the twenty-five squares of the quadrat (Figure 3.6).

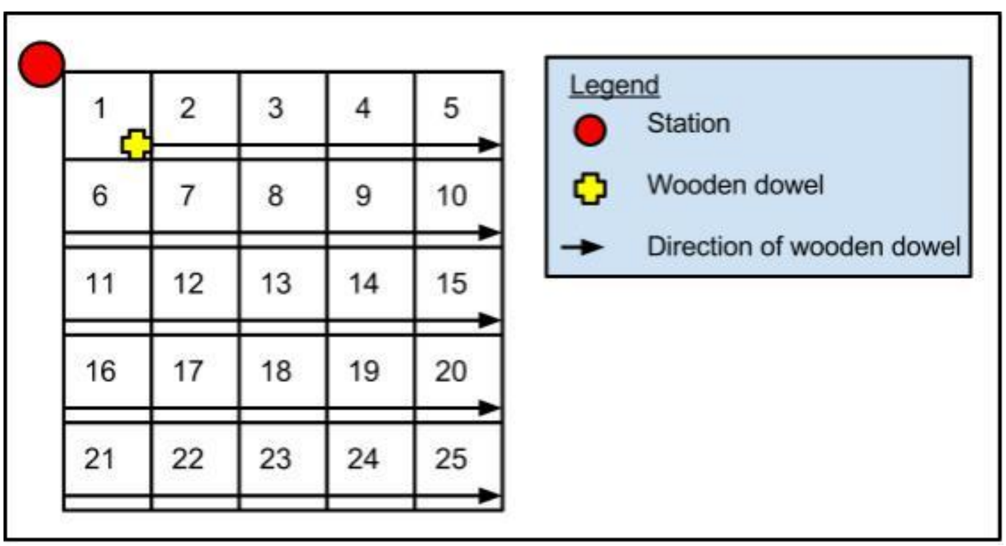

Figure 3.6 Pattern used for vegetation survey.

The species with the highest number of "hits" was considered the dominant species within the plot. The procedure was repeated at all of the stations within all of the study areas.

CHAPTER FOUR

RESULTS

4.1 Summary of Characteristics within Restoration and Reference

A total of 98 vegetation plots were sampled at the restoration sites which included Cogmagun River, St. Croix West and Walton River in 2010. The dominant vegetation as well as station information is listed in Appendix B. The dominant vegetation which came up the most often within the restoration marshes was non-vegetation, such as bare ground and dead material. The dominant vegetation which came up least often were *Atriplex glabriuscula*, *Elymus repens*, *Polygonum lapathifolium*, *Rubus allegheniensis*, *Solidago sempervirens*, and *Typha latifolia*. The elevation of the sampling plots within the restoration salt marshes ranged from 5.94 m CGVD 28 and 8.80 m CGVD 28. The distance to creek of the sampling plots within the marshes ranged from 2.97 m and maximum 90.07 m.

A total of 50 vegetation plots were sampled at the reference sites which included Cogmagun River and Walton River in 2010. The dominant vegetation as well as station information is listed in Appendix B. The dominant vegetation which came up the most often within the reference marshes was *Spartina patens*. The dominant vegetation which came up least often was *Festuca rubra*. The elevation of sampling plots within the restoration salt marshes ranged from 4.62 m CGVD 28 to 7.27 m CGVD 28. The distance to creek of sample plots within the marshes ranged 4.71 m to 80.87 m.

4.2 Geodetic Elevation and Vegetation Comparison

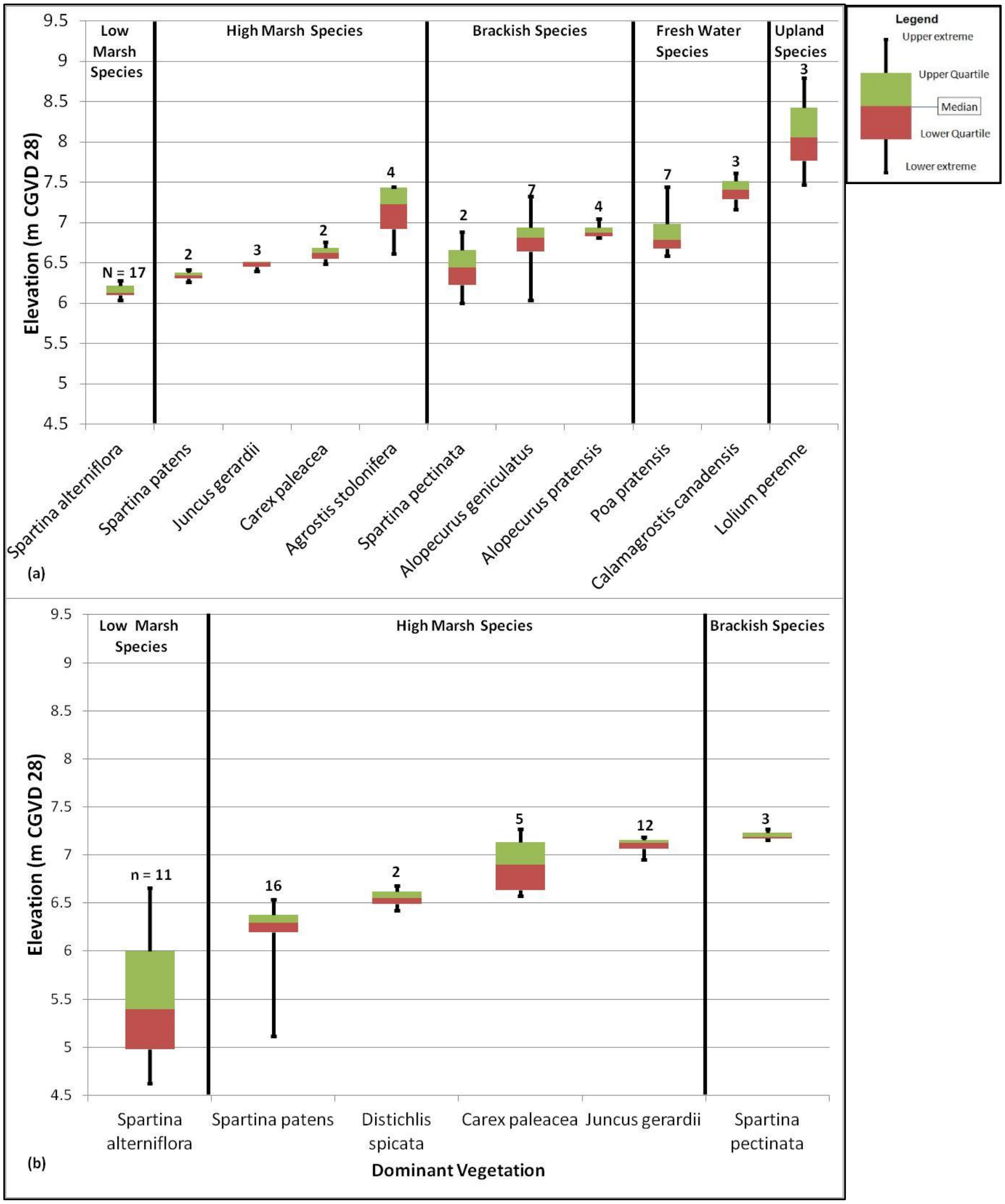

Figure 4.1 a) Range of elevation for dominant vegetation within restoration salt marshes b) Range of elevation for dominant vegetation within reference salt marshes.

Within restoration sites, 11 different plant species were found to be dominant whereas there were 6 different species found to be dominant within reference sites (Figure 4.1). The species have been placed into vegetation communities based on literature. These vegetation communities include low marsh, high marsh, brackish, fresh water and upland species. The species found within the restoration sites span low marsh to upland vegetation communities whereas the species within the reference sites span low marsh to brackish vegetation communities. The upland species within the restoration sites were found at sample plots within a range of elevation of 7.47 m CGVD 28 to 8.80 m CGVD 28. The reference sites did not have this elevation range as measured at the sample plots since the maximum elevation was 7.27 m CGVD 28 and no upland species were found to be dominant in the sample plots.

The median elevation for *Carex paleacea*, *Juncus gerardii*, *Spartina patens* and *Spartina pectinata* were at higher elevations at the reference sites than at the restoration sites. The only species to have a lower median elevation at the reference site as compared to the restoration site was *Spartina alterniflora*.

4.2.1 Comparison of Geodetic Elevation and Similar Vegetation Species

There were 5 similar species, *Carex paleacea*, *Juncus gerardii*, *Spartina alterniflora*, *Spartina patens* and *Spartina pectinata*, that were dominant at some of the sample plots at both the restoration and reference sites. The mean elevation of these species at the restoration and reference sites were compared using a two-sample t-test. There were three of these that did not have significantly different mean elevations between the restoration and reference sites which were *Carex paleacea* (T-test: df = 3.188, t = 1.473 and p-value = 0.232), *Spartina patens* (T-Test: df = 4.237, t = -1.163 and p-value = 0.306), and *Spartina pectinata* (T-test: df = 1.011, t = 1.737 and p-value = 0.330). The plots where *Juncus gerardii* resides within the restoration sites were found at significantly lower mean elevations than within the reference sites (T-test: df = 3.545, t = 15.212 and p-value = <0.001). The plots where *Spartina alterniflora* resides within the restoration sites were found at significantly higher mean elevations than within the reference sites (T-test: df = 10.161, t = -3.255, p-value = 0.008).

4.2.2 Range of Elevation

The range of elevation for four of the species, *Carex paleacea*, *Juncus gerardii*, *Spartina alterniflora*, and *Spartina patens*, studied is larger at the reference sites than at the restoration sites. The only species that had a smaller range of elevation at the reference sites than at the restoration sites is *Spartina pectinata*.

The range of elevation for sample plots which contained *Carex paleacea* at the reference sites is larger than at the restoration sites since at the reference sites it spans 0.69 m whereas at the restoration sites it spans 0.28 m.

The range of elevation for sample plots which contained *Juncus gerardii* at the reference sites is larger than at the restoration site since at the reference sites it spans 0.23 m whereas at the restoration sites it spans 0.11 m.

The range of elevation for sample plots which contained *Spartina alterniflora* at the reference sites is much larger than at the restoration sites since at the reference sites it spans 2.03 m whereas at the restoration sites it spans 0.24 m.

The range of elevation for sample plots which contained *Spartina patens* is much larger at the reference site than at the restoration sites since at the reference sites it spans 1.43 m whereas at the restoration sites it spans 0.15 m.

The range of elevation for sample plots which contained *Spartina pectinata* at the reference sites is smaller than at the restoration sites since this range at the reference sites it spans 0.11 m whereas at the restoration sites it spans 0.88 m.

CHAPTER FIVE

DISCUSSION & CONCLUSION

5.1. Discussion

The similar vegetation present within the restoration and reference marshes match those found within marshes along the Eastern North America as stated by Weis and Butler (2009). The salt marsh vegetation within the restoration sites that is trying to reach equilibrium is competing with existing fresh water and upland species. The vegetation community structure found within the reference marshes matches those found with New England salt marshes (Bertness, 1991; Crain et al., 2004). The low marsh was dominated by *Spartina alterniflora*, and the high marsh was dominated by *Spartina patens* on the seaward side and *Juncus gerardii* on the upland side.

5.1.1 Range of Elevation

Byers and Chmura found that the range of elevation for *Spartina alterniflora* and *Spartina patens* increased when there was an increase in tidal range (2007). Within the reference marshes, a larger range of elevation was found for *Spartina alterniflora* and *Spartina patens* than the other vegetation on the sites which agreed with these results (Byers and Chmura, 2007). The large tidal range within the reference sites in the upper Bay of Fundy and the increased range of *Spartina alterniflora* and *Spartina patens* may account for the lack of upland species on these sites.

The species which reside within the reference sites occur at ranges of elevation in a stepwise fashion from *Spartina alterniflora* dominating the low marsh to *Spartina pectinata* dominating the brackish section of the high marsh. Within the restoration sites, the species dominating each vegetation community do not occur in the same pattern as the reference sites. The zonation is however slowly appearing and it is felt that the pattern will emerge once the sites begin to reach a climax community (Bowron et al. 2011c, Mitsch and Gosselink, 2007). It is unclear as to how long this process will take. The species will begin to adjust the range of elevation in which they reside because of several factors which include tidal inundation, salinity and competition between species (Mudd et al., 2004; Bertness, 1991; Nixon 1982). The dominant species with the largest range of elevation within the reference sites, listing them in order of mean elevations from lower to higher are *Spartina alterniflora*, *Spartina patens* and *Carex paleacea*. The same pattern is evident in the restoration sites but at smaller ranges of elevation for each of these species. The low intertidal borders are influenced by abiotic conditions and the high intertidal borders are influenced by competition (Crain et al., 2004). It would seem then that the top elevation range in the restoration sites is influenced by competition with fresh water and upland species.

Juncus gerardii is within a very small range of elevation close to the upland within the reference sites as this species is not tolerant to water logging (Cooper, 1982) and salinity levels greater than 50ppt (Crain at al., 2004). Within restoration sites, *Juncus gerardii* is found within a range that is normally dominated by *Carex paleacea* and *Spartina patens*. *Juncus gerardii* may be at this range within the restoration sites because of competition, water logging and salinity. It cannot occupy the higher elevations in the restoration marsh due to the competition with the upland species that still occur. It can be assumed that *Juncus gerardii* is able to reside at these lower elevations because of a current lower salinity level and water logging. When a salt marsh is dyked and the tidal flow is eliminated, salts within the sediments begin to leach out causing the salinity of the soil to become extremely low (Byers and Chmura, 2007). As time passes after the dykes have been breached and tidal flows begin to bring salt water onto the marsh, it is expected that the salinity of the sediment will increase. At the time of this study, it had only been one year since the dykes at the Cogmagun and St. Croix West restoration sites had been breached. The increase in soil salinity will tend to eliminate *Juncus gerardii* at the current elevations but it will also inhibit the growth of competing upland species. Therefore, it is expected that *Juncus gerardii* will occur at higher elevations and the difference between the mean elevation at the reference and restoration sites will no longer be significantly different.

Spartina alterniflora was found at a significantly higher mean elevation at the restoration sites as compared to the reference sites. *Spartina alterniflora* is salt tolerant and is able to grow at lower elevations where the salinity is higher and the length of inundation is longer (Byers and Chmura, 2007). The higher mean elevation in the restoration sites seems mostly due to missing sampling data along the fringe marsh. This is the portion of the marsh outside of the dyke wall on the creek side. Also, a portion of what would be the low marsh is still occupied by the remnants of the dykes which are of a much higher elevation.

Sample plots which contained *Spartina pectinata* were found within a small range of elevation at the highest sampled elevations within the reference sites. This species was not refered to within the literature review in terms of range of elevation. The range of elevations within the restoration sites that *Spartina pectinata* resides at, is normally dominanted by *Carex paleacea*, *Spartina patens* and *Spartina alterniflora* as can be seen on the reference sites. Since *Spartina pectinata* and *Juncus gerardii* have similar higher range sizes within similar elevations at the reference sites, it can be expected that the factors which influence *Juncus gerardii* are similar to those that affect *Spartina pectinata*. *Juncus gerardii* is heavily influenced by high levels of salinity and extensive water logging. Therefore is not able exist in the lower elevations as seen within the reference sites. *Spartina pectinata* is able to extend its range into lower elevation because of current lower salinity levels and decreased water logging caused by the previous dyking and the elimination of tidal flow. *Spartina pectinata* within the restoration sites is unable to extend its upper range due to competition with upland species. As tidal water inundates the site and levels of salinity in the sediment increase, it is expected that the upland species will no longer be able to maintain their range and *Spartina pectinata* will be able to dominate higher elevations. Therefore, it is expected that *Spartina pectinata* will occur at higher elevations within the restoration sites and the difference between the mean elevation at the reference and restoration sites will no longer be significantly different.

5.2 Future Work

Sediment deposition, colonization by vegetation, and their inter-relationships are important factors in the development and growth of salt marshes. Knowledge of these factors is especially important in the restoration of these vital ecosystems.

The distribution of vegetation across the marsh surface is influenced by salinity of the sediment, duration of tidal flooding and competition between plant species. Several studies conducted within New England salt marshes, have explored these factors which influence the distribution of vegetation across the marsh (e.g. Crain et al., 2004; Bertness, 1992; Bertness, 1987; Bertness, 1991). A comprehensive study of these factors within the Bay of Fundy has not been conducted. It is vital to complete a comprehensive study which includes: sediment characteristics, elevation, distance to creek, inundation time, and soil salinity as each of these may affect vegetation community structure across the marsh surface. Once this study is complete, it will become more clear which factors are influencing vegetation community structure within Bay of Fundy salt marshes. From those factors a predictive model can be developed. The model will assist in determining the degree and pattern of re-establishment and distribution of vegetation within restoration sites since time of restoration. It can also help to determine which factors will need to be sampled to give a representative picture of what is occurring within each marsh. The model may be able to assist in determining which of several candidate sites would benefit the most from restoration activities.

Vegetation plays an important role in the deposition of inorganic sediment, compaction and accretion of organic matter. Studies have been completed on how vegetation enhances sedimentation and how this influence affects the sediment characteristics across the marsh surface (e.g.Townend et al., 2011; Leonard and Croft, 2006).

Understanding the distribution of vegetation across the marsh and how this affect the sediment will allow for better judgment on the location of sediment cores. Sediment cores are costly to process and if fewer cores need to be taken, it will lead to less costly projects. It is important that the study spans a few years of data instead of simply one as it appears changes in vegetation and sediment occur each year in restoration sites.

There are other options to restore a salt marsh excluding dyke breaches. The other options include excavating fill to form a dredged wetland, reintroducing species that were previously on the site, and opening tide gates to return tidal flow (Sullivan, 2001). It is important to identify how these other restoration methods affect the ultimate outcome and how quickly changes occur within the restoration site.

The compiling of data from reference sites that experience similar environmental conditions may ultimately eliminate the need for a paired reference site for each restoration site.

5.3 Conclusion

The goal of the research was to analyze the relationship between vegetation community structure and geodetic elevation within restoration and reference macrotidal salt marshes in the Bay of Fundy. Similar dominant vegetation were found within the restoration and reference sites. Within the reference sites, dominant species of vegetation were found at ranges of elevation in a stepwise fashion from low marsh vegetation at low elevations to brackish vegetation at high elevations. The same pattern is not readily evident within the restoration sites but three of the five similar species studied are found in the same stepwise order as within the reference sites. They are *Carex paleacea*, *Spartina patens* and *Spartina alterniflora*.

Juncus gerardii, *Spartina pectinata*, and *Spartina alterniflora* have significantly different means and ranges of elevation within the restoration and reference sites. This is due to salinity, frequency and duration of inundation, and competition.

Portions of the low marsh of the restoration sites were not included in the data analysis due to missing data and the remaining portions of the dykes. Both of these cause the exclusion of potential ranges of elevation for *Spartina alterniflora*. It is felt that the species will begin to dominate similar ranges of elevation in the restoration sites as compared to the rference sites with a longer time after the breaching of the dykes.

Elevation plays a key role in determining the intensity of abiotic and biotic factors which influence vegetation across the marsh surface. The areas at low elevations are inundated during each tide whereas areas at high elevations are only inundated during the highest tides. By being inundated more frequently and for longer periods of time, the salinity of the soil increases which influences the vegation that is able to survive. The opposite is found at higher elevations where inundation is less and the species which thrive are unable to tolerate being inundated frequently and are not tolerant of high levels of soil salinity. The species at high elevations must be good competitors in order to compete for growing space with not only the other salt marsh species studied but also with freshwater and upland species.

REFERENCES

Allen, J.R.L. 1990. Salt marsh growth and stratification: A numerical model with special reference to the Seven Estuary, southwest Britian, Maine Geology 95: 77-96.

Allen, J. R. L. 2000. Morphodynamics of Holocene salt marshes: a review sketch from the Atlantic and Southern North Sea coasts of Europe. *Quaternary Science Review*, 19: 1155- 1231.

Allen, J.R.L. and Pye, K. 1992. Coastal saltmarshes: their nature and significance. In. J.R.L. Allen and K. Pye (eds), *Saltmarshes: Morphodynamics, conservation and engineering significance.* Cambridge: Cambridge University Press, U.K., 1-18.

Aspden, R. J., Vardy, S. and Peterson, D. M. 2004. Salt marsh microbial ecology: Microbes, benthic mats and sediment movement. In Fagherazzi, S., Marani, M. and Blum (Eds.), *Coastal and Estuarine Studies: The Ecogeomorphology of Tidal Marhes* (pp. 115-136). Washington, DC: American Geophysical Union.

Beckman Coulter. 2009. Beckman Coulter: Multisizer 3 Coulter Counter Brochure.

Bertness, M.D. 1991. Interspecific interactions among high marsh perennials in a New England salt marsh. *Ecology* 72(1): 125-137.

Bertness, M. D. and Ellison, A. M. 1987. Determinants of pattern in a New England salt marsh plant community. *Ecological Monographs*, 57(2): 129 – 147.

Bertness, M. D., Gough, L. and Shumway, S. W. 1992. Salt tolerances and the distribution of fugitive salt marsh plants. *Ecology*, 73(5): 1842 – 1851.

Blott, S. J. and Pye, K. 2001. Gradistat: A grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Prcesses and Landforms*, 26: 1237-1248.

Blum, L. K. and Christian, R. R. 2004. Belowground protection and decomposition along a tidal gradient in a Virginia salt marsh. In Fagherazzi, S., Marani, M. and Blum (Eds.), *Coastal and Estuarine Studies: The Ecogeomorphology of Tidal Marhes* (pp. 47-73). Washington, DC: American Geophysical Union.

Bockelmann, A. C., Bakker, J. P., Neuhaus, R., and Lage, J. 2002. The relation between vegetation zonation, elevation and inundation frequency in a Wadden Sea salt marsh. *Aquatic Botany*, 73: 211 – 221.

Bowron, T. et al. 2011a. Post-Restoration Monitoring (Year 1) of the Cogmagun River Salt Marsh Restoration Project. Report for NSDTIR

Bowron, T. et al. 2011b. Post-Construction Monitoring (Year 1) for the St. Croix River High Salt Marsh and Floodplain Wetland Restoration Project. Report for NSDTIR

Bowron, T. et al. 2011c. Post-Construction Monitoring (Year 5) of the Walton River Salt Marsh Restoration Project. Report for NSDTIR

Broome, S.W., Seneca, E.D., and Woodhouse, W.W. JR., 1988. Tidal salt marsh restoration. *Aquatic Botany* 32: 1-22.

Burke, R.W. 1982. Free surface flow through salt marsh grass. Technical Report *WHOI-82-50*, Woods Hole Oceanographic Institution, Woods Hole, MA, 252p.

Byers, S. E. and Chmura, G. L. 2007. Salt marsh vegetation recovery on the Bay of Fundy. *Estuaries and Coasts*. 30(5): 869-877.

Cahoon, D.R., Day, J.W., and Reed, D.J. 1999. The influence of surface and shallow subsurface soil processes on wetland elevation: A synthesis. *Current topics in wetland biogeochemistry* 3:72-88.

Cahoon, D. R., Ford, M. A. and Hensel, P. F. 2004. Ecogeomorphology of *Spartina patens* – dominated tidal marshes: Soil organic matter accumulation, marsh elevation dynamics, and disturbance. In Fagherazzi, S., Marani, M. and Blum (Eds.), *Coastal and EstuarineStudies: The Ecogeomorphology of Tidal Marhes* (pp. 247 - 266). Washington, DC: American Geophysical Union.

Callaway, J.C. 2001. Hydrology and substrate. In: Zedler, J.B. *Restoring Tidal Wetlands*. Chapter 3, CRC Press, Boca Raton, California: 89 – 117.

Callaway, J.C, Sullivan, G., Desmond, J.S., Williams, G.D., and Zedler, J.B. 2001. Assessment and monitoring. In: Zedler, J.B. *Restoring Tidal Wetlands*. Chapter 6, CRC Press, Boca Raton, California: 271 – 336.

Chmura, G.L., Chase, P. and Bercovitch, J. 1997. Climatic controls on the middle marsh zone in the Bay of Fundy. Estuaries 20: 689-699.

Christiansen, T., Wiberg, P.L. and Milligan, T.G. 2000. Flow and sediment transport on a tidal salt marsh surface. *Estuarine Coastal and Shelf Science* 50(3): 315-331.

Cooper, A. 1982. The effects of salinity and waterlogging on the growth and cation uptake of salt marsh plants. *New Phytologist*, 90(2): 263:275.

Crain, C. M., Silliman, B. R., Bertness, S. L. and Bertness, M. D. 2004. Physical and biotic drivers of plant distribution across estuarine salinity gradients. *Ecology*, 85(9): 2539 – 2549.

Curran, K. J., Hill, P.S., Schell, T.M., Milligan, T.G and Piper, D.J.W. 2004. Inferring the mass fraction of floc-deposited mud: application to fine-grained turbidities. *Sedimentology*, 51: 927-944.

Davidson-Arnott, R. G. D., van Proosdij, D., Ollerhead, J., and Schostak, L. 2002. Hydrodynamics and sedimentation in salt marshes: examples from a macrotidal marsh, Bay of Fundy. *Geomorphology* 48: 209-231.

deGelleke, L 2011. Inverse Floc "Drawers" Model presentation. Sent via email September 16, 2011

Desplanque, C. and Mossman, D.J. 2004. Tides and their seminal impact on geology, geography, history, and socioeconomics of the Bay of Fundy, eastern Canada. *Atlantic Geology,* 40 (1): 1-130.

Desplanque, C. and Mossman, D.J. 2001. Bay of Fundy Tides *Geoscience Canada* 28 (1): 1-11.

ESRI. 2010. Vertical datums. *AcrGIS Resource Center: Desktop 10*. Retrieved March 7, 2013, from http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//003r00000015000000.htm.

Fagherazzi, S., Marani, M. and Blum, L.K. 2004. Introduction: The coupled evolution of geomorphological and ecosystem structures on salt marshes. In Fagherazzi, S., Marani, M. and Blum (Eds.), *Coastal and Estuarine Studies: The Ecogeomorphology of Tidal Marhes* (pp. 1-5). Washington, DC: American Geophysical Union.

French, J.R. and Spencer, T. 1993. Dynamics of sedimentation in a tide dominated backbarrier salt marsh, Norfolk, United Kingdom. *Marine Geology* 110: 315–331.

Friedrichs, C. T. and Perry, J.E. 2001. Tidal salt marsh morphodynamics: A synthesis. *Journal of Coastal Research.* SI(27): 7-37.

Gardener, L. R. 2004. Geologic history and the ergodic principle: Foundations for long-term ecological research in salt marshes. In Fagherazzi, S., Marani, M. and Blum (Eds.), *Coastal and Estuarine Studies: The Ecogeomorphology of Tidal Marhes* (pp. 189-207). Washington, DC: American Geophysical Union.

Greenberg, D.A., Petrie, B.D., Daborn, G.R. and Fader, G.B.J. 1997. Chapter Two: The physical environment of the Bay of Fundy. In Percy, J.A., Well, P.G. and Evans, A.J. (Eds) *Bay of Fundy Issues: A Scientific Overview*. Proceedings *of a Workshop, Wolfville Nova Scotia, January 29 – February 1 1996.* Environment Canada (Atlantic Region) Occasional Report No. 8, Dartmouth, N.S. and Sackville, N.B. Pages 11-36.

Hanson, A., Swanson, L., Ewing, D., Grabas, G., Meyer, S., Ross, L., Watmouth, M. and Kirkby, J. 2008. Wetlands Ecological Functions Assessments: An overview of Approachs. Canadian Wildlife Services Technical Report Series 497. Atlantic Region: 55pp.

Hinch, P. 2004. Moving toward integrated management of the Minas Basin: A capsule summary of progress. In Wells, P.G., Daborn, G.R., Percy, J.A., Harvey, J. and Rolston, S.J. (Eds) *Proceedings of the 5th Bay of Fundy Science Workshop and Coastal Forum "Taking the Pulse of the Bay", Wolfville, Nova Scotia, May 13-16, 2002*. Environment Canada (Atlantic Region) Occasional Report No. 21, Dartmouth, N.S. and Sackville, N.B. Pages 221-227.

Hsieh, Y.P. 2004. Dynamics of tidal salt barren formation and the record of present-day sea level change. In Fagherazzi, S., Marani, M. and Blum (Eds.), *Coastal and Estuarine Studies: The Ecogeomorphology of Tidal Marhes* (pp. 231 – 245). Washington, DC: American Geophysical Union.

Jacobson, H. and Jacobson Jr., G.L. 1987. Variability of vegetation in tidal marshes of Maine, USA. Canadian Journal of Botany 67: 230-238.

Jennings, S.C., Carter, R.W.G., Orford, J.D., 1993. Late Holocene salt marsh development under a regime of rapid relative sea level rise: Chezzetwok Inlet, N.S. Implications for the interpretation of paleo-marsh sequences. *Canadian Journal of Earth Sciences* 30: 1374-1384.

Jennings, S.C., Carter, R.W.G., Orford, J.D., 1995. Implications for sea-level research of salt marsh and mudflat accretionary processes along paraglacial barrier coasts. *Marine Geology* 124: 129-136.

Keddy, P. 1999. Wetland Resotoration: The potential for assembly rules in the service of conservation. *Wetlands* 19(4): 716-732.

Keusenkothen, M. A. and Christian, R. R. 2004. Responses of salt marshes to disturbances in an ecogeomorphological context, with a case study of trampling by deer. In Fagherazzi, S., Marani, M. and Blum (Eds.), *Coastal and Estuarine Studies: The Ecogeomorphology of Tidal Marhes* (pp. 203-230). Washington, DC: American Geophysical Union.

Krank, K. and Milligan, T. G. 1991. Grain Size in Oceanography. In Syvitski, J.P.M (Ed.), *Princliples, Methods, and Application of Particle Size Analysis* (pp. 332 – 345). New York: Cambridge University Press.

Lawrence, D.S.L., Allen, J.R.L., and Havelock, G.M. 2004. Salt marsh morphodynamics: An investigation of tidal flows and marsh channel equilibrium. *Journal of Coastal Research* 20(1): 301-316.

Leonard, L.A. 1997. Controls of sediment transport and deposition in an incised mainland marsh basin, southeastern North Carolina. *Wetlands* 19(3): 617-626.

Leonard, L. A. and Croft, A. L. 2006. The effect of standing biomass on flow velocity and turbulence in *Spartina alterniflora* canopies. *Estuarine, Coastal and Shelf Science* 69: 325 – 336.

Leonard, L.A. and Luther, M.E. 1995. Flow hydrodynamics in tidal marsh canopies. *Limnology and Oceanography* 40(8): 1474-1484.

Leonard, L. A. and Reed, D. J. 2002. Hydrodynamics and sediment transport through tidal marsh canopies. *Journal of Coastal Research* 36: 459-469.

Mitsch, W. J. and Gosselink, J. G. 2007. Wetland Ecosystem Development. *Wetlands 4th Edition* (pp. 231 – 258). Hoboken, New Jersey: John Wiley & Sons, Inc.

McCave, I.N., Hall, I. R. and Bianchi, G. G. 2006. Laser vs. settling velocity differences in silt grain size measurements: Estimation of palaeocurrent vigor. *Sedimentology*, 53:919 – 928.

Mudd, S. M., Fagherazzi, S., Morris, J. T. and Furbish, D. J. 2004. Flow, sedimentation and biomass production on a vegetated salt marsh in South Carolina: Toward a predictive model of marsh morphologic and ecologic evolution. In Fagherazzi, S., Marani, M. and Blum (Eds.), *Coastal and Estuarine Studies: The Ecogeomorphology of Tidal Marhes* (pp. 165-188). Washington, DC: American Geophysical Union.

Nepf, H.M. 2004. Vegetated Flow Dynamics. In Fagherazzi, S., Marani, M. and Blum (Eds.), *Coastal and Estuarine Studies: The Ecogeomorphology of Tidal Marhes* (pp. 137-163). Washington, DC: American Geophysical Union.

Nepf, H.M., Sullivan, J.A. and Zavistoski, R.A. 1997. A model for diffusion within emergent vegetation. *Limnology and Oceanography* 42: 1735-1745.

Nixon, S.W. 1982. The ecology of New England high salt marshes: A community profile. United States Department of the Interior, Washington, D.C., USA.

Nyman, J.A., Walters, R.J., DeLaune, R.D. and Patrick Jr., W.H. 2006. Marsh vertical accretion via vegetative growth. *Estuaries Coastal Shelf Science* 69(3-4): 370-380.

Pethick, J.S. 1992. Saltmarsh geomorphology. In: Allen, J.R.L. and Pye, K. (eds), *Saltmarshes: Morphodynamics, conservation and engineering significance.* Cambridge: Cambridge University Press: 41-62.

Pethick, J.; Leggett, D., and Husain, L., 1990. Boundary layers under salt marsh vegetation development in tidal currents. In: Thornes, J.B. (ed.), *Vegetation and Erosion*. London: Wiley: 113-124.

Reed, D.J. 1990. The impact of sea-level rise on coastal salt marshes. *Progress in Physical Geography*, 14(4): 465-481.

Reed, D. J., Spencer, T., Murray, A. L., French, J. R. and Leonard, L. 1999. Marsh surface sediment deposition and the role of tidal creeks: Implications for created and managed coastal marshes. *Journal of Coastal Conservation* 5: 81-90.

Shi, Z.; Pethick, J.S.; Burd, F., and Murphy, B., 1996. Velocity profiles in a salt marsh canopy. *Geo-Marine Letters* 16(4): 319-323.

Silvestri, S. and Marani, M. 2004. Salt marsh vegetation and morphology: Basic physiology, modelling and remote sensing observations. In Fagherazzi, S., Marani, M. and Blum (Eds.), *Coastal and Estuarine Studies: The Ecogeomorphology of Tidal Marhes* (pp. 5- 25). Washington, DC: American Geophysical Union.

Sullivan, G. 2001. Establishing vegetation in restored and created coastal wetlands. In: Zedler, J.B. *Restoring Tidal Wetlands*. Chapter 4, CRC Press, Boca Raton, California: 119-158.

Townend, I., Fletcher, C., Knappen, M., and Rossington, K. 2011. A review of salt marsh dynamics. *Water and Environment Journal.* 25: 477-488.

van Proosdij, D., Davidson-Arnott, R.G.D., Ollerhead, J. 2006. Controls on spatial patterns of sediment deposition across a macro-tidal salt marsh surface over single tidal cycles. *Estuarine, Coastal and Shelf Science,* 69: 64-86.

van Proosdij, D., Lundholm, J., Neatt, N., Bowron, T., and Graham, J. 2010. Ecological re-engineering of a freshwater impoundment for salt marsh restoration in a hypertidal system. *Ecological Engineering* 36: 1314-1332.

Warren, R. S., Fell, P.E., Rozsa, R., Brawley, A.H., Orsted, A.C., Olsen, E.T., Swamy, V., and Niering, W.A. 2002. Salt marsh restoration in Connecticut: 20 years of science and management. *Restoration Ecology* 10: 497–513.

Weis, J. S. and Butler, C. A. 2009. Salt Marshes: a natural and unnatural history. Rutgers University Press, New Jersey: 1-254.

APPENDIX A: SEDIMENT CHARACTERISTICS

Summary of sediment characteristics for Cogmagun River restoration site. (Symbols for DIGS: m = Source slope, Rolloff Diameter = (dhat), Floc Limit = (df) and Floc Fraction = (Kf))

Site	Station ID	Water Content (%)	Organic Matter (%)	Bulk Density (g/cm^3)	Mean Grain Size (µm)	Mean Grain Size (Description)	m	*dhat* (µm)	d_f (µm)	K_f
COG	L1S1	73.18	36.37	0.34	9.596	Medium Silt	0.37	14	14	0.66
COG	L1S4	31.76	7.32	0.97	7.273	Fine Silt	0.19	15	15	0.74
COG	L2S2	50.00	9.72	0.55	8.838	Medium Silt	0.19	16	14	0.67
COG	L3S2	63.02	13.26	0.41	8.820	Medium Silt	0.53	14	14	0.67
COG	L3S4	39.51	13.43	0.66	8.995	Medium Silt	0.42	15	13	0.64
COG	L4S4	38.28	9.51	0.81	8.650	Medium Silt	0.43	13	13	0.66
COG	L5S2	76.88	30.66	0.22	10.256	Medium Silt	0.65	16	14	0.63
COG	L5S4	52.07	12.08	0.51	9.816	Medium Silt	0.23	18	12	0.57

Summary of sediment characteristics for Cogmagun River reference site. (Symbols for DIGS: m = Source slope, Rolloff Diameter = (dhat), Floc Limit = (df) and Floc Fraction = (Kf))

Site	Station ID	Water Content (%)	Organic Matter (%)	Bulk Density (g/cm^3)	Mean Grain Size (µm)	Mean Grain Size (Description)	m	*dhat* (µm)	d_f (µm)	K_f
COG-R	L1S4	32.80	8.92	1.02	8.579	Medium Silt	0.56	13	14	0.70
COG-R	L2S1	70.96	32.85	0.22	7.392	Fine Silt	0.52	12	15	0.76
COG-R	L2S3	54.38	11.28	0.71	9.837	Medium Silt	0.16	16	9	0.49
COG-R	L2S5	32.56	2.05	1.14	7.531	Fine Silt	0.62	12	15	0.76
COG-R	L3S2	58.71	16.39	0.49	10.135	Medium Silt	0.51	14	14	0.64
COG-R	L4S1	56.76	16.22	0.34	10.048	Medium Silt	0.27	18	15	0.66
COG-R	L4S3	46.47	11.53	0.85	7.481	Fine Silt	0.56	11	12	0.69
COG-R	L5S2	49.85	11.29	0.69	7.707	Fine Silt	0.45	12	13	0.71

Summary of sediment characteristics for St. Croix West restoration site. (Symbols for DIGS: m = Source slope, Rolloff Diameter = (dhat), Floc Limit = (df) and Floc Fraction = (Kf))

Site	**Station ID**	**Water Content (%)**	**Organic Matter (%)**	**Bulk Density (g/cm^3)**	**Mean Grain Size (μm)**	**Mean Grain Size (Description)**	**m**	***dhat* (μm)**	**d_f (μm)**	**K_f**
SCW	L1S1	32.55	3.73	1.13	6.480	Fine Silt	0.17	13	7	0.51
SCW	L1S2	42.39	5.41	1.07	7.261	Fine Silt	0.39	15	14	0.70
SCW	L1S3	23.83	5.90	1.07	9.611	Medium Silt	0.44	18	14	0.60
SCW	L2S1	32.66	4.71	1.03	5.922	Fine Silt	0.51	10	9	0.64
SCW	L2S2	31.51	4.37	1.15	8.001	Medium Silt	0.45	17	12	0.62
SCW	L2S4	31.04	5.90	1.12	7.588	Fine Silt	0.52	16	12	0.63
SCW	L3S1	35.06	4.55	1.10	6.849	Fine Silt	0.65	11	9	0.59
SCW	L3S3	38.40	31.05	0.64	8.036	Medium Silt	0.73	11	12	0.67
SCW	L3S4	38.44	4.41	0.89	9.526	Medium Silt	0.42	10	11	0.58
SCW	L3S5	19.38	2.78	1.30	8.511	Medium Silt	0.30	26	12	0.58
SCW	L4S2	36.65	8.22	0.95	8.008	Medium Silt	0.55	16	14	0.67
SCW	L4S3	35.19	15.93	0.85	8.039	Medium Silt	0.44	9	6	0.43
SCW	L4S4	36.91	4.30	1.07	7.240	Fine Silt	0.44	13	9	0.56
SCW	L4S5	38.74	4.78	0.93	7.104	Fine Silt	0.38	14	11	0.64
SCW	L4S7	18.36	4.01	1.35	9.284	Medium Silt	0.49	14	9	0.46
SCW	L4S8	35.43	3.78	1.15	9.386	Medium Silt	0.47	12	11	0.55
SCW	L5S1	45.40	4.98	0.78	7.252	Fine Silt	0.63	11	9	0.60
SCW	L5S2	51.55	6.12	0.67	6.734	Fine Silt	0.51	9	8	0.57
SCW	L5S3	42.87	4.52	0.88	7.894	Fine Silt	0.48	12	9	0.53
SCW	L5S4	33.02	4.41	1.32	8.357	Medium Silt	0.53	18	12	0.58
SCW	L5S5	34.75	4.16	1.02	9.396	Medium Silt	0.35	10	9	0.50
SCW	L5S6	40.51	4.07	0.91	6.316	Fine Silt	0.47	11	9	0.61
SCW	L5S8	40.94	5.67	0.95	10.724	Medium Silt	0.49	15	12	0.60
SCW	L5S9	24.31	3.60	1.06	9.673	Medium Silt	0.44	19	14	0.60
SCW	N01	39.61	5.34	0.88	6.592	Fine Silt	0.51	12	9	0.58
SCW	N02	32.33	3.74	1.08	4.347	Fine Silt	0.43	11	9	0.59
SCW	N03	35.67	4.17	1.12	6.056	Fine Silt	0.38	17	12	0.57
SCW	N04	26.89	6.36	1.20	5.157	Fine Silt	0.40	15	12	0.63
SCW	N05	38.55	4.44	1.02	6.155	Fine Silt	0.42	40	12	0.51

Continuation of sediment characteristics for St. Croix West restoration site. (Symbols for DIGS: m = Source slope, Rolloff Diameter = (*dhat*), Floc Limit = (d_f) and Floc Fraction = (K_f))

Site	Station ID	Water Content (%)	Organic Matter (%)	Bulk Density (g/cm^3)	Mean Grain Size (µm)	Mean Grain Size (Description)	m	*dhat* (µm)	d_f (µm)	K_f
SCW	Y06	29.77	5.86	1.08	9.593	Medium Silt	0.39	16	11	0.53
SCW	Y07	46.11	4.72	0.73	8.561	Medium Silt	0.33	20	9	0.51
SCW	Y08	39.02	4.34	1.09	8.001	Medium Silt	0.45	13	11	0.60
SCW	Y09	37.07	3.96	1.00	7.301	Fine Silt	0.30	15	9	0.56
SCW	Y10	35.96	3.96	1.08	7.844	Fine Silt	0.53	10	9	0.55
SCW	Y11	37.46	4.63	0.89	5.768	Fine Silt	0.57	9	8	0.61
SCW	Y13	35.62	3.88	1.08	9.616	Medium Silt	0.44	14	9	0.53
SCW	Y14_Y02	42.41	4.33	0.79	8.010	Medium Silt	0.51	15	12	0.62
SCW	Y15	32.01	9.63	1.11	7.587	Fine Silt	0.49	14	11	0.60
SCW	Y16	36.45	4.88	1.13	7.908	Fine Silt	0.42	13	9	0.55
SCW	Y17	35.25	5.29	0.95	8.621	Medium Silt	0.38	14	11	0.55
SCW	Y18	32.06	5.05	0.82	8.942	Medium Silt	0.45	10	9	0.50
SCW	Y19	40.79	5.05	0.96	8.043	Medium Silt	0.46	12	12	0.63
SCW	Y20	36.97	9.49	0.83	8.090	Medium Silt	0.63	13	9	0.52
SCW	Y21	37.73	3.99	1.22	8.345	Medium Silt	0.48	11	9	0.53
SCW	Y22	35.75	3.99	1.00	8.390	Medium Silt	0.46	15	12	0.61
SCW	Y23	34.27	4.12	1.10	8.365	Medium Silt	0.37	9	9	0.53
SCW	Y24	40.57	4.72	0.99	7.039	Fine Silt	0.37	11	8	0.56

Summary of sediment characteristics for Walton River restoration site. (Symbols for DIGS: m = Source slope, Rolloff Diameter = (dhat), Floc Limit = (df) and Floc Fraction = (Kf))

Site	Station ID	Water Content (%)	Organic Matter (%)	Bulk Density (g/cm^3)	Mean Grain Size (µm)	Mean Grain Size (Description)	m	*dhat* (µm)	d_f (µm)	K_f
WS	L1S2	59.98	13.32	N/A	10.730	Medium Silt	0.54	11	9	0.55
WS	L1S3	47.63	10.26	0.81	9.390	Medium Silt	0.53	13	12	0.63
WS	L1S4	43.86	7.33	0.70	8.240	Medium Silt	0.43	13	12	0.66
WS	L5S2	51.97	7.19	0.72	8.280	Medium Silt	0.51	12	12	0.66
WS	L5S3	50.67	9.93	0.79	9.530	Medium Silt	0.36	15	12	0.63
WS	L5S5	47.11	9.19	0.75	8.090	Medium Silt	0.44	12	12	0.66

Summary of sediment characteristics for Walton River restoration site. (Symbols for DIGS: m = Source slope, Rolloff Diameter = (dhat), Floc Limit = (df) and Floc Fraction = (Kf))

Site	Station ID	Water Content (%)	Organic Matter (%)	Bulk Density (g/cm^3)	Mean Grain Size (µm)	Mean Grain Size (Description)	m	*dhat* (µm)	d_f (µm)	K_f
WRS	L1S1	63.10	21.70	0.44	8.559	Medium Silt	0.65	12	13	0.67
WRS	L1S2	57.91	9.51	0.51	9.171	Medium Silt	0.67	13	13	0.64
WRS	L1S3	54.21	11.93	0.69	8.721	Medium Silt	0.39	15	14	0.68
WRS	L3S2	57.47	12.15	N/A	8.867	Medium Silt	0.53	14	14	0.68
WRS	L3S5	55.66	9.60	0.59	7.575	Fine Silt	0.38	13	13	0.70
WRS	L3S8	41.47	7.33	0.84	7.768	Fine Silt	0.44	13	12	0.67

APPENDIX B: STATION INFORMATION AND DOMINANT VEGETATION

Summary of station location information and dominant vegetation for Cogmagun River restoration site.

Site	Station ID	Easting	Northing	Elevation (m CGVD 28)	Distance to Creek (m)	Dominant Vegetation
COG	L1S1	411012.84	4992271.42	7.50	34.19	*Typha latifolia*
COG	L1S2	410980.01	4992304.14	6.77	19.24	*Atriplex glabriuscula*
COG	L1S3	410941.29	4992341.91	6.58	13.76	Bare Ground
COG	L1S4	410905.35	4992376.90	6.66	12.33	Bare Ground
COG	L1S5	410879.78	4992401.95	6.63	10.02	Bare Ground
COG	L2S1	411031.35	4992280.41	7.17	52.89	*Calamagrostis canadensis*
COG	L2S2	410999.30	4992318.51	6.74	43.29	Bare Ground
COG	L2S3	410967.75	4992357.06	6.74	30.99	Bare Ground
COG	L2S4	410948.87	4992380.33	6.76	10.13	Bare Ground
COG	L2S5	410931.47	4992401.58	6.75	8.91	Bare Ground
COG	L3S1	411050.46	4992298.95	6.88	75.74	*Spartina pectinata*
COG	L3S2	411022.27	4992339.58	6.76	42.31	Dead Material
COG	L3S3	410996.20	4992376.65	6.77	8.20	Bare Ground
COG	L3S4	410982.89	4992396.46	6.77	9.93	Bare Ground
COG	L4S1	411139.79	4992244.65	7.02	54.36	*Agrostis stolonifera*
COG	L4S2	411110.43	4992284.82	6.74	57.88	Dead Material
COG	L4S3	411081.22	4992325.16	6.80	50.45	Dead Material
COG	L4S4	411051.90	4992365.67	6.84	13.24	Dead Material
COG	L4S5	411032.70	4992392.70	6.75	11.61	Dead Material
COG	L5S1	411192.27	4992211.88	7.32	17.18	*Poa palustris*
COG	L5S2	411166.88	4992254.91	6.79	25.52	Dead Material
COG	L5S3	411141.25	4992297.70	6.78	25.02	Dead Material
COG	L5S4	411115.93	4992340.18	6.81	21.57	Bare Ground
COG	L5S5	411087.91	4992386.50	6.87	11.26	Dead Material

Summary of station location information and dominant vegetation for Cogmagun River reference site.

Site	Station ID	Easting	Northing	Elevation (m CGVD 28)	Distance to Creek (m)	Dominant Vegetation
COG-R	L1S1	412013.05	4992990.04	7.27	56.87	*Spartina pectinata*
COG-R	L1S2	412022.65	4992940.93	6.66	15.49	*Spartina alterniflora*
COG-R	L1S3	412032.05	4992891.86	6.95	10.82	*Juncus gerardii*
COG-R	L1S4	412041.53	4992842.82	7.18	10.62	*Juncus gerardii*
COG-R	L1S5	412051.02	4992794.10	5.90	10.23	*Spartina alterniflora*
COG-R	L2S1	412066.58	4993014.31	7.16	63.64	*Spartina pectinata*
COG-R	L2S2	412074.06	4992964.92	7.01	14.81	*Juncus gerardii*
COG-R	L2S3	412081.61	4992915.57	7.03	37.13	*Juncus gerardii*
COG-R	L2S4	412089.13	4992866.13	7.12	40.49	*Juncus gerardii*
COG-R	L2S5	412096.69	4992816.62	7.10	38.78	*Festuca rubra*
COG-R	L2S6	412099.89	4992789.27	5.71	31.87	*Spartina alterniflora*
COG-R	L3S1	412126.92	4993007.96	7.19	80.87	*Spartina pectinata*
COG-R	L3S2	412131.43	4992958.26	7.14	62.12	*Juncus gerardii*
COG-R	L3S3	412135.83	4992908.52	7.08	29.87	*Juncus gerardii*
COG-R	L3S4	412140.42	4992858.68	7.12	25.11	*Juncus gerardii*
COG-R	L3S5	412145.36	4992811.61	5.33	30.19	*Spartina alterniflora*
COG-R	L4S1	412181.62	4992982.62	7.14	79.06	*Carex paleacea*
COG-R	L4S2	412187.62	4992932.90	7.15	51.55	*Juncus gerardii*
COG-R	L4S3	412192.40	4992892.12	7.18	33.25	*Juncus gerardii*
COG-R	L4S4	412198.43	4992851.65	5.39	26.93	*Spartina alterniflora*
COG-R	L5S1	412240.42	4992991.30	7.12	28.50	*Juncus gerardii*
COG-R	L5S2	412255.09	4992943.58	7.16	27.15	*Juncus gerardii*
COG-R	L5S3	412270.97	4992898.10	4.97	28.82	*Spartina alterniflora*

Summary of station location information and dominant vegetation for St. Croix West restoration site.

Site	Station ID	Easting	Northing	Elev.	Distance to Creek (m)	Dominant Vegetation
SCW	L1S1	418590.33	4980311.48	6.70	5.20	Bare Ground
SCW	L1S2	418607.78	4980320.87	7.04	24.98	*Alopecurus geniculatus*
SCW	L1S3	418625.35	4980330.28	8.80	32.57	*Lolium perenne*
SCW	L2S1	418619.64	4980242.92	6.91	7.53	*Elymus repens*
SCW	L2S2	418658.30	4980253.38	7.45	29.35	*Poa pratensis*
SCW	L2S4	418735.53	4980272.79	7.43	18.53	*Agrostis stolonifera*
SCW	L3S1	418621.85	4980168.51	6.79	7.43	*Poa pratensis*
SCW	L3S3	418705.10	4980193.63	8.12	56.33	*Rubus allegheniensis*
SCW	L3S4	418735.43	4980204.70	6.83	61.20	*Alopecurus geniculatus*
SCW	L3S5	418773.14	4980218.36	7.46	30.57	Bare Ground
SCW	L4S2	418593.28	4980095.18	6.91	28.17	*Alopecurus pratensis*
SCW	L4S3	418628.71	4980077.03	7.10	24.52	*Poa pratensis*
SCW	L4S4	418666.04	4980062.58	6.55	52.52	Bare Ground
SCW	L4S5	418703.35	4980048.34	6.81	90.07	*Alopecurus geniculatus*
SCW	L4S7	418777.91	4980019.64	7.47	43.85	*Lolium perenne*
SCW	L4S8	418805.12	4980010.38	6.00	15.16	*Spartina pectinata*
SCW	L5S1	418459.56	4980039.22	6.04	16.38	*Alopecurus geniculatus*
SCW	L5S2	418498.65	4980030.71	6.25	34.20	Standing Water
SCW	L5S3	418537.93	4980022.22	6.32	59.44	Standing Water
SCW	L5S4	418576.81	4980013.55	6.59	25.68	*Poa pratensis*
SCW	L5S5	418615.81	4980005.11	6.65	14.22	*Poa pratensis*
SCW	L5S6	418653.71	4979991.70	6.61	28.50	Mud
SCW	L5S8	418732.79	4979979.11	7.05	28.99	*Alopecurus pratensis*
SCW	L5S9	418771.14	4979970.11	8.06	20.83	*Lolium perenne*
SCW	N01	418590.51	4980121.50	6.71	11.88	*Poa pratensis*
SCW	N02	418664.29	4980290.43	7.11	15.17	Bare Ground
SCW	N03	418747.68	4980144.99	6.90	5.34	Bare Ground
SCW	N04	418739.18	4980248.46	7.17	35.05	Bare Ground
SCW	N05	418796.98	4980022.18	6.76	27.10	*Carex paleacea*
SCW	Y06	418758.11	4979935.42	7.45	16.18	*Agrostis stolonifera*
SCW	Y07	418721.41	4979934.52	6.67	16.93	*Alopecurus geniculatus*
SCW	Y08	418680.52	4979951.91	6.86	6.88	*Poa pratensis*
SCW	Y09	418641.64	4979961.15	6.68	3.51	*Polygonum lapathifolium*
SCW	Y10	418521.47	4980001.14	6.54	71.40	*Juncus effusus*

Continuation of station location information and dominant vegetation for St. Croix West restoration site.

Site	**Station ID**	**Easting**	**Northing**	**Elev.**	**Distance to Creek (m)**	**Dominant Vegetation**
SCW	Y11	418466.17	4980007.54	6.47	44.02	Dead Material
SCW	Y13	418573.20	4980041.03	6.60	29.58	*Alopecurus geniculatus*
SCW	Y14_ Y02	418510.91	4980083.39	6.36	6.53	*Juncus effusus*
SCW	Y15	418529.92	4980107.88	6.33	5.95	Bare Ground
SCW	Y16	418637.91	4980137.75	6.81	32.74	*Alopecurus pratensis*
SCW	Y17	418628.15	4980211.40	6.84	10.76	*Alopecurus pratensis*
SCW	Y18	418600.88	4980368.34	7.62	15.56	*Calamagrostis canadensis*
SCW	Y19	418802.16	4980187.41	7.33	26.46	*Alopecurus geniculatus*
SCW	Y20	418809.94	4980150.01	7.41	20.81	*Calamagrostis canadensis*
SCW	Y21	418645.31	4980025.74	6.63	38.11	Bare Ground
SCW	Y22	418668.57	4980020.61	6.66	59.29	Bare Ground
SCW	Y23	418720.93	4980142.11	6.81	9.43	Bare Ground
SCW	Y24	418741.40	4980155.15	6.86	14.14	Bare Ground

Summary of station location information and dominant vegetation for Walton River restoration site.

Site	Station ID	Easting	Northing	Elevation (m CGVD 28)	Distance to Creek (m)	Dominant Vegetation
WS	L1S1	422429.94	5007994.80	6.40	37.44	*Juncus gerardii*
WS	L1S2	422424.56	5007955.46	6.11	48.01	*Spartina alterniflora*
WS	L1S3	422418.97	5007915.91	6.28	64.13	*Solidago sempervirens*
WS	L1S4	422413.51	5007876.36	6.19	24.27	*Spartina alterniflora*
WS	L2S1	422362.97	5008013.93	6.62	14.47	*Agrostis stolonifera*
WS	L2S2	422355.51	5007975.07	6.05	24.98	*Spartina alterniflora*
WS	L2S3	422347.86	5007935.84	6.12	25.81	*Spartina alterniflora*
WS	L3S1	422295.79	5008034.03	6.51	26.79	*Juncus gerardii*
WS	L3S2	422290.39	5007994.58	6.10	10.93	*Spartina alterniflora*
WS	L3S3	422285.20	5007954.97	6.07	2.97	*Spartina alterniflora*
WS	L3S4	422279.82	5007915.65	6.07	7.61	*Spartina alterniflora*
WS	L4S1	422231.65	5008061.42	6.48	32.76	*Carex paleacea*
WS	L4S2	422224.63	5008022.26	6.04	8.52	*Spartina alterniflora*
WS	L4S3	422217.11	5007983.04	6.11	38.14	*Spartina alterniflora*
WS	L4S4	422209.68	5007943.81	6.09	24.37	Standing Water
WS	L4S5	422202.43	5007904.66	6.24	35.05	*Spartina alterniflora*
WS	L5S1	422170.20	5008095.05	6.50	48.73	*Juncus gerardii*
WS	L5S2	422163.73	5008055.87	5.94	9.88	N/A
WS	L5S3	422157.05	5008016.60	6.14	29.21	*Spartina alterniflora*
WS	L5S4	422150.39	5007977.45	6.28	49.80	*Spartina alterniflora*
WS	L5S5	422143.74	5007938.23	6.13	47.90	*Spartina alterniflora*
WS	L5S6	422137.07	5007899.09	6.22	16.14	*Spartina alterniflora*
WS	L6S1	422120.96	5008151.52	6.42	37.84	*Spartina patens*
WS	L6S2	422114.80	5008112.20	6.22	32.50	*Spartina alterniflora*
WS	L6S3	422108.79	5008072.75	6.13	26.64	*Spartina alterniflora*
WS	L6S4	422102.65	5008033.32	6.27	16.52	*Spartina patens*
WS	L6S5	422096.56	5007993.93	6.23	5.99	*Spartina alterniflora*

Summary of station location information and dominant vegetation for Walton River reference site.

Site	Station ID	Easting	Northing	Elevation (m CGVD 28)	Distance to Creek (m)	Dominant Vegetation
WRS	L1S1	421934.40	5008010.99	6.58	20.36	*Carex paleacea*
WRS	L1S2	421942.48	5008049.99	6.12	20.01	*Spartina alterniflora*
WRS	L1S3	421950.42	5008087.89	6.22	19.68	*Spartina patens*
WRS	L1S4	421958.60	5008127.77	5.94	16.90	*Spartina patens*
WRS	L1S5	421960.18	5008148.30	4.62	11.75	*Spartina alterniflora*
WRS	L2S1	421888.00	5008027.09	6.63	53.79	*Carex paleacea*
WRS	L2S2	421890.11	5008066.82	6.41	59.25	*Spartina patens*
WRS	L2S3	421892.53	5008106.55	6.30	39.53	*Spartina patens*
WRS	L2S4	421895.08	5008146.27	6.29	21.30	*Spartina patens*
WRS	L2S5	421897.73	5008186.20	6.31	10.06	*Spartina patens*
WRS	L2S6	421900.47	5008226.00	6.38	38.01	*Spartina patens*
WRS	L2S7	421903.57	5008265.43	5.11	14.12	*Spartina patens*
WRS	L2S8	421904.15	5008267.06	4.99	12.48	*Spartina alterniflora*
WRS	L3S1	421837.58	5008031.15	7.27	58.61	*Carex paleacea*
WRS	L3S2	421840.19	5008047.81	6.68	53.59	*Distichlis spicata*
WRS	L3S3	421844.07	5008070.45	6.54	44.08	*Spartina patens*
WRS	L3S4	421850.71	5008109.78	6.29	4.71	*Spartina patens*
WRS	L3S5	421857.39	5008148.04	6.37	28.82	*Spartina patens*
WRS	L3S6	421864.12	5008188.31	6.23	9.60	*Spartina patens*
WRS	L3S7	421870.79	5008227.55	6.43	13.21	*Distichlis spicata*
WRS	L3S8	421877.36	5008265.88	6.10	27.16	*Spartina alterniflora*
WRS	L4S1	421789.19	5008034.05	6.90	30.12	*Carex paleacea*
WRS	L4S2	421790.91	5008073.88	6.20	9.76	*Spartina patens*
WRS	L4S3	421792.84	5008113.60	6.11	5.75	*Spartina patens*
WRS	L4S4	421794.80	5008152.50	6.48	37.54	*Spartina patens*
WRS	L4S5	421797.08	5008193.25	6.18	25.52	*Spartina patens*
WRS	L4S6	421799.23	5008233.17	4.71	9.74	*Spartina alterniflora*