Spatial and Temporal Variations in Sediment Composition Within Newly Restored Salt Marshes

by

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ABSTRACT

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Salt marsh ecosystems are highly vulnerable to climate change and sea-level rise. Adaptation strategies such as managed realignment, or dyke realignment, allow for the growth of new salt marsh in areas where one had been previously destroyed through dyking by historical settlers. Two newly restored salt marshes in the Bay of Fundy were monitored through this study. The spatial and temporal variations in water content, organic matter content, organic carbon content and sediment grain size were examined across the salt marsh surfaces. This study found that newly restored salt marshes in the Bay of Fundy can sequester carbon immediately after restoration. Carbon sequestration values resemble those in previously restored marshes in the surrounding areas. This study determined that there is a spatial variation in sediment characteristics across the salt marsh surface. This spatial variation is tied to varying elevation within the tidal frame. Spatial variations of sediment characteristics are not exclusively consistent over time but do tend to follow the same patterns. The sediment characteristics measured at both newly restored salt marshes used in this study were compared to previously restored salt marshes in Nova Scotia. All sediment characteristics data falls within similar ranges, creating a better understanding of what sediment characteristics to expect when restoring a salt marsh in the Bay of Fundy.

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CHAPTER 1

Introduction

As climate change and consequent sea-level rise threaten coastal ecosystems, it becomes increasingly important to develop new adaptation and mitigation strategies to protect human infrastructure. Dyke realignment and salt marsh restoration processes are still relatively new climate change adaptation strategies in Canada. The process of managed realignment has been adopted in the Bay of Fundy to help increase coastal protection for various anthropogenic structures such as buildings, roads and agricultural lands. It is necessary to conduct thorough post-monitoring programs to understand the processes that occur after managed realignment as the salt marsh is re-established. The data collected during this post monitoring will help develop a framework regarding what to expect following managed realignment and help make predictions about future similar sites. The restoration trajectory of salt marshes within managed realignment sites in the Upper Bay of Fundy is still yet to be entirely determined and understood.

1.1 Climate Change Threat to Coasts

Globally, humans and ecosystems are experiencing the effects of climate change, such as an increased frequency of extreme weather events, increased desertification and land degradation (Oppenheimer et al., 2019). Impact on ecosystems includes loss of biodiversity, thawing of permafrost, soil carbon loss, and other carbon sinks (IPCC, 2019). Coastal ecosystems such as salt marshes are highly vulnerable to climate change, explained by their exposure to sea-level rise. Through multiple processes, coastal wetlands can grow and respond to sea-level change

(Pratolongo et al., 2019). Coastal wetlands react to changes in relative sea level, defined as the height of the sea compared to the land in that area (Khan et al., 2015). If the relative sea-level changes, the ecological state of the wetland changes causing a shift in the plant habitats due to differences in the hydrologic conditions (Khan et al., 2015). When water conditions within the site change, plants will be forced to migrate landward to regain the same hydrological conditions that were present before. However, one of the concerns regarding rapid sea-level rise is the uncertainty surrounding the ability of coastal wetlands to keep up with the changes (Reed, 1990; Boorman et al., 1989; Kirwan et al.).

Climate change and overall warming will change the complex network of processes and services produced by wetlands. Overall, there are still many questions surrounding the impacts of climate change on coastal wetlands. Greenhouse gases are a primary cause of climate change, and although coastal wetlands are considered excellent carbon sinks (Chmura et al., 2003), it is unknown to what extent. Other factors, such as nutrients and precipitation, which may limit plant growth, could potentially prevent wetlands from remaining excellent carbon sinks (Pratolongo et al., 2019; Rozema et al., 1991). This uncertainty points to the need to understand the ecomorphodynamic feedback and the complexity of the wetland system response. Most models (Spencer et al., 2016; Ward et al., 2016; Schuerch et al., 2018) must simplify the system. The variabilities regarding sediment properties must be investigated to fill this gap.

1.1.1 Coastal Development Threatening Coastal Areas

Barbier et al. (2011) estimate that 50% of salt marshes worldwide have been victims of coastal development. Coastal development can cause the complete loss of natural land, it can fragment coastal habitats, and it can lead to higher erosion levels which in turn drive higher levels of pollution to enter the coastal and marine environments (Giuliani & Bellucci, 2019: Sheppard, 2019).

Salt marshes have been converted and used for multiple different human activities over the years. Agriculture is the most significant anthropogenic cause of salt marsh loss (Glover and Higham, 1996). Building dykes to protect agricultural lands from flooding is the most extensive alteration of salt marsh ecosystems that humans have created (Mendelssohn and Morris, 1999). Dykes are found on many salt marshes not only in Nova Scotia but around the world. Seventy percent of the salt marshes in the Bay of Fundy are estimated to have been dyked for agricultural reasons (Gordon and Cranford, 1994). This conversion to agricultural land has caused the degradation and destruction of 65% of the Atlantic Canada salt marshes (Pratolongo et al., 2019). A technique called dyke realignment was adopted to restore the salt marshes.

1.2 Salt Marshes

Salt marshes are coastal wetland ecosystems found near saltwater bodies. They depend on tides to flood and drain the wetland surface for growth. They can form in areas protected from intense wave energy in the upper intertidal zone in mid and high latitudes (Davidson-Arnott et al., 2002). Shelter from big waves allows for sediment deposition and vegetation growth, which explains why salt marshes can develop in areas such as lagoons, bays, river mouths, estuaries, deltas and sheltered islands and reefs (Davidson-Arnott et al., 2002). Salt marshes are located in the zones on the coastline between the high tide line and the sublittoral zone (Vernberg, 1993). They are essential for sediment exchange between mudflats and coastal waters. They are located within the transition zone between terrestrial and marine ecosystems (Davidson-Arnott et al., 2002). Fine sediments deposited by the tides and runoff from surrounding uplands accumulate in the salt marshes, making them a sediment sink. Salt marshes are organic matter, organic carbon and contaminant sinks. Salt marshes are sediment sinks because fine sediments deposited by the tides and runoff from surrounding uplands accumulate (Davidson-Arnott et al., 2002; Gordon et al., 1985). Salt marshes are also incredibly resilient, as demonstrated by their ability to withstand some of the strongest currents initiated by the largest tides in the world, for example, in the Bay of Fundy (Pratolongo et al., 2019).

1.3 Ecosystem Services Provided by Salt Marshes

Ecosystem services are resources that provide multiple benefits, such as the production of goods and survival sustaining processes (Barbier, 2019). Salt marsh ecosystems have some of the highest biodiversity and primary production rates in the world. However, coastal ecosystems are some of the most greatly endangered ecosystems globally (Barbier et al., 2011). Fifty percent of salt marshes are either deteriorated or lost globally due to anthropogenic activities (Barbier et al., 2011). The loss and degradation of these ecosystems could have unpredictable negative impacts on the equilibrium of the surrounding ecosystems. A better understanding of salt marsh patterns is needed to help protect them (Zedler and Kercher, 2005). Coastal wetlands' abilities to provide ecosystem services decreases as they degrade (Barbier, 2019). Despite acknowledging the existence of the many important ecosystem services provided by coastal systems, there is lack of methods for determining the benefits of salt marshes which prevents policy-makers from making progress that will help protect them (Barbier, 2019). Salt marshes provide habitats for shorebirds, waterfowl and other living organisms (Barbier, 2019; Davidson-Arnott et al., 2002). Salt marsh ecosystems also provide erosion and flood control, water quality and purification, pollution reduction and carbon sequestration (Barbier, 2019).

1.3.1 Erosion Control

Salt marshes protect from coastal erosion and wave attenuation through plant roots and emergent vegetation. The roots create a strong matrix binding sediments together with their roots, preventing sediment erosion (Feagin et al., 2009). Salt marsh plants also provide a level of protection by creating drag. Leonardi et al. (2015) looked at the relationship between wave power and salt marsh erosion to determine the range of wave power against which salt marshes can protect. Their study found that there is no threshold above which salt marshes cannot provide coastal protection. Salt marsh erosion is controlled by average wave conditions and is susceptible to changes in the mean wave energy (Leonardi et al., 2015). Only 1% of coastal erosion rates are attributed to high wave energy and storm surges. Moderate storms, which occur more often, cause the most damage (Leonardi et al., 2015). Sediment deposits on the salt marsh surface can provide enough sedimentation for vertical growth and increased coastal protection, as long as vertical growth can keep up with sea-level rise (Allen, 1990; Davidson-Arnott et al., 2002).

1.3.2 Water Quality

Good water quality allows ecosystem biodiversity to thrive. Salt marshes increase water quality through filtration as it trickles through the many layers of sediments into the water table (Vernberg, 1993). Sediments can filter pollutants, catch excess nutrients, and prevent microorganisms from entering the water table (Vernberg, 1993). Salt marsh plants impact the water quality through purification and filtration, which can drastically improve salt marsh water quality.

1.3.3 Carbon Sink

Salt marshes store organic carbon through consistent tidal flooding and salt marsh plants' help (Wollenberg et *al*., 2018). Salt marshes' ability to sequester organic carbon exceeds that of terrestrial forests (Gispert et al., 2020), making them valuable ecosystems that can lower the atmospheric concentrations of CO_2. As salt marsh ecosystems continue to be lost and degraded globally, the carbon they are storing is emitted into the atmosphere, contributing to global emissions.

Protecting salt marshes from the impacts of climate change increases global organic carbon storage. In some areas, salt marshes are being considered for carbon offset programs (Chmura, 2013). Salt marshes need to have the ability to adapt and grow with the sea-level rise to be considered carbon sinks in the future. Chmura (2013) suggests that if salt marshes are restricted by human development or topography, vegetation will not survive the high sea levels as marsh accretion and inland marsh development would not occur.

1.3.4 Carbon Sequestration

Salt marshes conduct approximately 50% of the total annual organic carbon burial worldwide (Chmura et al., 2003). This type of carbon is referred to as “blue carbon” and is the type of carbon stored in marine and coastal environments (Pendleton et al., 2012). No current data explicitly outlines how much carbon is stored in salt marshes globally, seeing as each site differ. Individual site assessments are needed to determine these values. It is vital to understand how climate change will impact salt marsh’s ability to sequester carbon and which conditions are favourable for optimal sequestration.

1.4 Salt Marsh Ecomorphodynamics

The interaction of erosion, sediment and vegetation dynamics are important salt marsh ecomorphodynamics that help explain the changes of the marsh surface and the channels located within it (Figure 1.1) (Coco et al., 2013: D'Alpaos et al., 2007). The morphology of a salt marsh is a vegetated and sloping surface, along with growing creeks with proximity to the ocean. Salt marshes can grow vertically and horizontally as they accumulate sediment (Davidson-Arnott et al., 2002). Ice formation and scour impact salt marsh geomorphology. As the ice moves through the marsh, frozen sediment can cause erosion and intertidal sedimentation (Dionne, 1989; Pratolongo et al., 2019). The vegetation in the low marsh area is most often flooded, sometimes by up to 4 meters of water in areas such as the Bay of Fundy. The high marsh area only floods during exceptionally high tides. High marsh exhibits higher diversity of vegetation due to lower salinity levels.

1.4.1 Elevation Change Within Tidal Frame

If there is insufficient sediment in the system, salt marshes are not able to accrete. Pethick (1981) observed high sedimentation rates on newly restored salt marshes. The vertical growth of tidal salt marshes is controlled by elevation and sediment deposition rate (Temmerman et al., 2003). Salt marsh flooding frequency decreases as they accrete and rise higher within their tidal frame. When this happens, the salt marsh growth rate slows, achieving equilibrium in the tidal frame. When the marsh surface and the tidal frame are in equilibrium, there is consistent vertical salt marsh growth under rising sea levels (Temmerman et al., 2003).

Salt marshes accrete depending on the locations of the various channels. Sediment deposition and vertical growth decrease with increased distance from the creek. Higher elevations are found on the channel banks because they are often flooded (D'Alpaos et al., 2019). This creates a concave-up marsh profile.

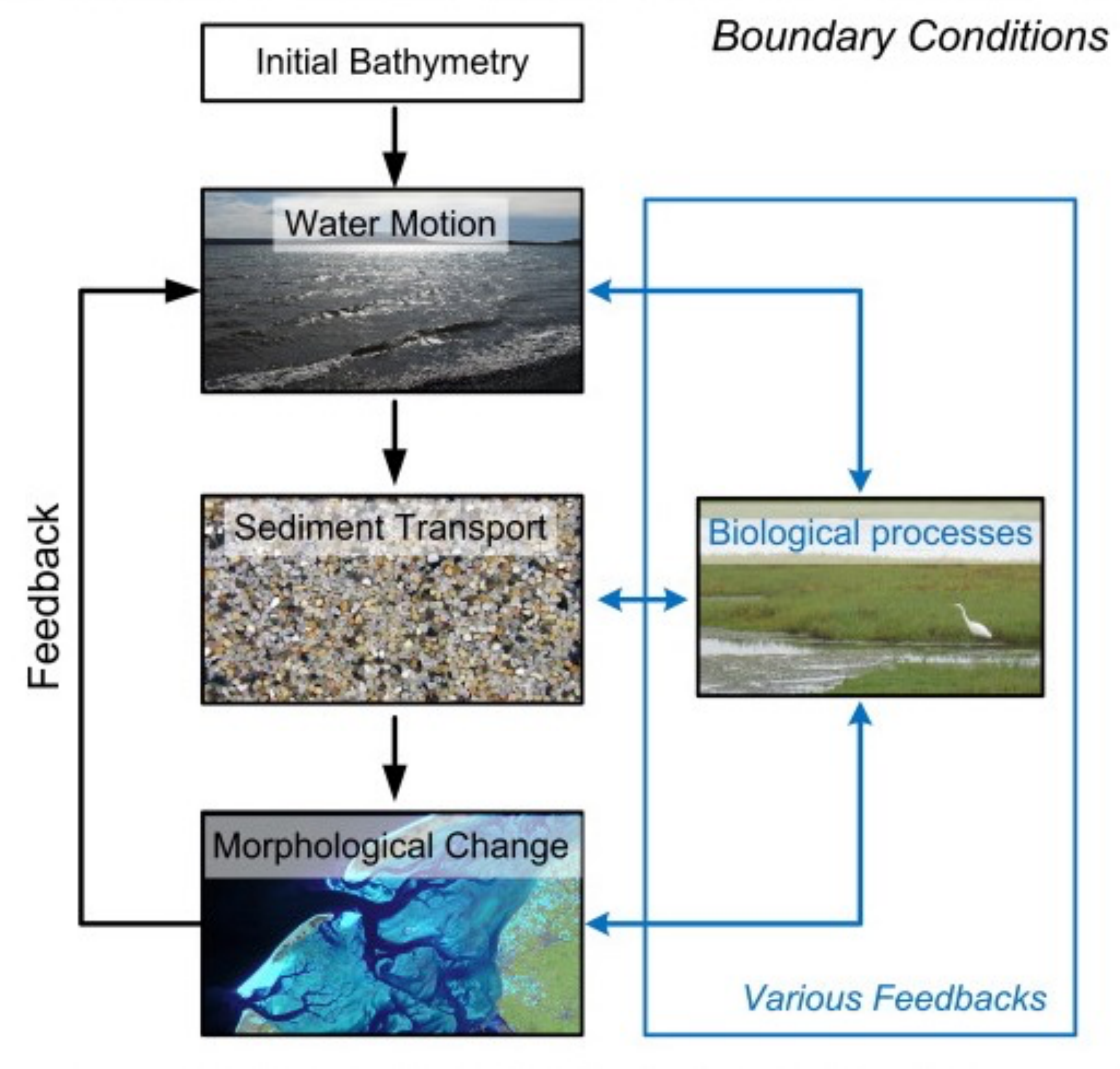


Figure 1.1. Summary of the Ecomorphodynamic Processes Occurring Within a Coastal Wetland Site. The tide is the main driver for water motion. It impacts the initial bathymetry through sediment transport, creating morphological change. This change then becomes the new equilibrium, and the process continues in a morphodynamical feedback loop. Biological processes such as vegetation growth greatly impact the geomorphology of salt marshes through bank stabilization. Reproduced from Figure 6 in Coco et al. (2013). Permission to reproduce granted by g.coco@auckland.ac.nz (Appendix D, Figure D.1).

1.4.2 Factors Affecting Sedimentation

Sedimentation is the increase of sediment deposition on the salt marsh surface and influences its accretion ability. When the tide flows over a vegetated salt marsh, the water velocities slow down. Low velocities create an opportunity for sediment deposition to occur due to decreased entrainment capacity. Neumeier and Amos (2006) found that vegetation, such as *Spartina*, can considerably slow the water velocity. They also noted that turbulence decreases closer to the marsh surface when it is highly vegetated, creating another opportunity for sediment deposition. Fully vegetated salt marsh surfaces have high sedimentation rates and decreased erosion (Neumeier & Amos, 2006).

The availability of sediment greatly impacts sedimentation. Generally, when there is high sediment availability within the system, it can increase deposition on the marsh surface. Poirier et al. (2017) found that suspended sediment concentration varied seasonally, with higher concentrations in the winter. van Proosdij et al. (2006) suggests that salt marsh sediment budgets vary seasonally and differ between years. High levels of suspended sediment concentrations do not always result in an increase in sediment deposition on the marsh surface. Most sediment deposition can occur in the creek and marsh banks before it reaches the main platform.

Grain size and inundation frequency will impact sedimentation through their influence on the ability to deposit. Grain size on natural salt marshes is characteristically finer landward because lower velocities can entrain fine particles for longer. Smaller particles tend to settle in flocs, whereas larger particles settle in single particles (Christiansen et al., 2000). Larger sediment particles need higher velocity waters to remain entrained. Water velocities decrease across the salt marsh surface meaning larger sediment particles will be deposited first and on the marsh edges. This explains why smaller particles are found more landward as they only require low velocities to be entrained. If the marsh surface floods often, high sedimentation rates will occur on the entire surface because more opportunities for sediment deposition arise.

1.5 Climate Change Adaptation

Coastal marsh systems are integral parts of our ecosystems, especially in the face of climate change and sea-level rise (Wigand et al., 2015). Coastal marshes provide coastal protection, as well as various essential ecosystem services. Dyke realignment and salt marsh restoration is an innovative strategy adopted in Nova Scotia that provides humans with the opportunity to protect their coastal ecosystems through natural infrastructure.

1.5.1 Dyke Realignment

Roughly half of Nova Scotia's coastal wetlands were dyked in the 1600s, converting them to available agricultural land (Sherren et al., 2016). This transformation lowered coastal resilience due to the lack of adaptive wetland. As the sea-level rises, dykes will no longer protect the agricultural land at their current elevations (van Proosdij et al., 2013). The adaptation strategy is to breach the dyke in selected areas and restore the foreshore to coastal salt marsh to mitigate the impacts of sea-level rise (Sherren et al., 2016). Breaching dykes allows for the new salt marsh to form and provide additional coastal protection through erosion control. This process has been undertaken on Nova Scotia and New Brunswick coasts before, but a better understanding of salt marsh restoration trajectory is still needed (Bowron et al., 2013a; Bowron et al., 2013b, Bowron et al., 2015a; Bowron et al., 2015b). This process has also occurred in northern Europe and the United States (Esteves, 2016; Williams and Faber, 2001).

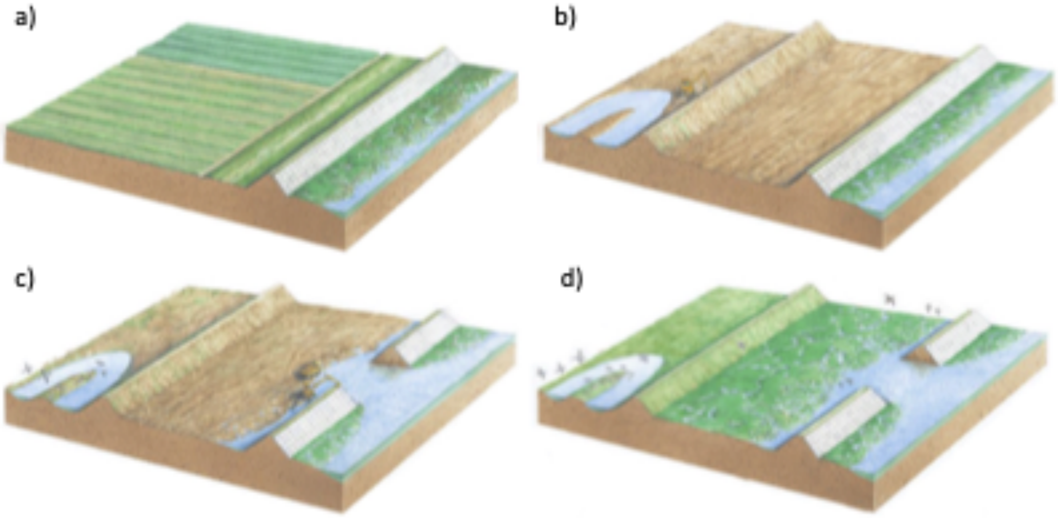


Figure 1.2 Illustration of Managed Realignment Process. a) the original dyke with little foreshore marsh. b) the construction of the realigned dyke. c) the breach of the original dyke, allowing for tidal flooding to occur behind it. d) the newly restored salt marsh growth and increased coastal protection. Reproduced from: TransCoastal Adaptations, Centre for Nature-Based Solutions, (2019). Permission to reproduce granted by dvanproo@smu.ca (Appendix D, Figure D.2).

Managed realignment, or dyke realignment, provides better sea defences that are more economical because the newly established marsh protects the new dyke and attenuates wave energy (Figure 1.2) (Pratolongo et al., 2019). Tidal inundation of the land following managed realignment typically results in salt marsh populated by vegetation (Mossman et al., 2012). Mossman et al. (2012) noted that although the plant species are mostly the same between the managed realignment sites and the reference sites (well-established natural salt marshes), they differ in abundance. Understanding these differences and the sedimentation processes occurring during managed realignment will inform on best practices for these projects. This thesis will address the gap in the current literature by monitoring salt marsh restoration trajectory through sediment analysis and salt marsh surface patterns.

1.6 Purpose

1.6.1 Objectives

This research looked at the temporal and spatial variation of sediment composition on newly restored salt marsh surfaces. This study helped determine if the current sampling frequency (once per year) truly represents the grain sizes and sediment composition of salt marsh restoration sites in the Bay of Fundy. This thesis provided data and insight to the NSERC ResNet project (web address), which looks at understanding the various ecosystem services that Canadian landscapes can provide society. The ResNet project goal is to develop how Canada monitors, models and manages the working landscapes it possesses to ensure prosperity for Canadians. This thesis expands on the understanding of ecosystem services that salt marshes can deliver, specifically their ability to provide coastal protection and organic carbon sequestration.

The study determined the differences in sediment characteristics between summer and fall at two recently restored salt marsh sites through sediment analysis. The sediment characteristics included in this study are disaggregate inorganic grain size (DIGS), organic matter, organic carbon content and water content. The sediment characteristics are compared to reference conditions, previously restored sites, and natural marshes in the Bay of Fundy. The organic carbon content will be measured and interpreted in the context of the newly restored salt marsh's ability to sequester carbon. Understanding these sediment characteristics and how they vary over space and time will allow us to understand how and why the salt marsh will grow and change as it becomes more established.

1.6.2 Research Questions

The research questions are:

1. To determine if there is a spatial variation in sediment characteristics across the marsh surface at each study site.
2. To determine if differing elevation within the tidal frame influences variations in sediment characteristics.
3. To determine if any spatial variation observed in the first objective is consistent over time.
4. To determine if and how sediment characteristics of both study sites compare to reference conditions which are from other restored salt marshes in Nova Scotia.

This study will be conducted at two recently restored managed realignment sites: the Belcher Street Marsh (NS091) in the Cornwallis estuary (Figure 2.2) and the Converse Marsh (NS044) in the Cumberland Basin (Figure 2.3). In 2018, both sites were breached and are now home to quickly developing salt marshes. This thesis will be part of their post-monitoring restoration program. Through sediment sample analysis, this study will track the change in organic carbon over four months and determine if there is variability in carbon sequestration over the salt marsh surface. This information, along with data collected about other sediment characteristics, will be provided and included in the ResNet project to help understand what ecosystem services are present in Canada.

1.7 Preview of Thesis

The second chapter presents the Bay of Fundy and the two restored salt marshes located within it. The third chapter presents a detailed explanation of the methods used during this study.

Methods for data collection, analytical analysis and statistical analysis will be presented and explained here.

The fourth chapter of this thesis presents the results, including tables, figures, and maps to provide the best possible understanding. In the fifth chapter, these results are explained and interpreted in the context of the research questions determined above. The literature review serves as a basis for the interpretation of the data presented in the results. These data are compared to data from reference conditions. The concluding chapter summarizes the findings and suggestions for future research needed to understand the managed realignment process further.

CHAPTER 2

Study Area

In this chapter, the reasoning for the selection of each site is explained. Managed realignment and salt marsh restoration projects have taken place at both sites, despite their remarkably different physical characteristics. This chapter will provide an overview of the Bay of Fundy, the location of both sites, the relationship this research has with previous research, factual information about each site and how this research will help inform future research projects.

2.1 Bay of Fundy

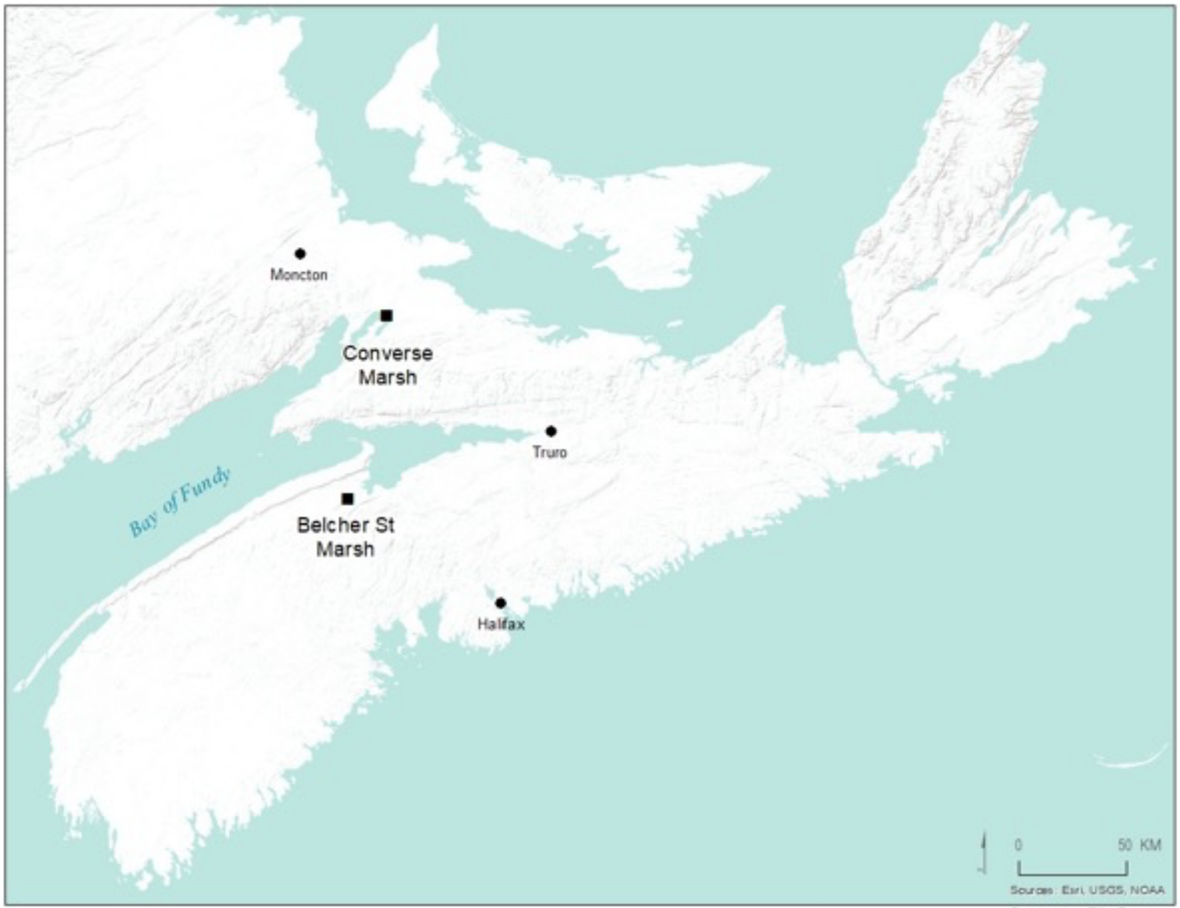
This research was conducted at two managed realignment sites within the Upper Bay of Fundy. The Bay of Fundy is located between Canada's Maritime Provinces: Nova Scotia and New Brunswick. It has over 270 kilometres of coastline, and its unique shape creates the highest tides in the world. The shape of the bay amplifies the tides, allowing the upper reaches of the tides to frequently exceed 15 meters (Desplanque & Mossman, 2001). These tides are semi-diurnal and have high suspended sediment concentration, which allows for successful salt marsh restoration projects (Davidson-Arnott et al., 2002).

Many macrotidal salt marshes are found along the coasts of the Bay of Fundy, vegetated by shrubs, grasses, and herbs (Davidson-Arnott et al., 2002). They develop in the intertidal zone, in areas protected from intense wave action to allow sediment deposition and vegetation growth (Davidson-Arnott et al., 2002).

2.2 Study Sites

2.2.1 Reasoning for Site Selection

The Belcher Street Marsh and the Converse Marsh are both study sites that have been used in dyke realignment and salt marsh restoration projects carried out by CB Wetlands & Environmental Specialists Inc. (CBWES) and Saint Mary's University as part of the Making Room for Wetlands Project at TransCoastal Adaptation Center for Nature-based Solutions (web address). In 2018, the dyke at both sites was breached, leading to quickly developing salt marshes. Prior to the dyke breach, baseline ecological monitoring was conducted at both sites to ensure an adequate understanding of the site condition and various sediment characteristics. The goal for both managed realignment projects was to restore the former salt marsh and provide coastal protection from sea-level rise, storm surge and protect various anthropogenic infrastructures from flooding damages. This thesis plays an important role in monitoring the restoration of these tidal wetlands by providing insight into each site's sediment characteristics, their spatial and temporal variations, and the services delivered by salt marshes after restoration. The data gathered for the Belcher Street Marsh and the Converse Marsh will be compared to reference conditions at each marsh and data compiled from other salt marsh restoration sites in Nova Scotia.



Sources: Esri, USGS, NOAA

Cartographer: Elise Rogers

Figure 2.1. The Bay of Fundy and a Regional Setting Map Showing the Location of the Belcher Street Marsh and Converse Marsh Managed Realignment Sites.

2.2.2 Belcher Street Marsh

This site was chosen by the Nova Scotia Department of Agriculture (NSDA) in 2017 to become the site of a salt marsh restoration project as a part of the Making Room for Wetlands project funded by the Coastal Restoration Fund from DFO. Restored salt marshes at this location can reduce the risk of flooding in Kentville, New Minas and Port Williams (Graham et al., 2020). A restoration monitoring plan was established to track the development of the project. The monitoring program was developed using other previously completed projects with similar goals. Indicators such as geospatial attributes, soils and sediments and vegetation were used to determine the health of the ecosystem and the success of the project. After the first year of monitoring the post-dyke breach, sediment deposition caused increased elevation in most areas on the marsh surface, and freshwater species retreated (Graham et al., 2020). A decrease in soil water and organic matter indicate that the restored area is approaching the characteristics of reference conditions. The reference conditions are 1.5 ha of natural tidal wetland located on the opposite side of the river. The reference site has a defined low and high marsh with similar vegetation to the Belcher Street Marsh.

The Belcher Street Marsh (NS091) is located east of Kentville, Nova Scotia, on the north side of the Cornwallis River System. This river system is located in the Minas Basin, within the Bay of Fundy. The dykes along the river channel bank follow the river channel's sinuosity since they were built close to the river bank. They are subject to high levels of erosion in response to the natural tendency of the river to meander (Graham et al., 2020). Since the dyke was built so close to the river, it eliminated any natural flood plain or tidal wetland habitat.

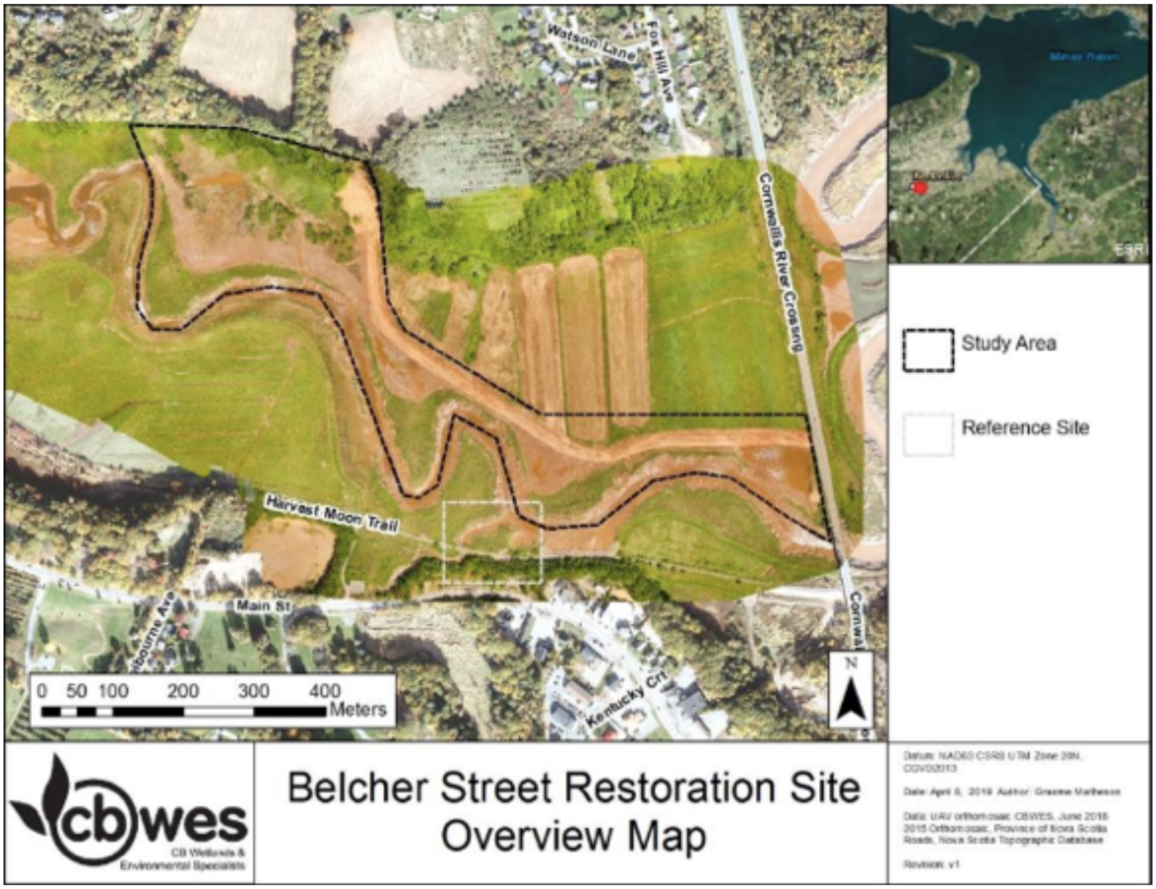


Figure 2.2. Location of the Belcher Street Marsh Reference and Restoration Site. Reproduced from Figure 1 Bowron et al. (2019). Permission to reproduce granted by jen.m.graham@cbwes.com (Appendix D, Figure D.3).

Prior to the restoration project, the site's land use consisted of agricultural lands protected from tidal waters by the deteriorating dyke (Graham et al., 2020). The dyke was at high risk of failing, exacerbated by sea-level rise projections (van Proosdij et al., 2013). Through dyke realignment, this project successfully reached its objective to restore a total of 9.7 ha of tidal wetland habitat (3.2 ha of foreshore marsh and convert 6.5 ha of agricultural land) (Graham et al., 2020). The marsh became fully vegetated within two years of re-introduction of tidal flow. High rates of sedimentation are connected to the high suspended sediment concentrations reaching up to 15 g/L and the site's position relative to the location of the turbidity maximum (Graham et al., 2020). The salt marsh surface increased in elevation at all measured locations from 2018 to 2019, with elevational differences ranging from 25.8 ± 0.94 cm to 35.3 ± 0.30 cm (Graham et al., 2020). This sedimentation increases the elevation of the marsh platform within the tidal frame, causing decreased inundation frequency. The salt marsh surface now only floods when tides reach 15 m (chart datum).

2.2.3 Converse Marsh

Nova Scotia Department of Agriculture (NSDA) identified the Converse marsh as an area in need of realignment and salt marsh restoration due to the accelerated loss of foreshore marsh, rapid erosion of the dyke and the expenses related to maintaining a dyke in this location (Bowron et al., 2020). Many roads and properties are at high risk of being damaged should the dyke fail. This project aimed to protect anthropogenic land uses such as roads and farmlands through dyke realignment and salt marsh habitat restoration (Bowron et al., 2020).

In 2016, CEWES developed a plan to realign the dyke and restore salt marsh within the Converse Marsh. They also developed one year of ecological monitoring before the realignment and one year of post-restoration monitoring to track the project's progress (Bowron et al., 2020). Saint Mary's University (SMU) was granted the necessary funding from the Department of Fisheries and Oceans Coastal Restoration Fund to complete the monitoring four years post-project completion. This dyke realignment and salt marsh restoration project was also intended to set a precedent in understanding possible issues and challenges that may arise during other future adaptation projects in the area. The reference conditions for this site are based on fringe marsh plots found at the Converse study site, sites located in the Bay of Fundy with the same morphology and other salt marsh restoration projects (Bowron et al., 2020).

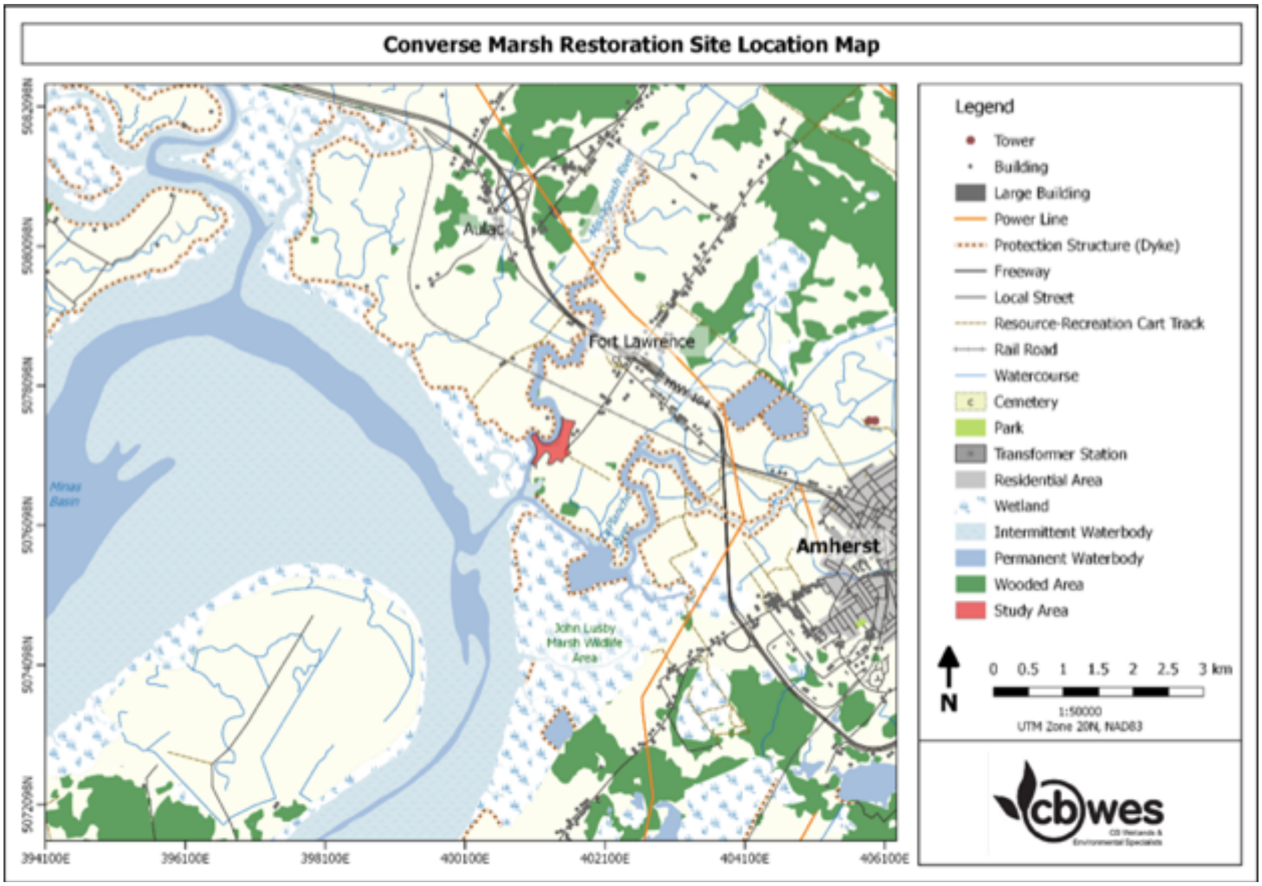


Figure 2.3. Tantramar Marsh and the Converse Project Site. Reproduced from Figure 1 of Bowron et al. (2019). Permission to reproduce granted by jen.m.graham@cbwes.com.

The Converse Marsh (NS044) is located within the Tantramar Marsh system, which contains many tidal and non-tidal wetlands, and connects Nova Scotia to New Brunswick. The Converse Marsh is located on the east side of the Missaguash River, on the Nova Scotian side. This river is one of many which flows through the Tantramar system and into the upper end of the Bay of Fundy (Bowron et al., 2020). For the last 400 years, this complex marsh system was one of the largest wetland networks in the area and included many salt marshes, brackish tidal fresh, and freshwater wetlands at the head of the Bay of Fundy inland. The dyke system along the Missaguash river is built very close to the river bank. Due to rising sea levels and climate change, the dyke was cause for concern as it was undergoing abundant erosion, increasing its risk of failing. Prior to the dyke breach, the land behind the dyke was uncultivated agricultural land.

The dyke realignment projects aimed to realign the dyke and flood the land located behind the current dyke, creating a salt marsh that will provide coastal protection to agricultural land currently being used and the Fort Lawrence Road and Parks Canada property. After the first year of post monitoring following the dyke realignment (2019), data were collected regarding geospatial attributes, hydrology, soils and sediments, and vegetation. Sediment accretion caused 40% of survey points to be between 15 and 50 cm higher than the initial LiDAR surface (Ellis et al., 2018). The restored area is ~15.4 ha (Bowron et al., 2020).

CHAPTER 3

Data and Methods

Sediment samples were collected at two newly restored salt marshes in the Upper Bay of Fundy, Belcher Street Marsh and Converse Marsh, in August and November of 2020. These samples were analyzed for grain size distribution, water content, organic matter content and organic carbon content. This analysis will inform how well once per year sampling represents the sediment composition of the managed realignment sites. This study will help determine to what extent managed realignment sites can provide the same ecosystem services as reference conditions. This study also aims to fill the gaps in the current literature regarding the restoration trajectory of salt marshes within managed realignment sites. This chapter will explain the various methodologies used to complete this study.

3.1 Preparation for Data Collection

Points were placed randomly on the salt marsh surface using a stratified random sampling technique in ArcGIS 10.6 Desktop. Fifty points were placed on the map for each site, following the application of the stratified random sampling technique. After evaluating each point to determine if it was acceptable for the study, only 30 points were used. The points were evaluated by binning the salt marsh surface into 12 elevation categories to ensure that the points were located at various places on the marsh surface (Figure 3.3). Points were placed at different elevations, inundation frequencies and vegetation cover to get a representative dataset, as these differences impact the characteristics of the sediment at that specific location. Points located in inaccessible areas of the marsh were removed from the map. Points from CBWES were included for both the Belcher Street Marsh (Figure 3.1) and Converse Marsh map (Figure 3.2). These points were included because this study will help inform if the current protocols of CBWES sampling once per year represent marsh sediment characteristics. In addition to the CBWES points, the Converse marsh map also included marker horizon points included in past studies on the marsh to help compare and track the restoration progress of this site. Once both maps were complete with the desired points, the coordinates were extracted and transferred to the Network Real-Time Kinematic (NRTK) in preparation for field data collection.

3.2 Data Collection

3.2.1 Field Methods

Sediment samples were collected from both the Converse and the Belcher Street marshes. Each point was staked out using the NRTK or a handheld GPS. Upon arriving at the point, a photograph was taken of the sample location, a labelled bamboo stick was placed on the site, a short description of the site was noted, and the sediment sample was taken. The samples were collected using vials to scrape the top ~0.5 cm of the marsh surface. The labelled bamboo stick allowed for easy sampling reproducibility. The sampling occurred twice at each site, once in the summer (August) and once in the late fall (November). The timing of sample collection was arranged so that the tidal conditions were kept very similar for each sampling round. However, due to distinct differences in inundation frequencies at both sites, sampling in relation to the ideal tidal conditions was impossible. Three tidal heights that inundated the marsh surface were desired before data collection to ensure that the salt marshes were recently flooded.

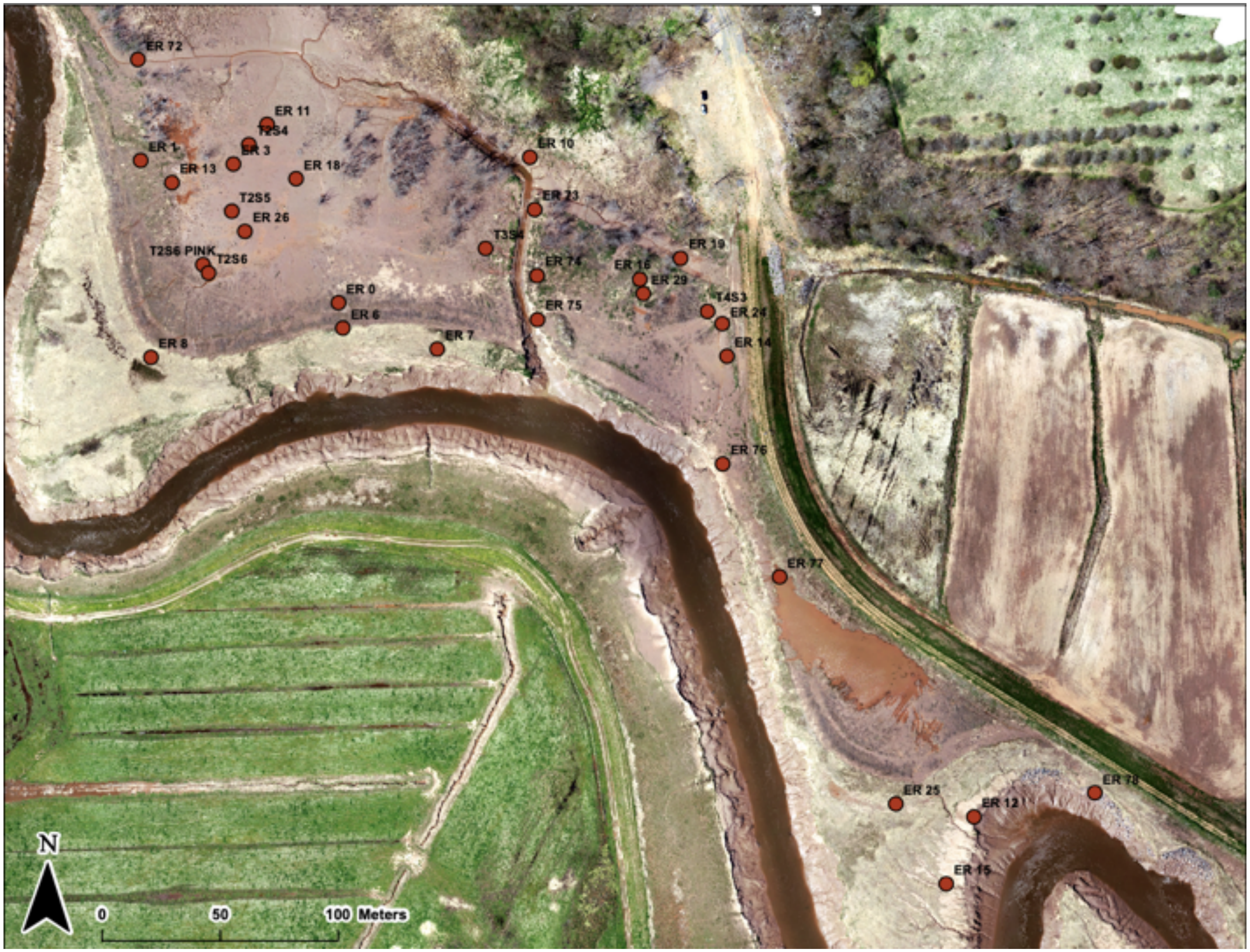


Figure 3.1. Map of Sediment Sample Distribution at the Belcher Street Marsh (NS091). Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/05/18.

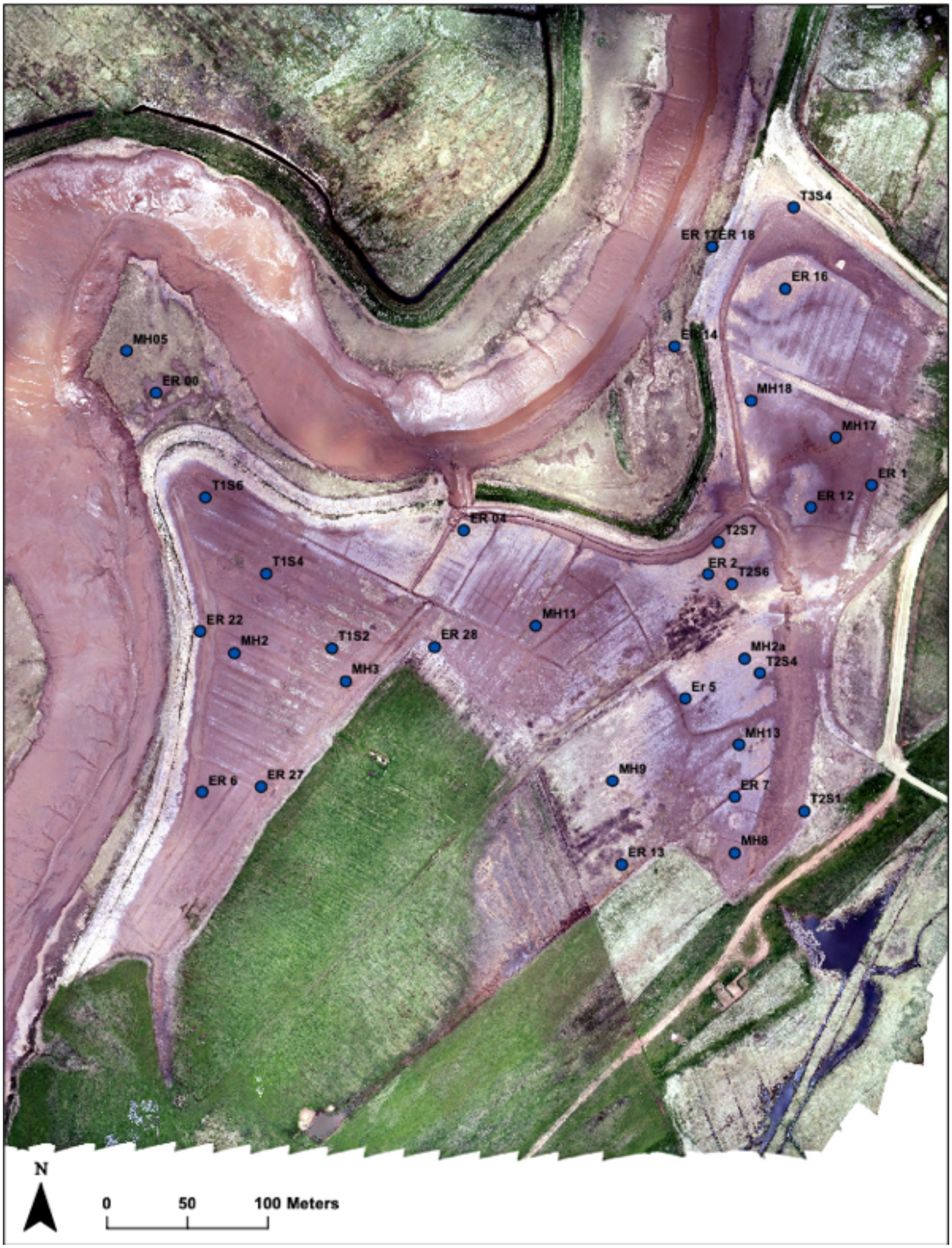


Figure 3.2. Map of sediment sample distribution at the Converse marsh (NS044). Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/06/01.

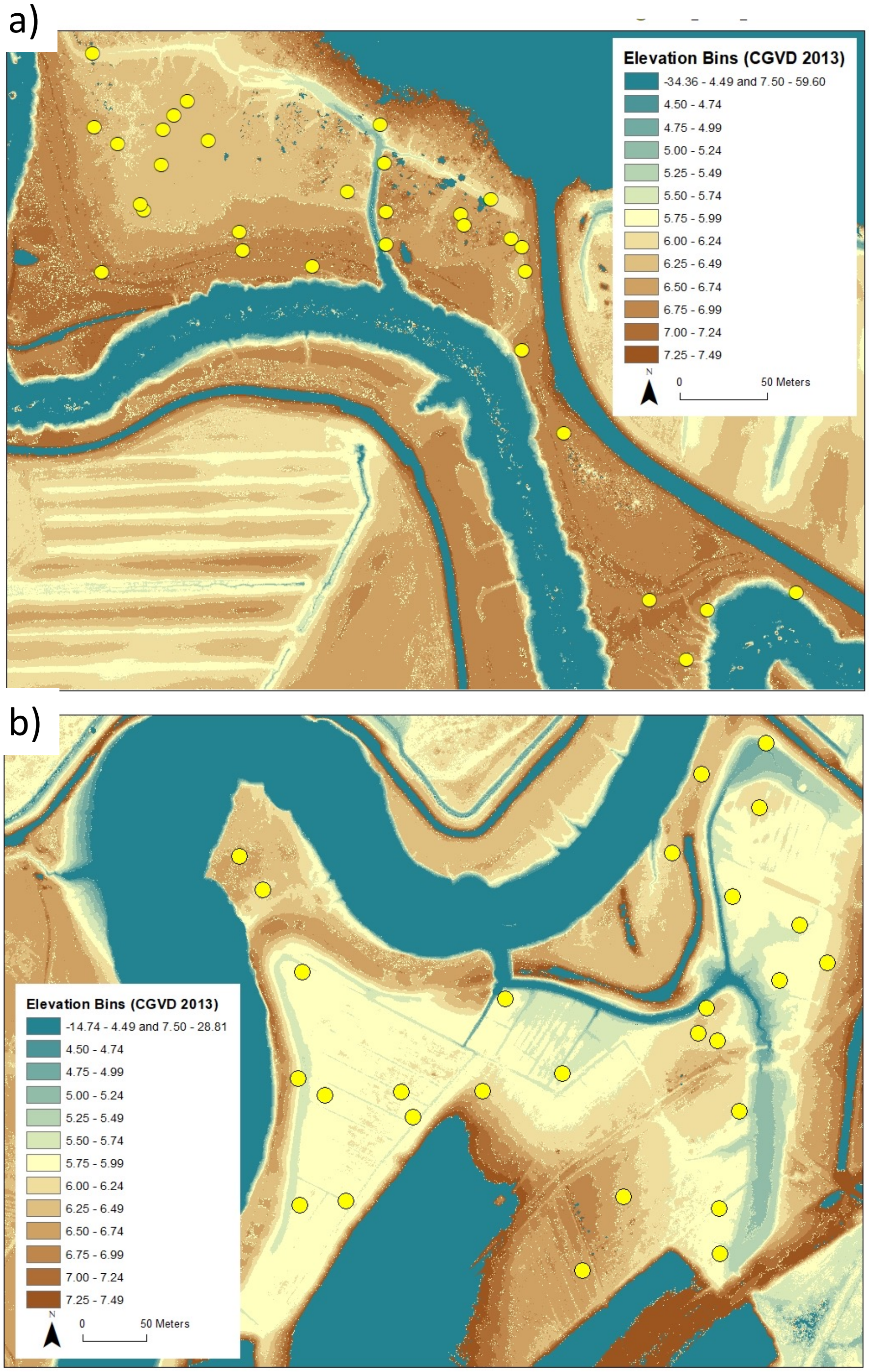


Figure 3.3. a) Elevation gradient divided into 0.25 m (chart datum) bins for the Belcher Street Marsh. Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/05/18. b) Elevation gradient divided into 0.25 m (chart datum) bins for the Converse Marsh. Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/06/01. The yellow circles represent the sample locations.

The Converse marsh floods frequently, but the Belcher Street marsh only floods after a 15-meter tide, which is relatively infrequent. Therefore, the Converse marsh was frequently flooded before both sampling rounds, but the Belcher Street marsh did not flood before the summer sampling round. It flooded in November before data collection occurred. Sampling within a week of three tides covering the marsh surface provided representative samples. Data collection was conducted at both sites within one week to ensure similar weather conditions and tidal conditions. Samples were transported in a cooler and then frozen upon arrival at the lab. Samples must be frozen because the organic matter content will be measured, and freezing the samples prevents decomposition within the sample.

3.2.2 Secondary Data

Secondary data were used to complete the maps. The orthomosaic photos were taken by a graduate student, Samantha Lewis, through the Maritime Provinces Spatial Analysis Research Centre at Saint Mary's University. A DJI Phantom 4 Remotely Piloted Aircraft System (RPAS) was used to complete the flights. The Belcher Street marsh imagery flights were conducted on 2020/05/18, and the flights for the Converse Street marsh imagery were done on 2020/06/01.

Other types of secondary data include the data points taken from CBWES to sample at their locations and the marker horizon locations. These coordinates were provided for the study, as they will help inform both CBWES and TransCoastal Adaptation on the effectiveness of their sampling methods.

3.3 Analytical Methods

The sediment samples collected were analyzed multiple times to determine various sediment characteristics. A different method is employed to determine water content, organic matter content, organic carbon content and disaggregated grain size of the sample. Each method will be outlined and explained in the following sections. The set of equations used to determine the organic matter content and organic carbon content will also be presented.

3.3.1 Lab Analysis

When samples were ready to be analyzed, they were removed from the freezer a day beforehand to thaw out. Two sub-samples were taken from the vial to complete the analysis. The first sub-sample was used to calculate water content, organic matter content and organic carbon content, following the method used in Wollenberg et al. (2018). The second sub-sample was used to calculate disaggregate inorganic grain size (DIGS), following Law et al.'s methods (2018) .

3.3.1.1 Measurement of Water Content

The first step to calculate the water content was to weigh each empty crucible. Then, wet sediment was added to the crucible and weighed again to determine the initial weight of the sample. The weight was recorded by carefully associating the sample ID to the crucible ID. The sediment samples were dried in the oven at 105℃ for 24 hours. The samples were removed from the oven after 24 hours and cooled at room temperature in a desiccator for one hour. Samples were weighed again to determine the weight change. The following equation was used to calculate water content:

$$Water\ content\ (\%) = \left(\frac{wet\ weight - weight\ 105\ C}{wet\ weight}\right) * 100$$

3.3.1.2 Measurement of Organic Matter Content

The first step to calculate organic matter content is to grind up the samples using a mortar and pestle. The Loss on Ignition (LOI) is a method that allows for the calculation of organic matter content and the organic carbon content. It calculates the weight loss through a burning process. The samples are placed in a muffle furnace at 550℃ for four hours (Wollenberg et *al.*, 2018). The samples are placed in the muffle furnace before turning it on to avoid any burn risk and break any crucibles. The timing begins once the oven reaches the appropriate temperature. After four hours, the muffle furnace is turned off, and the samples are left to cool overnight. The following day, samples are removed from the muffle furnace and placed in a desiccator for an hour before they are weighed. This difference in weight represents the organic matter content in the sample. The following equation is used to determine the organic matter content in the sample:

$$Organic\ Matter\ content\ (\%) = \left(\frac{weight\ 105\ C - weight\ 550\ C}{weight\ 105\ C}\right) * 100$$

3.3.1.3 Measurement of Organic Carbon Content

An equation developed specifically for salt marshes by Craft et al. (1991) is used to convert organic matter content to carbon content. The LOI fraction is the fraction of the sample that was lost during the loss on ignition procedure. This value is also the fraction of organic matter content. The organic matter content equation was used without multiplying it by 100 to achieve this value.

$$Organic\ Carbon\ fraction = (0.40 * LOI\ fraction) + (0.025 * LOI\ fraction)^2$$

3.3.1.4 Measurement of Grain Size

An analysis of disaggregated inorganic grain size distribution (DIGS) was performed using a Coulter Multisizer III to determine the grain size of each sample, following the same methodology as Law et al. (2018). A DIGS sample has all organics removed using hydrogen peroxide (H_2O_2). Before running the analysis, the inorganic sediments were suspended in a 1% NaCl solution and disaggregated using an ultrasonic probe. The volume of diluted sediment was normalized to 100% and therefore not recorded. Two tubes with apertures of 30 µm and 200 µm were used to acquire the DIGS distribution. The Coulter Multisizer III expressed the DIGS as the log of equivalent volume fraction versus the log of the diameter. The assumption was that volume fraction is equal to mass fraction, suggesting constant particle density across all sizes (Law et al., 2018). Once the first dilution was made, multiple other dilutions were necessary to achieve proper concentration.

3.3.2 Data Visualization and Statistical Analysis

ArcGIS 10.6 Desktop was used to create comprehensive maps summarizing the results found in the previous section. The same methodology was used to create maps for the Belcher Street Marsh and the Converse Marsh. To map the mean grain size, water content and organic carbon content at both sites, for both sampling rounds, the data was organized into tables in Microsoft Excel. The tables were saved as .CSV files, uploaded into ArcGIS and displayed on the orthomosaics generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis. The data were binned into five equal intervals. Graduated symbols were used to increase the ease of visual pattern and relationship detection on the map.

Grain size diameter versus normalized volume concentration plots were created in SigmaPlot. This type of plot was used because it allows for pattern recognition (Kranck and Milligan, 1991). The ratio between cycle lengths was kept the same on the x-axis and y-axis for easy comparison between months and sites. Samples that differed from the normal pattern displayed on the figure were marked using different colours.

Mean grain size, water content and organic carbon content for August and November were plotted against elevation in Microsoft Excel to detect any existing relationships. Additionally, the mean grain size was plotted against organic carbon content to detect any existing relationship. The Folk and Ward method in Gradistat was used to determine the mean grain size. This was completed for Belcher Street Marsh and Converse Marsh. The R^2 value and the p-value were determined for each variable at either site using the Regression tool in the Data Analysis Toolbox in Microsoft Excel. The p-value was used to determine whether a result was significant at a confidence level of 95%.

The change in sediment composition from August to November was mapped using ArcGIS 10.6 Desktop. The differences in each variable from August to November were calculated by subtracting the August values from the November values for each individual point. If the difference was positive, it symbolized an increase in the variable for that sample location. If the difference was negative, it represented a decrease in the variable for that sample location. The differences were entered into a table in Microsoft Excel. The table was saved as a .CSV file, uploaded and then displayed on the orthomosaics. The data were binned in equal size classes, and graduated symbols were used to represent the size of the change for the specific variable. Blue symbols represented an increase, and yellow symbols represented a decrease of that value.

The carbon density was calculated to determine the newly restored marshes' ability to sequester carbon. The bulk density (g cm^{-3}) of the sample is multiplied by the carbon fraction to determine the organic carbon density (g cm^{-3}). The bulk density was not calculated for the sediment samples taken for this study. The bulk density values were provided by CBWES for their sample locations and were multiplied by the organic carbon fraction determined in this study. The carbon fraction is the value attained using the carbon fraction equation. The carbon density could therefore only be calculated for the CBWES sample locations.

CHAPTER 4

Results

The spatial variability in sediment composition was measured in August and November at the Belcher Street Marsh, and the Converse Marsh managed realignment sites in the Upper Bay of Fundy. The goal was to determine if the sediment composition varied across the salt marsh surface and between seasons at each location. A total of 30 samples were collected during both months based on a stratified random sampling design. The sediment characteristics, specifically the mean grain size, water content and organic carbon content, will be examined by looking at the spatial variability, the influence of site variables such as elevation, overall change from August to November and comparing the results to reference data.

4.1 Spatial Variation of Sediment Characteristics

4.1.1 Belcher Street Marsh

In August (Figure 4.1), the mean grain size is 10.9 µm, while in November, the mean grain size is 11.0 µm, indicating minimal overall differences in the grain size between sampling periods. The grain size is classified as fine to coarse silt for August and November (Blot and Pye, 2001). In August, grain sizes ranging from 8 µm to 16 µm surround the creek and the main river (Figure 4.1, a). Smaller grain sizes are found scattered within the salt marsh surface, farther away from the creek. There are two exceptions with grain sizes larger than 16 µm found in the middle of the marsh surface (Figure 4.1, a). In November (Figure 4.1, b) there is a different pattern showing the largest grain sizes ranging from 16 µm to 22 µm located around the creek. The rest of the salt marsh surface is populated by smaller grain sizes, even around the main river.

The grain size diameter is plotted against the normalized volume concentration (Figure 4.1, c). The figure is plotted as log-log frequency distribution because it illustrates the relationships and patterns in the samples (Kranck & Milligan, 1991). The section of the figure showing similar size characteristics (finer than ~10 µm) was deposited as flocs. Their similarity in slopes is indicating that the samples were taken from a small geographical area. Above ~10 µm, the concentration mainly decreases promptly, indicating increasing diameter as the concentration decreases. Four samples represented by the coloured lines are found outside the observed trend (Figure 4.1, c). The red and green lines represent samples characterized by a lower concentration of mud fraction than the rest of the samples. Their higher and later peaks indicate a higher concentration of larger grain sizes. They are then both trailing off extremely quickly with decreasing concentration. These two samples are sample ER76 (red line, elevation of 6.79 m) and sample T2S5 (green line, elevation of 6.32 m). Sample ER13 (blue line, elevation of 6.20 m) has the finest grain size. Sample ER00 (pink line, elevation of 6.67 m) peaks higher and earlier than other samples despite the fine and coarse ends showing a common pattern.

In November (Figure 4.1, d), the mud fractions show similar slopes for most samples. This is indicating that the samples were taken within a set geographical area. Sample ER0 (blue line, elevation of 6.67 m) has the highest mud fraction. Sample ER1 (red line, elevation of 6.44 m) and T3S4 (cyan line, elevation of 6.33 m) have low concentrations of fine sediments and have the largest grain size represented by high peaks and a quickly decreasing concentration in the coarse end. Sample ER8 (orange line, elevation of 6.84 m) has a “normal” curve for the fine sediments but peaks early and has low concentrations of coarse sediments.

There is a high percent water content pattern across the marsh surface and low water content percent surrounding the creek in August (Figure 4.2, a). Water contents range from 25% to 65 %. The same pattern was noticed in November (Figure 4.2, b), only with a more considerable disparity between the water content percent from the creek to the rest of the marsh. The water contents range from 34% to 84 %. Overall, the water content is higher in November compared to August.

The percent organic carbon content shows a trend similar to the water content percent, simply on a smaller scale (Figure 4.2, c & d). In August, the low carbon contents percentages can be found surrounding the creek. The higher organic carbon content percentages are located further on the marsh surface. The organic carbon content percent ranges from 1.2% to 5.6 % (Figure 4.2, c). This pattern is accentuated by a larger difference in organic carbon content percentage between the samples surrounding the creek and the samples found on the inner marsh surface in November. The samples surrounding the creek range from 1.1% to 2.1 % organic carbon content, while the rest of the marsh surface has organic carbon content ranging up to 6.4% (Figure 4.2, d).

4.1.2 Converse Marsh

The mean grain size in August (Figure 4.3, a) is 11.3 µm, and the marsh surface mean grain size in November (Figure 4.3, b) is 11.0 µm, indicating there is a minimal difference in grain size from August to November. The grain size is classified as fine to coarse silt for August and November (Blott and Pye, 2001). In August, the mean grain size ranges from 7 µm to 17 µm. A decreasing grain size pattern with distance from the dyke breach can be observed. In November, the mean grain size ranges from 5 µm to 18 µm (Figure 4.3). The same pattern of decreasing grain size with increasing distance from the breach can be observed, however, with minor variation between the samples. The mean grain size range is wider in November than in August.

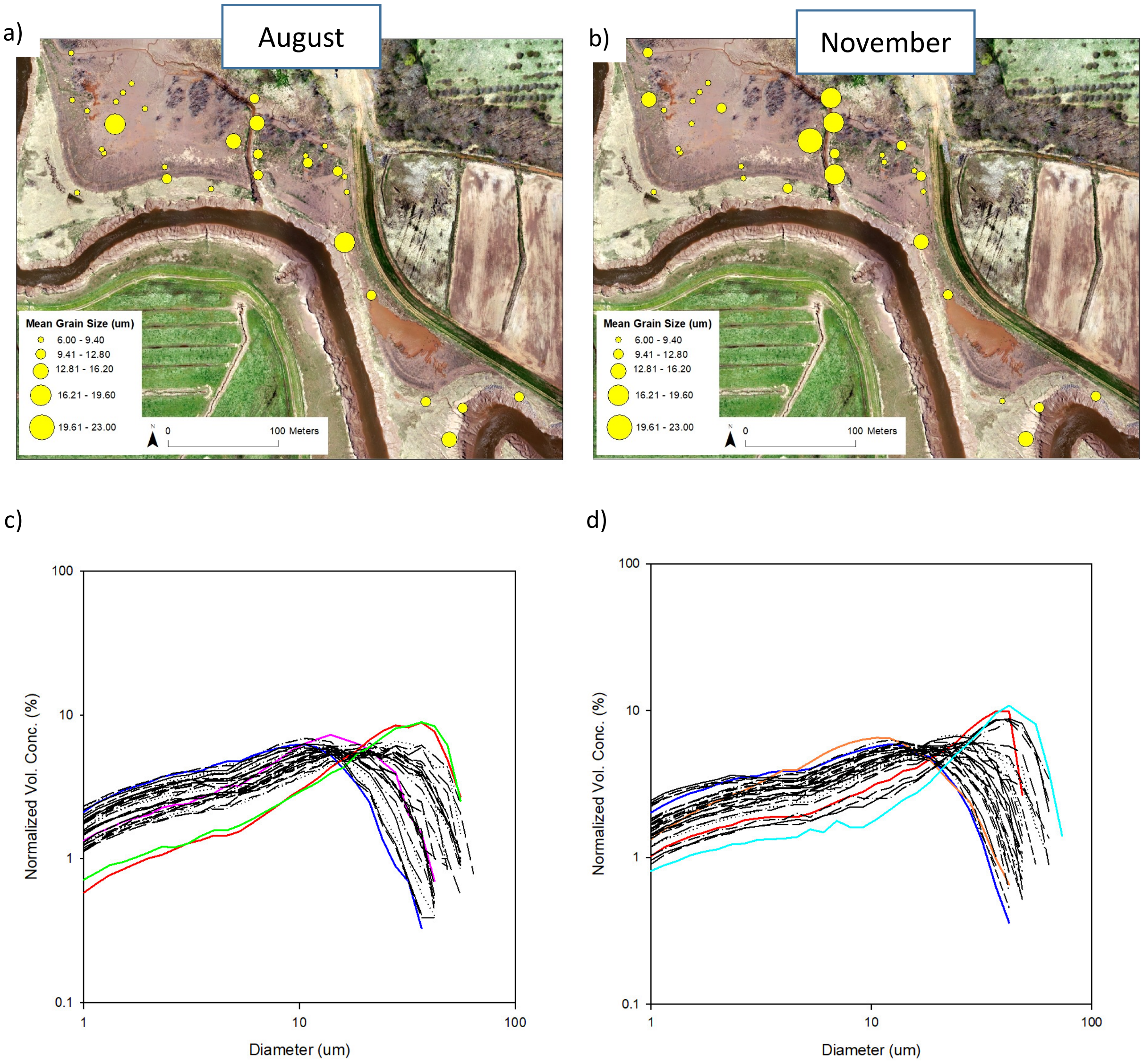


Figure 4.1 a) Mean grain size (µm) in August at the Belcher Street Marsh. b) Mean grain size (µm) in November at the Belcher Street Marsh. c) Grain size diameter plotted against the normalized volume concentration (%) for the Belcher Street Marsh in August. d) Grain size diameter plotted against the normalized volume concentration (%) for the Belcher Street Marsh in November. Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/05/18.

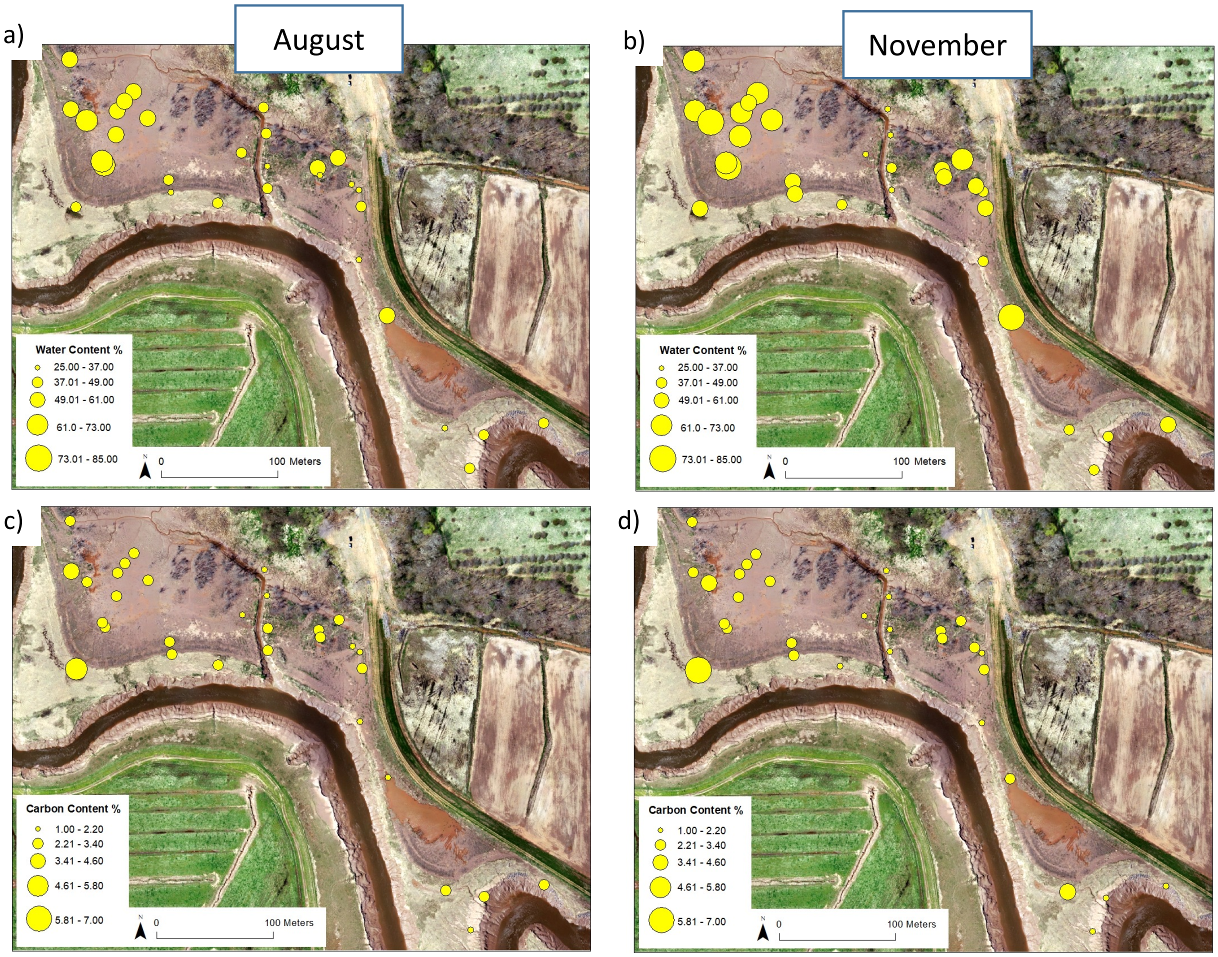


Figure 4.2. a) Water content in August at the Belcher Street Marsh. b) Water content in November at the Belcher Street Marsh. c) Organic carbon content in August at the Belcher Street Marsh. d) Organic carbon content in November at the Belcher Street Marsh. Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/05/18.

Likely, the samples in the fine fraction (finer than ~10 µm) are deposited as flocks (Figure 4.3, c). In August (Figure 4.3, c), the samples' fine/mud fraction slopes are all very similar, accurately indicating that the samples were taken from similar locations. Sample ER4 (red line, elevation of 5.89 m) and sample T2S7 (green line, elevation of 6.06 m) show the lowest mud fractions. These samples peak and trail off slightly later than the other samples, indicating a higher concentration of coarse sediment. Sample ER27 (blue line, elevation of 5.74 m) and sample MH9 (pink line, elevation of 6.36m) show a higher concentration of fine sediments, peaking at a small grain size and trailing off quickly with decreasing concentration (Figure 4.3, c).

In November, samples ER0 (blue line, elevation of 6.38 m) and ER4 (pink line, elevation of 5.89) have the lowest concentration of fine sediments, a high peak indicating a high concentration of coarse sediments and the largest grain sizes (Figure 4.3, d). Sample ER13 (green line, elevation of 6.15 m) has a regular fine sediment concentration, an early peak and the lowest coarse sediment concentrations. Sample ER2 (red line, elevation of 6.17 m) has an abnormally high concentration of fine sediments, no clear peak and showing low concentrations of coarse sediment (Figure 4.3, d).

In August (Figure 4.4, a), the water content percent ranges from 27% to 65 %. The pattern observed on the map is a high percent water content across the salt marsh surface, except around the creek leading away from the main river. The same pattern can be observed in November (Figure 4.4, b), where the water content ranges from 27% to 77%. Here, the lowest water content can again be found around the creek, while the highest water content is scattered across the rest of the marsh surface. The organic carbon content percent shows the same pattern as the water content, for August and November, only on a smaller scale (Figure 4.4, c) & d). In August, the organic carbon content ranges between 1% and 4 %. The samples with small organic carbon content near the creek are found within the 1% to 2.3% range (Figure 4.4, c). In November, the organic carbon content ranges from 1% to 4%, but the samples with the smallest organic carbon content found near the creek are all within the 1% to 1.7% range (Figure 4.4, d).

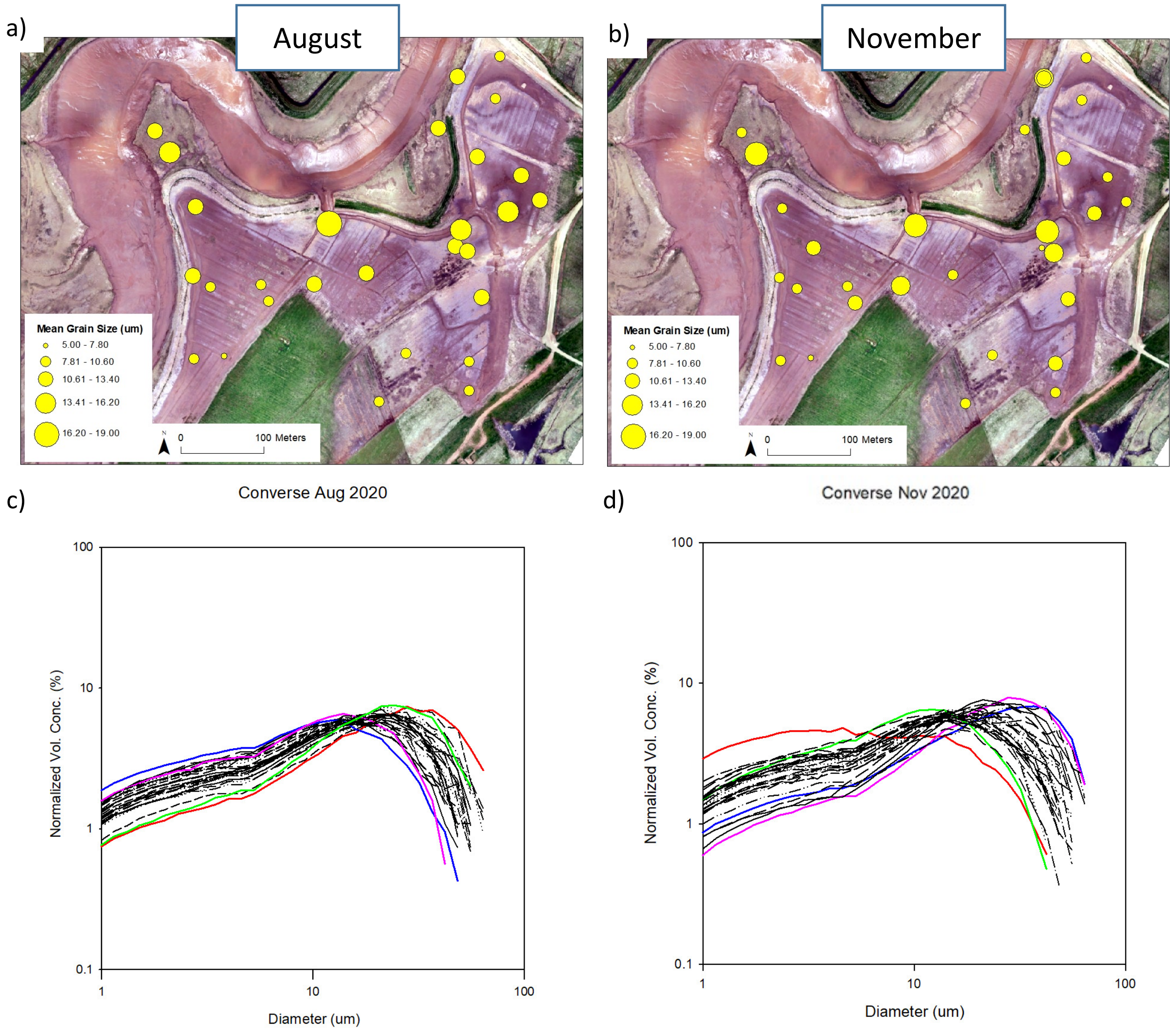


Figure 4.3. a) Mean grain size (µm) in August at the Converse Marsh. b) Mean grain size (µm) in November at the Converse Marsh. c) Grain size diameter plotted against the normalized volume concentration (%) in August at the Converse Marsh d) Grain size diameter plotted against the normalized volume concentration (%) in November at the Converse Marsh. Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/06/01.

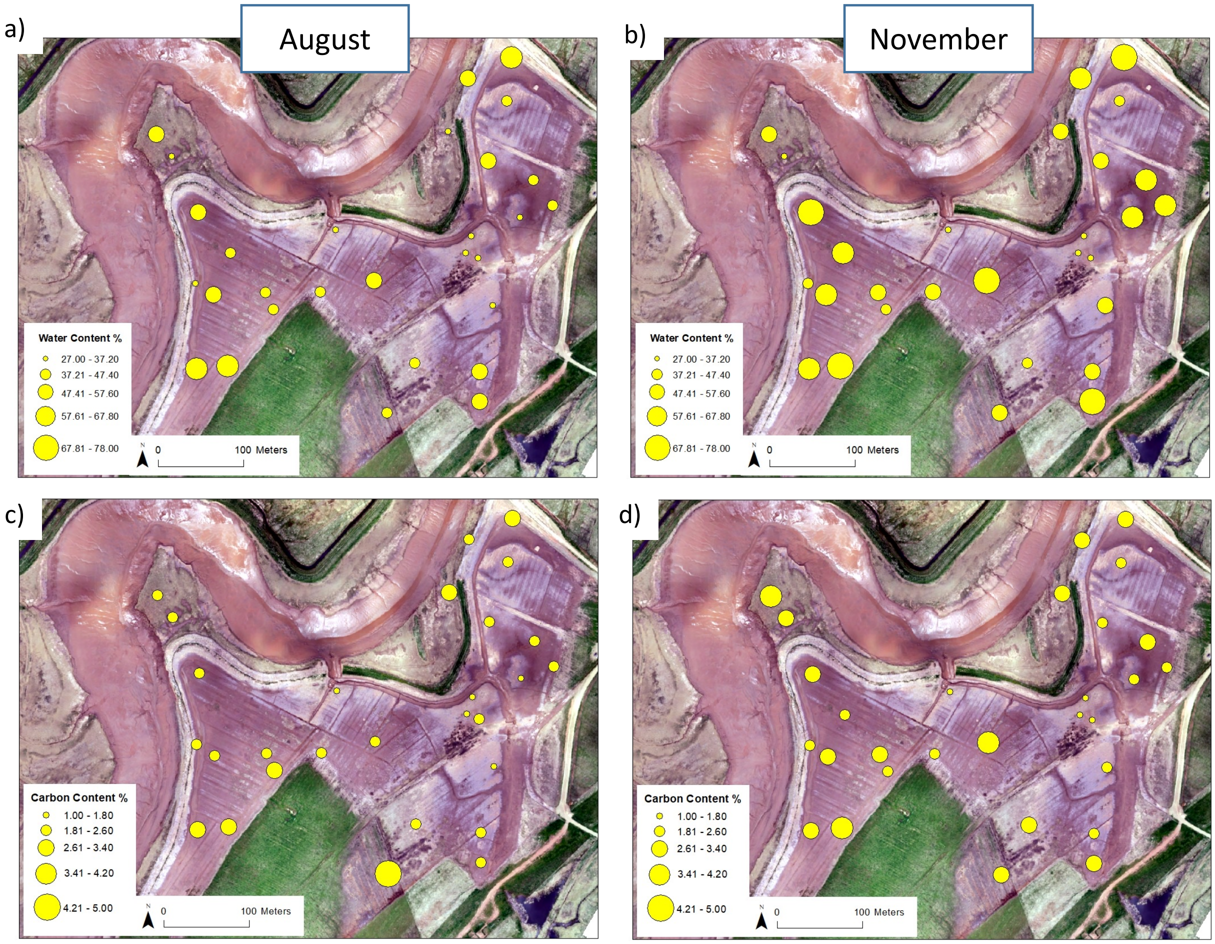


Figure 4.4. a) Water content in August at the Converse Marsh. b) Water content in November at the Converse Marsh. c) Organic carbon content in August at the Converse Marsh. d) Organic carbon content in November at the Converse Marsh. Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/06/01.

4.2 Elevation Change Within Tidal Frame

4.2.1 Belcher Street Marsh

There is not much variation in grain size between August and November and no large variation across the marsh surface (Figure 4.5). The small R^2 values indicate that the trendline does not explain most of the variability that can be found around the trendline (August R^2 = 0.109, November R^2 = 0.003). The p-value is showing no significant relationship between the mean grain size and the elevation for both August ($p = 0.07$) and November ($p = 0.749$) (Figure 4.5).

There is a visible decrease in the water content trendlines with increasing elevation (Figure 4.6). The R^2 value for August ($R^2 = 0.447$) shows that the trendline explains nearly 50% of the variability in the points found around it. In November ($R^2 = 0.074$), the trendline does not explain the variability. The p-value for August ($p = 3.84 \times 10^{-5}$) shows a significant relationship between the elevation and the water content percentage. The p-value for November ($p = 0.139$) is not showing a significant relationship between the elevation and water content percent.

Organic carbon trendlines (Figure 4.7) show an increase in organic carbon content percent with increasing elevation. However, the R^2 values are small for August and November ($R^2 =$ 0.015 and 0.105, respectively) and therefore do not explain variability around the trendline. The p-values for August ($p = 0.505$) and November ($p = 0.075$) are not indicating a significant relationship between increasing elevation and organic carbon content percent.

Organic carbon content decreases with increasing grain size (Figure 4.8), more so in the November trendline than the August trendline. The organic carbon content is mostly even across all grain size distributions for the August sampling round. The R^2 value (0.082) does not explain the variability of the points. The p-value (0.119) shows no significant relationship between the organic carbon content and the mean grain size (µm) at the Belcher Street Marsh in August. The slope of the trendline for November has a sharper decrease, indicating a trend of decreasing organic carbon content with increasing mean grain size (µm). The R^2 (0.362) does not explain the trendline. The p-value ($p = 3.463 \times 10^{-4}$) shows that there is a significant relationship between the organic carbon content percent and the mean grain size.

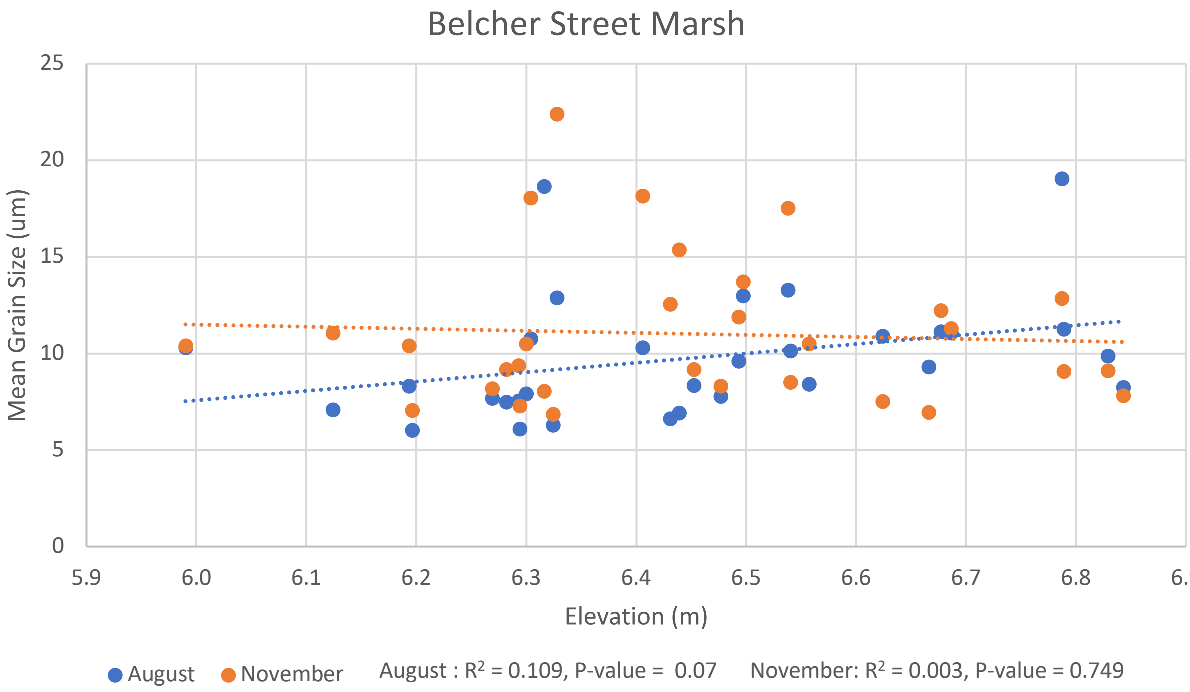


Figure 4.5. Scatterplot of mean grain size versus elevation at the Belcher Street Marsh study site.

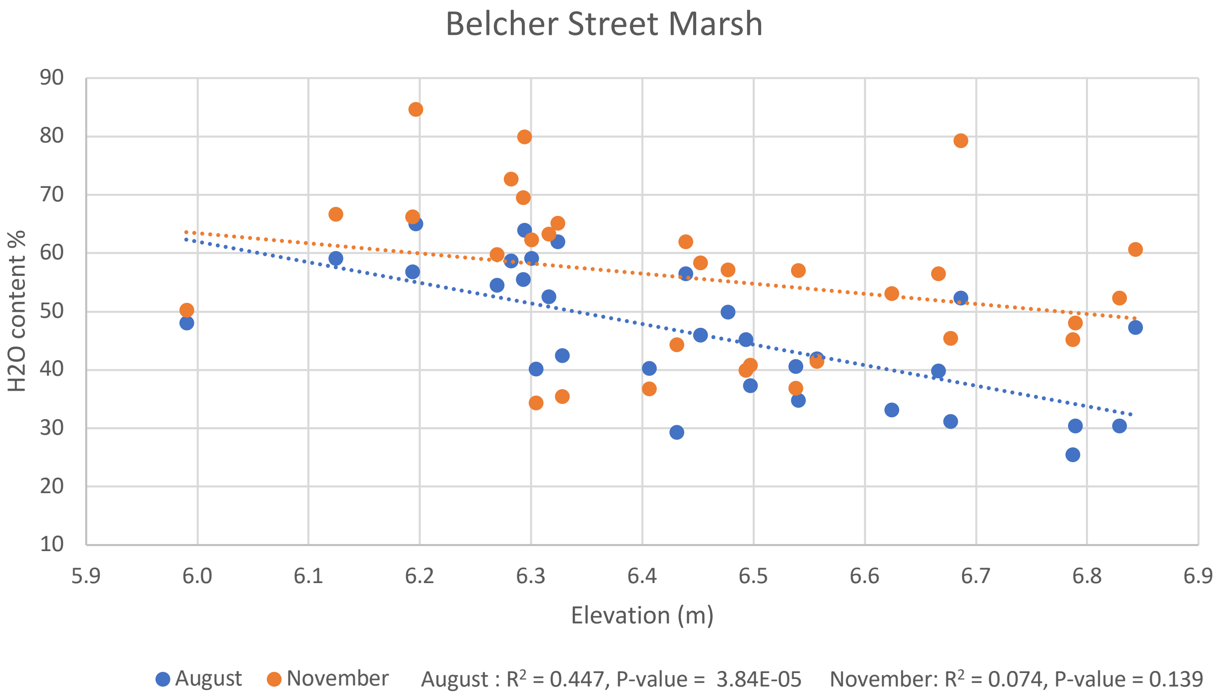


Figure 4.6. Scatterplot of water content versus elevation at the Belcher Street Marsh study site.

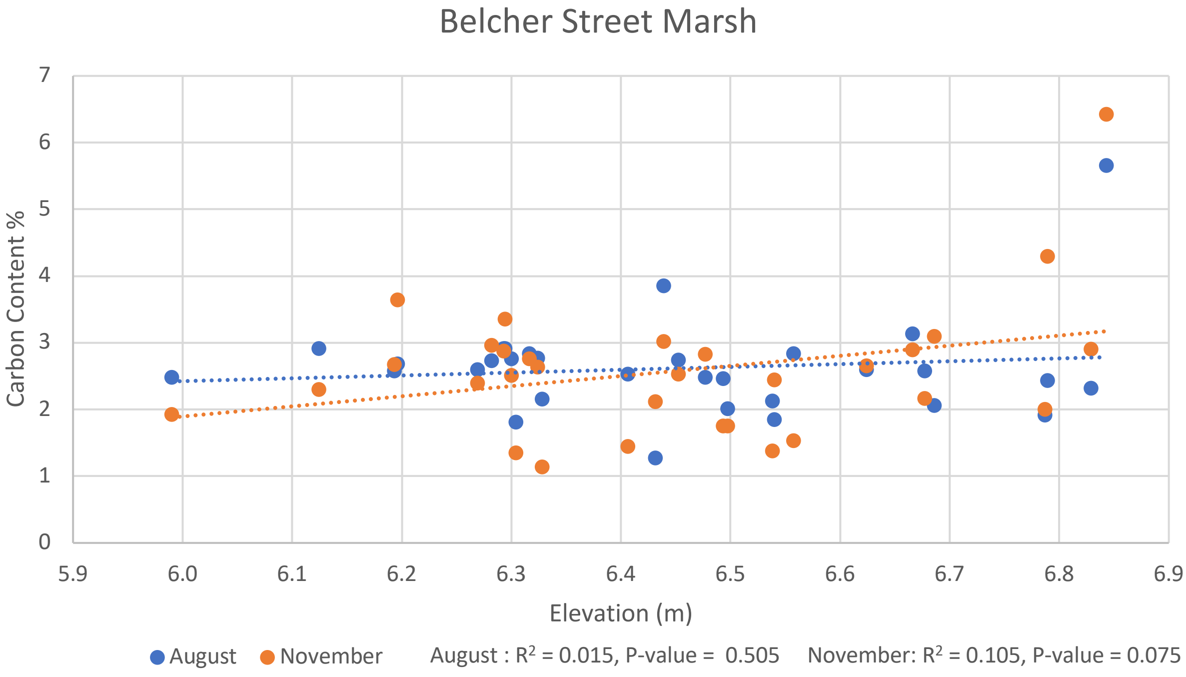


Figure 4.7. Scatterplot of organic carbon content versus elevation at the Belcher Street Marsh study site.

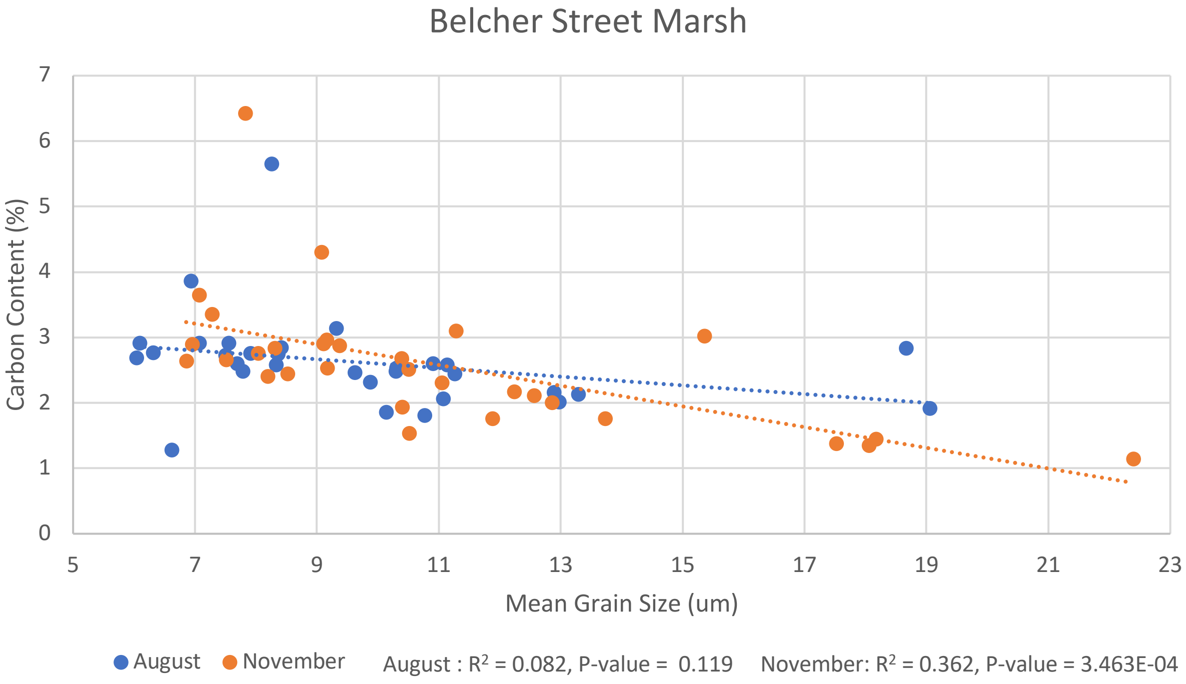


Figure 4.8 Scatterplot of organic carbon content versus mean grain size at the Belcher Street Marsh study site.

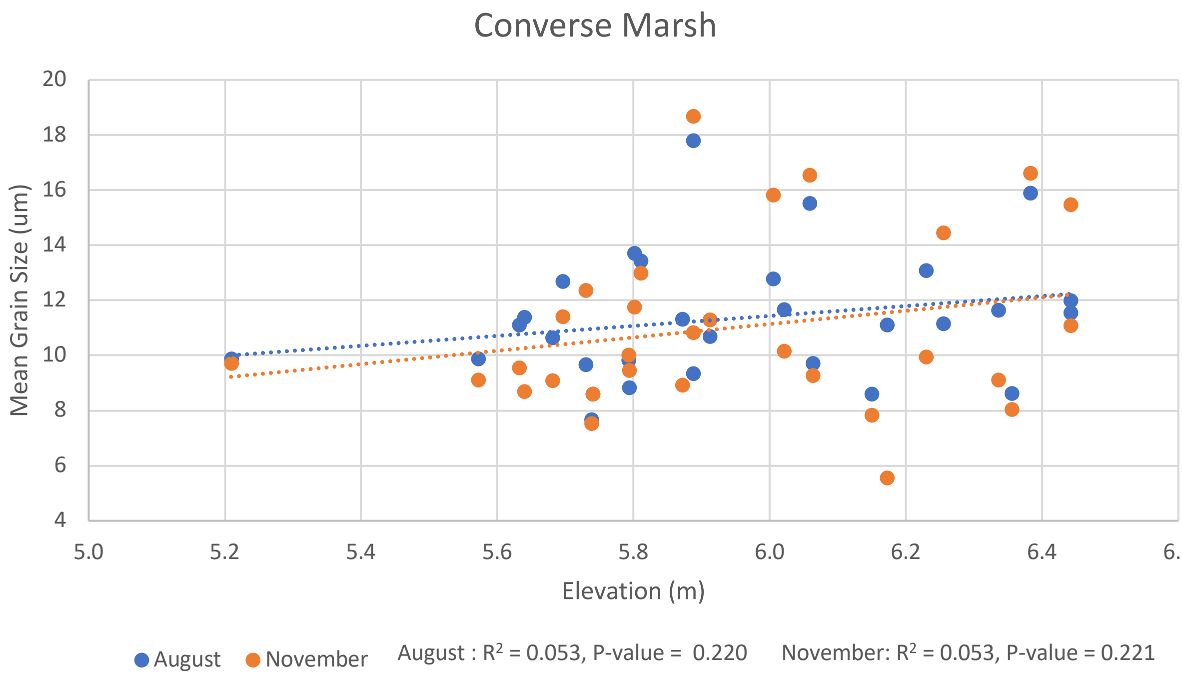
4.2.2 Converse Marsh

There is a minimal difference between the mean grain sizes from August and November. Both trendlines (Figure 4.9) show increasing grain size with increasing elevation and are incredibly close to each other on the figure. The p-values show no significant relationship between the elevation and the mean grain size for August ($p = 0.220$) and November ($p = 0.221$). The R^2 values are small and do not explain the point variability around the trendline ($R^2 = 0.053$ for August and November).

Overall, there is a lower percent water content in August compared to November, but both trendlines are decreasing (Figure 4.10). The p-values for August and November water content show a significant relationship between elevation and water content percent (0.004 and 6.83E-05, respectively). The R^2 values are not representative of the variability occurring around the trendline, as they are too small ($R^2 = 0.011$ for August and $R^2 = 0.045$ for November).

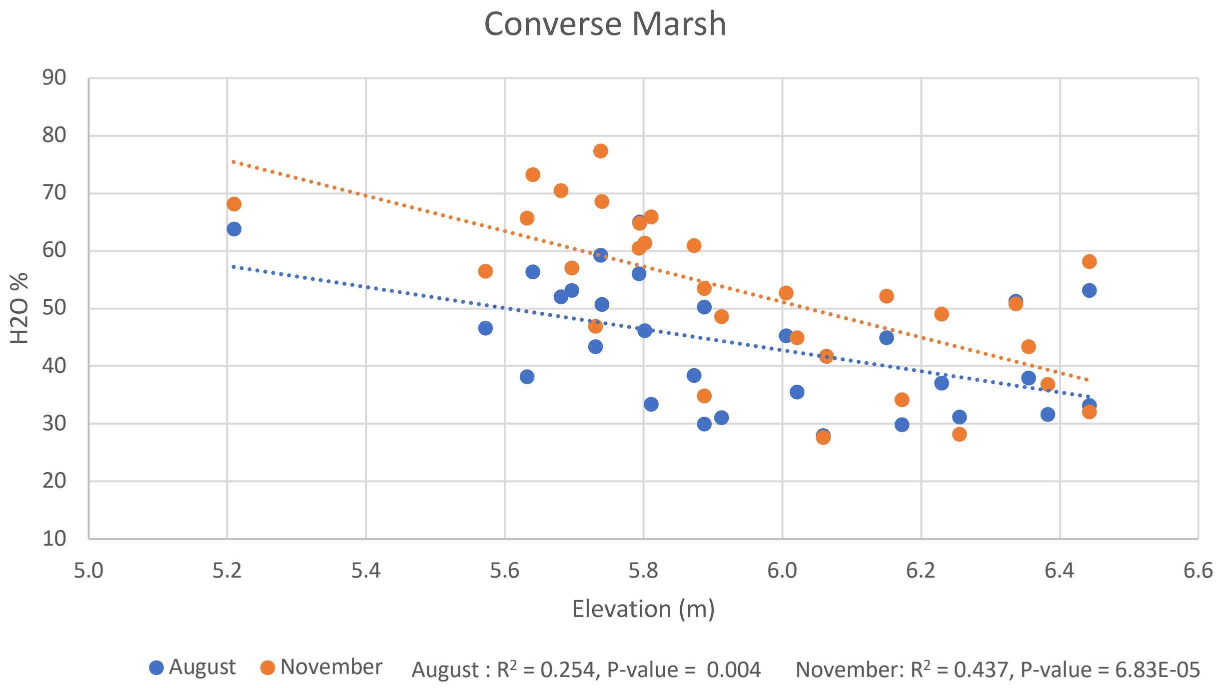
Visually, both trend lines show a decrease in organic carbon content with increasing elevation (Figure 4.11). It is not statistically significant as the p-value is 0.581 for August and 0.259 for November. This indicates no significant relationship between organic carbon content percent and elevation during either sampling round. Both R^2 values show that the trendline does not explain the variability found around it (0.011 for August and 0.045 for November).

The organic carbon content is decreasing with increasing mean grain size, as shown by both decreasing trendlines (Figure 4.12). The R^2 value does not explain the variability of the points for August or November ($R^2 = 0.285$ and 0.291, respectively). The p-values indicate a significant relationship between mean grain size and organic matter content for August (p-value = 0.003) and November (p-value = 0.002).



August : R^2 = 0.053, P-value = 0.220 November: R^2 = 0.053, P-value = 0.221

Figure 4.9. Scatterplot of mean grain size versus elevation at Converse Marsh study site.



August : R^2 = 0.254, P-value = 0.004 November: R^2 = 0.437, P-value = 6.83E-05

Figure 4.10. Scatterplot of water content versus elevation at Converse Marsh study site.

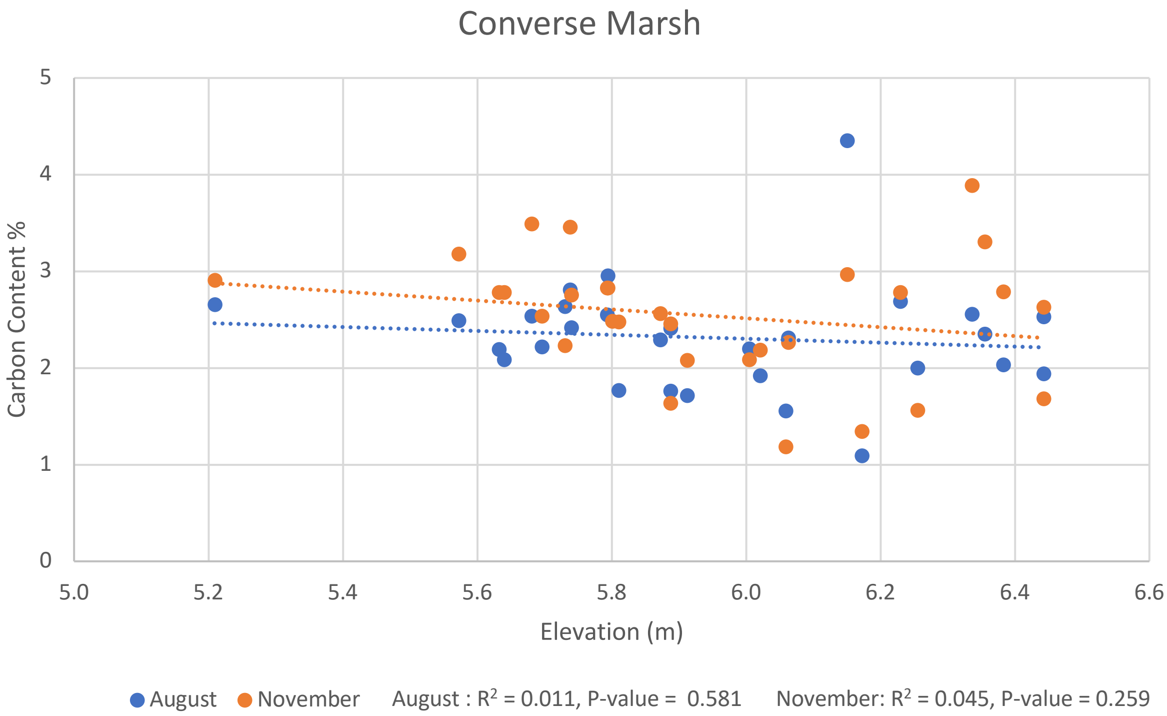


Figure 4.11. Scatterplot of organic carbon content versus elevation at Converse Marsh study site.

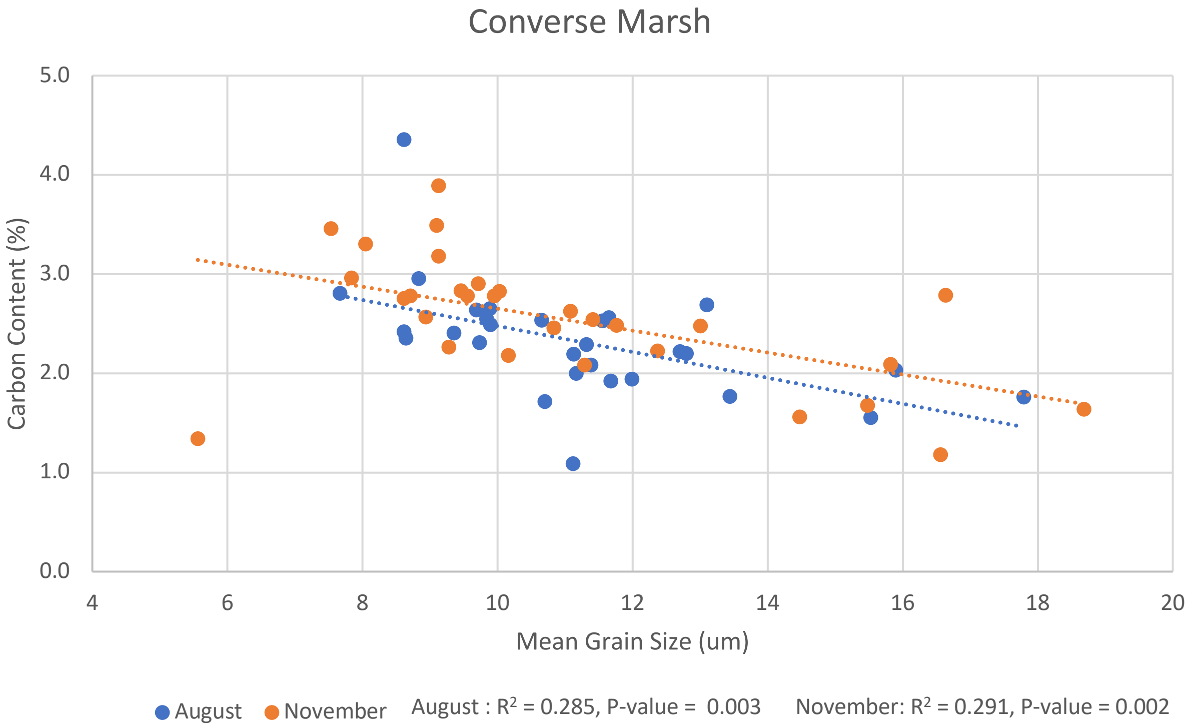


Figure 4.12. Scatterplot of organic carbon content versus mean grain size at Converse Marsh study site.

4.3 Temporal Variation of Sediment Characteristics

4.3.1 Belcher Street Marsh

In Figure 4.13, the blue circles represent an increase in grain size, and the yellow circle represents a decrease. The symbol's size represents the size of the change from August to November, relative to the other sample locations. There is an overall increase in sediment grain size across the marsh surface, as seen by most blue circles. The change in grain size ranges from an increase of 9.5 µm and a decrease of 10.63 µm. The map shows a clear increasing trend in grain size around the creek. These locations were recently flooded during the over marsh tide before the November sampling. The sample locations that are decreasing in mean grain size are not showing an obvious pattern.

There is an overall decrease in water content across the salt marsh surface (Figure 4.14, a). Conversely, there is an increase in water content in the samples surrounding the creek and the main river. The change in water content ranges from an increase of 7% and a decrease of 26%. The bigger symbols are representative of the largest change in water content, as can be seen by the large yellow circles representing a decrease in water content by 25%.

Most points have decreased in organic carbon content (Figure 4.14, b). There is a trend of decreasing organic carbon content near the creek and the main river. The increases in organic carbon content are not showing any obvious pattern. The relationships observed in mean grain size changes are inconsistent with those observed in the percent water content and percent organic carbon content change.

4.3.2 Converse Marsh

Most samples show a decrease in mean grain size from August to November (Figure 4.15). The grain size increases by a range of 0 µm to 3.49 µm and drops by a range of 0 µm to (-) 5.55 µm. The symbol size represents the magnitude of the change. The samples increasing in mean grain size are located near the creeks and the edges of the marsh.

The water content percent increases across the marsh surface from 0 to 22% (Figure 4.16, a). Only five samples show a decrease in water content from August to November, and there is a disparity in their locations. The decline in water content varies between 0 and 3%. The highest increase in water content is found near the creek. The samples decreasing in water content are in areas of higher elevation. Conversely, some areas of high elevation are showing an increase in water content.

The organic carbon content shows a trend like the water content: an overall increase in organic carbon content across the salt marsh surface. However, there are specific sample locations where the organic carbon content is decreasing. Similar to the samples increasing in grain size, the samples decreasing in organic carbon content are found near the creeks and around the marsh edge. The organic carbon content is rising by 1.33 % and decreasing by 1.38% (Figure 4.16, b).

Figure 4.13. Change in mean grain size (µm) from August to November at the Belcher Street Marsh. Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/05/18.

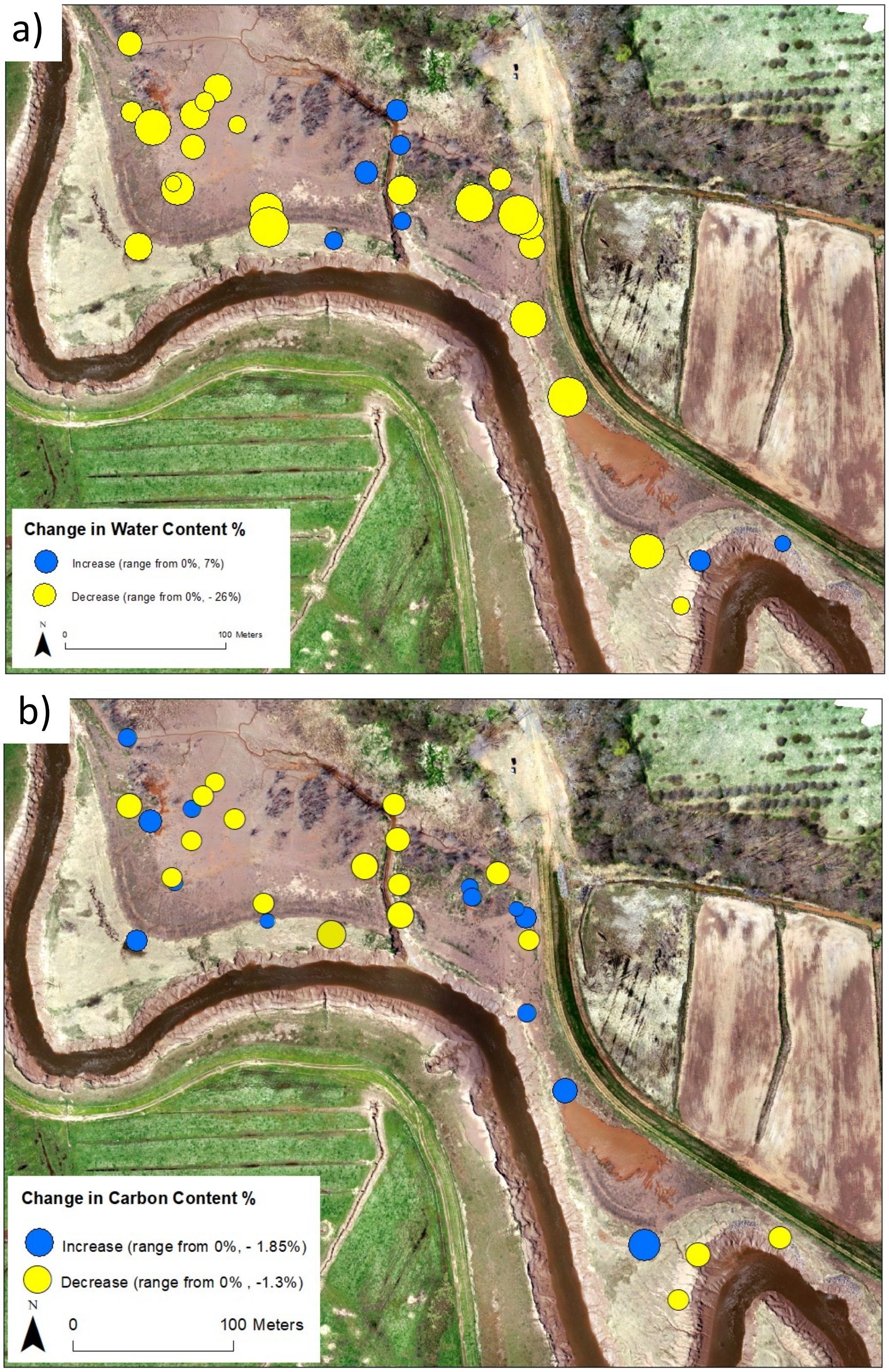


Figure 4.14. a) Change in Water Content Percent from August to November at the Belcher Street Marsh. b) Change in Organic Carbon Content Percent from August to November at the Belcher Street Marsh. Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/05/18.

Figure 4.15. Change in Mean Grain Size (µm) from August to November at the Converse Marsh. Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/06/01.

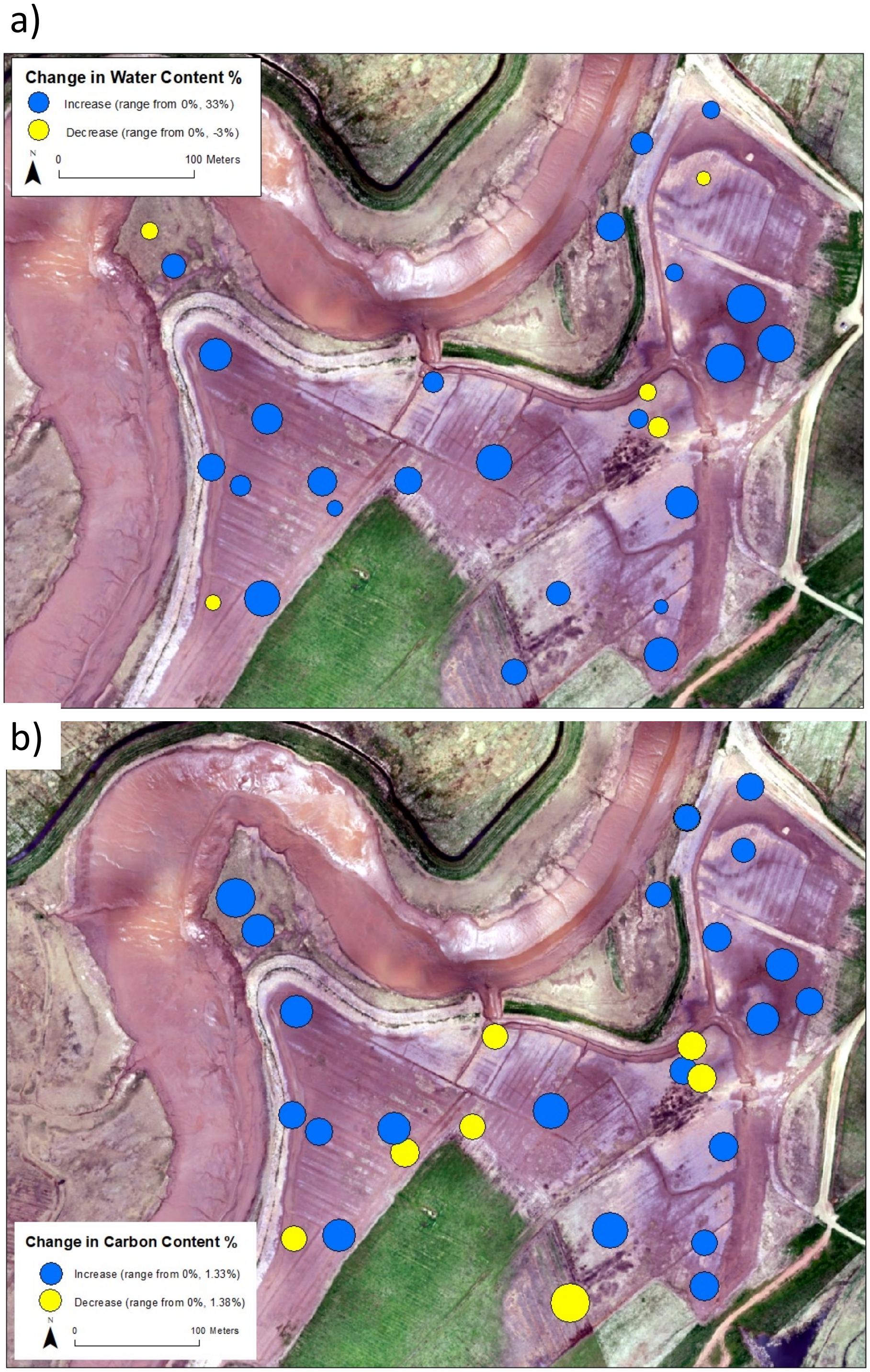


Figure 4.16. a) Change in Water Content Percent from August to November at the Converse Marsh. b) Change in Organic Carbon Content Percent from August to November at the Converse Marsh. Orthomosaic generated from low altitude aerial imagery collected by a DJI Phantom 4 RPAS, piloted by Samantha Lewis on 2020/06/01.

4.4 Comparison to Reference Sites

The reference conditions were measured by CBWES and Saint Mary's University before the dyke breach as part of the post-monitoring project of the managed realignment for both Belcher Street Marsh and the Converse Marsh. The reference conditions are necessary to provide reference values for the various variables measured during the post-monitoring process. They were published in various technical reports and provided for this study, as it will help determine if CBWES' current sampling methodology is representative of the salt marsh condition. Five points were used from the Belcher Street Marsh for this study, and seven points were used from the Converse Marsh. The tables in this comparison use organic matter content, whereas the maps display organic carbon content percent. Organic matter is used in these tables to conduct a comparison to the CBWES data.

4.4.1 Belcher Street Marsh

From 2017 to 2018, water content decreased from an average of 64.2 % to 44.2 % (Table 4.1). The average water content increased from 2018 to 2020, 49.2% in August and 56.1% in November. The organic matter percent values are much higher in the reference conditions compared to the current conditions. Reference conditions have a mean organic matter content of 20.6%. The average in 2018 was 4.6%, and the averages in 2020 were 6.1% and 5.7% for August and November, respectively.

There is no evident trend in mean grain size from reference conditions to the first year of post-monitoring (Table 4.2). The 2020 grain size points are still within the same size class, as all measured points are considered silt. In 2017, the grain size ranged from fine to medium silt, and in 2020, they range from fine to coarse silt.

The average organic carbon density for August is 0.019 g cm^{-3}, and the average organic carbon density for November is 0.017 g cm^{-3} (Table 4.3). The summary table includes the average, the standard deviation, the minimum and maximum values for all sediment characteristics at each site (Table 4.4).

4.4.2 Converse Marsh

The reference conditions are displaying higher water content than all post-monitoring data (Table 4.5). The average water content was 67.9% during the reference conditions, while the average water content for the post-monitoring samples is 25.1% in June, 43.3% in August and 52.0% in November. Since this table offers data for three sampling rounds in the same year, it also shows the increasing percent water content throughout the growing season.

The organic matter content is much higher in the reference conditions than in the current conditions (Table 4.5). The average organic matter for the reference condition is 26.7%. The organic matter content for the post-monitoring conditions is 5.0% in June 2020, 5.2% in August and 5.8% in November. The average organic matter is increasing throughout the growing season. A 90.7 % outlier is found at point T1S4 in August.

The average grain size is larger during the post-monitoring conditions than the reference conditions (Table 4.6). The average grain size during the reference conditions is 9.1 µm but is 11.4 µm in June 2020, 11.8 µm in August 2020 and 11.7 µm in November 2020. The average grain size throughout the growing season remains similar. Each sample varies through the months without displaying a noticeable trend.

In August, the mean organic carbon density is 0.071 g cm^{-3} and in November is 0.022 g cm^{-3} (Figure 4.7). The summary table includes the average, the standard deviation, the minimum and the maximum of the sediment characteristics measured at the Converse Marsh (Figure 4.8).

Table 4.1. Comparison of Water Content and Organic Matter Content at the Belcher Street Marsh including reference condition, Year 1 post-monitoring conditions and conditions sampled during this study.

Sample ID	**Water Content (%)**				**Organic Matter Content (%)**			
	2017 Reference Conditions	2018 Year 1	2020 August this study	2020 November this study	2017 Reference Conditions	2018 Year 1	2020 August this study	2020 November this study
T2S4	74.0	56.0	54.5	59.7	24.0	6.0	6.5	6.0
T2S5	76.0	52.0	52.5	63.2	24.0	6.0	7.1	6.9
T2S6	79.0	29.0	62.0	65.1	26.0	1.0	6.9	6.6
T3S4	44.0	44.0	42.4	35.4	14.0	4.0	5.4	2.9
T4S3	48.0	40.0	34.8	57.0	15.0	6.0	4.6	6.1
Average	64.2	44.2	49.2	56.1	20.6	4.6	6.1	5.7
St. Dev.	15.0	9.5	9.6	10.7	5.0	2.0	0.9	1.5

Table 4.1. Comparison of Mean Grain Size (µm) from Reference Conditions to Present

Sample ID	**2017** (reference conditions)	**2018** (Year 1)	**2020 August** (this study)	**2020 November** (this study)
T2S4	7.1	7.3	7.7	8.2
T2S5	9.5	6.3	18.7	8.0
T2S6	8.3	6.4	6.1	7.3
T3S4	9.5	20.9	12.9	22.4
T4S3	7.9	11.2	10.1	8.5
Average	8.5	10.4	11.1	10.9
St. Dev.	0.9	5.5	4.4	5.8

Table 4.3 Organic Carbon Density (g cm^{-3}) for the Belcher Street Marsh

Sample ID	**Organic Carbon (g cm^{-3})**	
	August	**November**
T2S4	0.016	0.015
T2S5	0.017	0.016
T2S6 pink	0.013	0.012
T3S4	0.028	0.015
T4S3	0.020	0.027
Average	0.019	0.017
St. Dev.	0.005	0.005

Table 4.4 Summary Table for the Belcher Street Marsh.

	August				**November**			
	Mean Grain Size (μm)	Water (%)	Organic Matter (%)	Organic Carbon (%)	Mean Grain Size (μm)	Water (%)	Organic Matter (%)	Organic Carbon (%)
Average	9.75	46.11	6.54	2.62	11.01	55.64	6.44	2.58
St. Dev.	3.12	11.18	1.81	0.73	3.77	13.54	2.48	0.99
Minimum	6.04	25.46	3.19	1.28	6.86	34.34	2.86	1.14
Maximum	19.05	65.02	14.14	5.66	22.39	84.59	16.07	6.43

Table 4.*5* Comparison of Water Content and Organic Matter Content at the Converse Marsh from Reference Conditions to Present. *High value may be an outlier associated with pseudofeces.

Sample ID	**Water (%)**				**Organic Matter (%)**			
	2017 reference conditions	2020 June Year 3	2020 August this study	2020 November this study	2017 reference conditions	2020 June Year 3	2020 August this study	2020 November this study
T1S2	80.1	36.0	46.6	56.5	77.0	6.6	6.2	7.9
T1S4	70.8	30.3	46.2	61.4	86.9	5.4	90.7*	6.2
T1S6	82.3	30.9	56.4	73.3	85.3	5.9	5.2	6.9
T2S4	55.3	25.2	31.1	48.6	31.1	5.6	4.3	5.2
T2S6	59.2	15.5	31.2	28.2	44.6	4.7	5.0	3.9
T2S7	50.5	18.8	27.9	27.6	17.8	3.9	3.9	3.0
T3S4	77.1	19.3	63.8	68.2	81.5	3.0	6.6	7.3
Average	67.9	25.1	43.3	52.0	60.6	5.0	5.2*	5.8
St. Dev.	11.9	7.0	12.8	16.9	26.7	1.1	29.9	1.7

Table 2.6. Comparison of Mean Grain Size (μm) from Reference Conditions to Present.

Sample ID	**2017** (reference conditions)	**2020 June** (Year 3)	**2020 August** (this study)	**2020 November** (this study)
T1S2	7.1	9.1	9.9	9.1
T1S4	10.6	15.0	13.7	11.8
T1S6	9.2	8.0	11.4	8.7
T2S4	7.6	6.9	10.7	11.3
T2S6	9.7	14.9	11.2	14.5
T2S7	7.2	16.2	15.5	16.6
T3S4	12.5	9.7	9.9	9.7
Average	9.1	11.4	11.8	11.7
St. Dev.	1.9	3.5	1.9	2.7

Table 4.7 Organic Carbon Density (g cm^{-3}) for the Converse Marsh.
*High value may be associated with pseudofeces.

Sample ID	**August**	**November**
	Organic Carbon (g cm^{-3})	Organic Carbon (g cm^{-3})
T1S2	0.021	0.027
T1S4	0.377*	0.026
T1S6	0.024	0.032
T2S4	0.014	0.017
T2S6	0.018	0.014
T2S7	0.017	0.013
T3S4	0.026	0.029
Average	0.020*	0.022
St. Dev.	0.125	0.007

Table 4.8 Summary table of the Converse Marsh.

	August				**November**			
	Mean Grain Size (µm)	Water (%)	Organic Matter (%)	Organic Carbon (%)	Mean Grain Size (µm)	Water (%)	Organic Matter (%)	Organic Carbon (%)
Average	11.33	43.81	5.81	2.31	11.00	52.89	6.35	2.54
St. Dev.	2.28	10.57	1.40	0.56	3.07	13.53	1.57	0.63
Minimum	7.67	27.92	2.73	1.09	5.56	27.63	2.96	1.18
Maximum	17.79	65.03	10.89	4.36	18.68	77.32	9.73	3.89

CHAPTER 5

DISCUSSION

This study looked at the spatial and temporal variations in sediment composition in two newly restored salt marshes in the Bay of Fundy in August and November. The research objectives were to determine if sediment characteristics varied spatially across the salt marsh surface and if these variations were consistent over time. This study analyzed the relationship between sediment characteristics and the elevation of the salt marsh surface. This information will be presented in the context of other similar studies. It will help inform on CBWES' once-per-year sampling technique and report the ability of newly restored salt marshes to provide essential ecosystem services such as organic carbon sequestration to ResNet.

5.1 Controls on Spatial Variations of Sediment Characteristics

All sediment characteristics show variability across both newly restored salt marsh surfaces during both months (August and November). At the Belcher Street Marsh (Figure 4.1), grain size is largest around the creek and becomes finer towards the inner marsh for August and November. This trend has been observed in other restored salt marshes (Roner et al., 2016; D'Alpaos et al., 2007; D'Alpaos et al., 2019). At the Converse Marsh (Figure 4.3), grain size decreases with increased elevation and distance from the dyke breach. As water floods the surface, its sediment transport capability reduces. The dense vegetation decreases current velocities (Leonard & Luther, 1995) and water turbulence while increasing particle capture (Mudd et al., 2010). These processes create opportunities for deposition (Christiansen et al., 2000; Leonard & Luther, 1995; Mudd et al., 2010) and are why finer sediments are found towards the inner marsh on the Belcher Street Marsh and farthest away from the dyke breach on the Converse Marsh. The sediment is transported and deposited by the same processes on both marshes. The difference in grain size patterns is due to the different elevation gradients on the marsh surfaces: Belcher Street Marsh being concave up and Converse Marsh increasing in elevation with distance from the dyke breach. Salt marshes with the same elevation gradient as the Converse Marsh have similar deposition patterns due to hydrodynamics attenuation (Yang et al., 2008; Law et al., 2018).

At the Belcher Street Marsh in August, samples ER76 (red line) and T2S5 (green line) (Figure 4.1, c) show very similar grain size compositions, yet are found on different parts of the marsh. They are not in the same elevation class, suggesting different inundation frequencies. Field observations for sample T2S5 show that it was taken within a patch of vegetation, which can explain the coarse sediment values. ER76 is expected to have higher values due to its proximity to the main river. Field observations for sample ER13 (blue line) show that it was taken from a patch of bare, wet sediment surrounded by vegetation. ER00 (pink line) is located on the edge of the newly restored marsh. Field observations indicate that it was taken from dry sediment that likely had not recently been flooded, explaining why it has low coarse grain size concentrations.

In November (Figure 4.1, d) ER00 (blue line) still has a small mean grain size but a higher concentration of fine silt and a lower concentration of coarse silt. The recent flood event that took place before sampling deposited fine sediment on the inner marsh surface. Sample ER8 (orange line) is located near the newly restored boundary similar to ER00 and demonstrates similar grain size distribution. Sample T3S4 is situated on the West side of the creek and has the largest grain size. This is expected after a recent deposition event because the high elevation near the creek and dense vegetation slow water velocities and increase deposition opportunity. Sample ER1 (red line) has a curve similar to sample T3S4 (cyan line) because of its proximity to the river during the recent inundation event. Its high vegetation cover increases particle capture.

At the Converse site, sample ER4 (red line) and sample T2S7 (green line) have similar grain size curves (Figure 4.3, c). They are inundated first due to their proximity to the creek. Their vegetation and increasing elevation will play a substantial role in slowing the water velocities and increasing particle capture. Samples ER27 (blue line) and MH9 (pink line) (Figure 4.3, c) are both located on the West side of the marsh near the marsh edge. This location is far from the breach, so the coarse particles fell out of suspension before arriving at this location.

In November, sample ER4 (pink line) shows the same pattern as August, which is expected based on its location near the breach. Sample ER0 (blue line) has a similar grain size curve as sample ER4. It is located on the foreshore marsh and is highly vegetated, increasing grain size through particle capture. Sample ER2 has an abnormal shape due to its high mud fraction, no peak, and low concentration of coarse sediments. This sample's proximity to T2S7 creates the assumption that it should have a similar grain size curve. Sample ER13 is located near the marsh's edge at higher elevations, indicating the small coarse fraction is due to low sedimentation and coarse particles falling out of suspension before arriving at this site.

Salt marsh water content is highly variable and dependent on recent weather events, flooding frequency and drainage quality of each specific location. At the Belcher Street Marsh, the inner marsh has higher water content due to poor drainage caused by the concave-up elevation profile of the marsh surface. This occurs in August and November. At the Converse

Marsh, the water content decreases with distance from the creek and increasing elevation for August and November.

The spatial variability in the percent organic carbon content is increasing with distance from the creek in August and November at the Belcher Street Marsh (Figure 4.2, c & d). This trend has been observed in other restored salt marshes (Roner et al., 2016; Reed et al., 1999). At the Converse Marsh, the lowest percent organic carbon content occurs near the creek at the sample locations with the highest elevations (Figure 4.4, c & d). Low percent organic carbon content is attributed to higher elevations because the marsh surface floods for shorter periods. Well-drained soils are oxidized, leading to rapid organic matter degradation. This causes low organic matter content and low organic carbon content (Roner et al., 2016). Lower elevations are flooded for extended periods, leading to hypoxic conditions, preventing organic matter degradation. This increases the percent organic carbon content in the sites with lower elevations (Roner et al., 2016). The Belcher Street Marsh has a concave-up elevation profile due to the high flooding frequency near the creek (Figure 3.3, a). The entire marsh surface is only flooded during tides exceeding 15 m (chart datum), explaining why the inner marsh has a higher percent carbon content. The Converse Marsh floods more regularly. Due to its elevation gradient increasing with distance from the coast (Figure 3.3, b), the carbon content is more dependent on organic matter content created by plants. Plant production increases organic matter accumulation in the soil, which explains why the densely vegetated areas of the marsh surface have high organic carbon content, despite having high elevations (Nyman et al., 1993). The percent organic carbon content is found within the percent organic matter content (Wollenberg et al., 2018).

Both salt marshes show the ability to sequester carbon shortly after restoration. This is indicative of their high potential to provide carbon sequestration as an ecosystem service to Canadians.

5.2 Controls on Temporal Variations of Sediment Characteristics

Sediment compositions vary across the growing season, as was identified by the sampling rounds occurring four months apart, in August and in November (Figures 4.1, 4.2, 4.3 & 4.4). Seasonal changes such as storms and higher velocity waters in the winter increase the possibility for larger grain size deposition across the marsh surface (Law et al., 2018; Yang et al., 2008). The observed changes in mean grain size at the Belcher Street Marsh (Figure 4.13) can be explained by the over marsh flood, which occurred a week before sampling in November. This tide completely flooded the marsh, causing a deposition event and increased the mean grain size (Yang et al., 2008). At the Converse Marsh (Figure 4.15), the fluctuation within the grain size from August to November indicates that deposition was occurring at different locations across the marsh surface. Other possible explanations include seasonal changes in water discharge and seasonal changes in vegetation-dependent sediment trapping (Yang et al., 2008). Seasonal differences such as increased storms and river discharge can greatly impact the deposition (Yang et al., 2008).

The water content at the Belcher Street Marsh is increasing from August to November (Figure 4.14, a) caused by the flooding event that occurred the week before sampling. The concave-up elevation profile of the marsh surface prevents rapid drainage and therefore increased pooling on the marsh surface following inundation (Figure 4.14, a). At the Converse Marsh, the water content increased from August to November (Figure 4.16, a). According to the CHS Tide

Charts for that area, higher tides flooded the marsh surface for an extended period before sampling in November.

The organic carbon content at the Belcher Street Marsh is decreasing across the marsh surface, specifically in the samples near the creek (Figure 4.14). Typically, vegetation degradation occurring during this time of year leads to higher percent organic carbon content (Zhou et al., 2007). The decrease in organic carbon content around the creek is attributed to minor flooding following the over marsh tide the previous week, increasing organic matter degradation and causing lower percent organic carbon content (Roner et al., 2016). The increase in percent organic carbon content at the Converse Marsh (Figure 4.16) is attributed to seasonal influences causing marsh vegetation decay.

Since organic carbon content increases during plant decomposition, more carbon-focused monitoring to determine if decomposition events cause permanent increases in the marsh carbon stock would be needed. Following up with organic carbon content measurements in the following year would be valuable to close this gap in the literature.

5.3 The Influence of Elevation

Elevation is related to the sedimentation of the salt marsh and the inundation frequency. The elevation gradient of the Belcher Street Marsh does not match the typical natural marsh, as can be seen by its lower elevations found in the inner marsh and the higher elevations near the bank. This concave marsh surface has been observed in other newly restored salt marshes (Temmerman et al., 2003; Roner et al., 2016). The elevation gradient is caused by decreasing suspended sediment concentrations with increasing distance from the creek (D’Alpaos, 2019). Suspended sediment concentrations decrease as water moves over the salt marsh surface.

Sediment deposition is occurring through settling and particle capture by plants (D'Alpaos, 2019). At the Belcher Street Marsh, the flooding occurs on the salt marsh banks and creeks first, where the tides most often flood due to the low elevations (Figure 3.3, a). The rest of the marsh floods depending on the height of the tide.

Conversely, this phenomenon does not occur at the Converse Marsh, which instead displays an increase in elevation with distance from the creek (Figure 3.3, b). The creeks allow water to enter the site before flooding the marsh. Williams and Orr's (2002) suggest that sedimentation rates depend on initial site elevation, often sunken due to prior land use (Spencer et al., 2017). The newly restored salt marsh was previously used for agriculture (Bowron et al., 2019). The site's initial elevation was increasing with distance from the dyke. When the dyke was breached, the elevation profile remained the same.

5.4 Comparing Current and Past Restoration Projects

Managed realignment had been undertaken in the Bay of Fundy by CBWES and In_CoaST at Saint Mary's University four times before the Belcher Street Marsh and Converse Marsh projects. The methodology is well developed, but a complete understanding of the various processes occurring during marsh restoration is yet to be achieved. One goal of this thesis was to determine if CBWES' once-per-year sampling technique represents the sediment composition and trajectory of a newly restored salt marsh. Since the sediment characteristics display no obvious trend from August to November at the Belcher Street Marsh (Table 4.1 & Table 4.2), sampling once per year is sufficient to understand how the marsh is establishing. However, this data is lacking as it does not include winter or spring data.

The CBWES team sampled at the Converse Marsh in June of 2020 (Table 4.4 and Table 4.5), which provides a better understanding of the marsh characteristics throughout the growing season. The mean percent organic matter and mean grain size do not vary enough throughout the growing season to justify increased sampling (Table 4.4 and Table 4.5). The mean water content measured in June 2020 (Table 4.4) is lower than the mean water content calculated for August and November. However, water content is variable and dependant on weather conditions such as rain events and marsh surface inundation. Therefore, these data do not indicate the need for increased sampling.

The four salt marsh restoration projects undertaken in the Bay of Fundy show a collective mean grain size range of 5.13 µm to 16.44 µm; an organic matter content range of 1.17 % to 29.64 %, and a water content range of 26.4 % - 81.1 % (Bowron et al., 2013a; Bowron et al., 2013b; Bowron et al., 2015a; Bowron et al., 2015b). Based on these results from Table 4.3 and Table 4.6, the mean grain size range for both sites is larger than the previously restored salt marsh ranges, with a maximum of 22.39 µm at Belcher Street Marsh and 18.68 µm at Converse Marsh. The Belcher Street Marsh's water content exceeds the range on both ends, with a lower minimum and higher maximum water content. The Converse Marsh water content is within the range relative to the previously restored marshes. The organic matter content is within the range of the previously restored marshes for Belcher Street Marsh. The outlier on the Converse Marsh increases the range of organic matter content. This outlier is believed to be associated with pseudofeces deposited on the marsh surface by invertebrates (Kraeuter, 1976).

Since the Belcher Street and Converse Marshes are newly restored, some variations within the site are expected, and the values will increasingly resemble the reference site with time (Graham et al., 2020). The salt marsh restoration projects at the Belcher Street Marsh and the

Converse Marsh are successful because the range of each sediment characteristic is comparable to previous salt marsh restoration projects in the Bay of Fundy.

Wollenberg et al. (2018) report a range of 2.0 % to 3.0 % organic carbon content over the last six years on the Aulac Marsh following managed realignment in the Bay of Fundy, New Brunswick. The reported organic carbon densities ranged from 0.019 g cm^{-3} to 0.029 g cm^{-3}. The percent organic carbon reported for the Belcher Street Marsh has a wider range, with a lower minimum and higher maximum (Table 4.4). The associated carbon density has a similar range, with a smaller minimum (0.013 g cm^{-3}) and an equal maximum (0.029 g cm^{-3}) when excluding the outlier (Table 4.3). The Converse Marsh reports a broader range for the percent carbon content and the organic carbon density, with lower minimums and higher maximums for both (Table 4.7 and Table 4.8). Wollenberg et al. (2018) report an average organic carbon density of 0.022 g cm^{-3}. Chmura et al. (2003) report an average organic carbon density of 0.026 g cm^{-3} for Wood Point Marsh, located near Aulac. The Belcher Street Marsh and the Converse Marsh both have very similar average organic carbon densities. These numbers are consistent with studies reporting high carbon accumulation rates following salt marsh restoration (Chmura et al., 2003 & Wollenberg et al., 2018). This accumulation will likely slow down with time (Wollenberg et al., 2018).

Roner et al. (2015) found an average organic carbon density of 0.044 g cm^{-3} in a salt marsh in the Venice lagoon, Italy. That study site is a semi-diurnal micro-tidal site, and therefore a different system. The variability in study site locations and systems suggests that all salt marsh ecosystems can sequester organic carbon. More calculations are needed to determine the average organic carbon density and the other newly restored marshes' accumulation rate in Nova Scotia.

Kelleway et al. (2016) found that salt marshes dominated by fine sediments have the greatest ability to store organic carbon. Salt marshes in the Bay of Fundy are predominantly fine to coarse silt. The Belcher Street Marsh and the Converse Marsh show that samples with smaller grain sizes have higher organic carbon content (Figure 4.8 & Figure 4.12). Managed realignment and restoration projects should be prioritized in areas dominated by fine grain size to increase carbon sequestration (Kelleway et al., 2016). This project reinforces the importance of managed realignment projects in the Bay of Fundy for increased carbon sequestration.

5.5 Project Limitation

This study had several limitations. These limitations include the infrequent flooding frequency at the Belcher Street Marsh. The August samples were not collected following an over-marsh tide because flooding at the Belcher Street Marsh is rare. This may skew the results and inaccurately represent the temporal variations of sediment composition. The COVID-19 pandemic influenced this project by preventing the initial sampling round planned for early spring, which would have given a complete view of the sediment composition changes throughout the growing season. It also caused uncertainty regarding laboratory access for sediment analysis due to health and safety protocols. Personal health was a limitation for this project as it prevented the November sampling round from being performed by the same person. This caused inconsistencies in data collection methods and resulted in a lack of field observations for that sampling round.

CHAPTER 6

CONCLUSION

Dyke realignment and salt marsh restoration are climate change adaptation and coastal protection strategies. This project will help develop a framework regarding what to expect following managed realignment and make predictions for future projects by using two recently restored salt marshes in the Bay of Fundy: The Belcher Street Marsh and the Converse Marsh. This study aimed to determine if there is a spatial variation in sediment characteristics across the salt marsh surface and if this variation is consistent; if differing elevations across the tidal marsh influences sediment characteristics; and compare the sites to previously restored salt marshes and reference sites in Nova Scotia. This study analyzed sediment samples from restored salt marshes for water content, mean grain size, organic matter, and carbon content.

Water content is highly variable as it is dependent on weather events, flooding frequency and drainage quality of each sample location. Water content is also greatly impacted by the elevation profile of the marsh. The Belcher Street Marsh is concave up, so water content was higher in the center of the marsh due to a pooling effect. The water content averaged 49.2 % in August and 56.1 % in November. The Converse Marsh has an increasing elevation with increasing distance from the creek. Therefore, water content is decreasing with increasing distance from the creek. The water content averaged 43.81 % in August and 52.89 % in November.

Mean grain size is largest around the creek and becomes finer with increasing distance from the creek at both the Belcher Street Marsh and the Converse Marsh. This is caused by the water's reduced sediment transport capability. The grain size patterns differ on the marshes due to their different elevation patterns. Densely vegetated areas tend to have larger mean grain sizes because the vegetation acts as a sediment catch. At the Belcher Street Marsh, the mean grain size averaged 11.1 µm in August and 10.9 µm in November. The mean grain size averaged 11.33 µm in August and 11.00 µm in November at the Converse Marsh.

Organic carbon content tends to be lowest in areas with high elevation because the marsh surface in these areas does not remain flooded for long and drains well. Sites with low elevation develop hypoxic conditions, which prevents organic carbon degradation. The organic matter at the Belcher Street Marsh averaged from 5.81 % in August and 6.35 % in November. The organic carbon at the Converse Marsh averaged 2.31 % in August and 2.54 % in November.

Sediment composition was found to differ between sampling rounds due to temporal variations. For example, seasonal differences between August and November can cause changes in water discharge, vegetation growth, and density, impacting sediment deposition across both marsh surfaces.

Elevation was found to be related to sedimentation and inundation frequency of the marsh surface. The elevation gradient of the Belcher Street Marsh and the Converse Marsh is different, which helps explain why different patterns are observed across each surface, with the Belcher Street Marsh being concave up and the Converse Marsh increasing in elevation with distance from the creek.

The Belcher Street Marsh and the Converse Marsh managed realignment projects were the fifth and sixth projects to be conducted in the Bay of Fundy. The range of each sediment characteristic is comparable to those previous projects recorded at Belcher Street Marsh and Converse Marsh.

Newly restored salt marshes are increasingly being looked at for their ability to store carbon as they become established. Organic carbon percent and densities at previously restored salt marshes are comparable to the Belcher Street Marsh and the Converse Marsh. After managed realignment, carbon sequestration occurs quickly and is expected to slow with time. Salt marshes dominated by fine sediments have the greatest ability to store carbon, such as the Belcher Street Marsh and the Converse Marsh, both dominated by fine to coarse silt.

To truly determine the value that managed realignment provides in terms of carbon sequestration, more research is needed to establish overall carbon stocks within salt marshes in the Bay of Fundy. However, based on the comparison between this study’s sites and previously managed realignment projects, future projects are expected to have results falling within the same range. In addition, continued monitoring of sediment characteristics in new and developing salt marshes will increase the understanding of their restoration trajectory.

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APPENDIX A

Sediment Characteristics at Study Sites

Table A.1 Sediment characteristics for the Belcher Street Marsh

Station ID	Easting	Northing	Elevation	August				November			
				Mean Grain Size (µm)	H2O %	OM %	C %	Mean Grain Size (µm)	H2O %	OM %	C %
ER 0	383529.27	4992473.05	6.67	9.32	39.87	7.84	3.14	6.95	56.46	7.24	2.90
ER 1	383445.41	4992533.38	6.44	6.93	56.47	9.65	3.86	15.36	61.94	7.56	3.02
ER 3	383484.74	4992531.98	6.28	7.50	58.64	6.83	2.73	9.16	72.71	7.42	2.97
ER 6	383531.19	4992462.20	6.83	9.88	30.34	5.80	2.32	9.10	52.32	7.27	2.91
ER 7	383571.17	4992453.28	6.56	8.41	41.87	7.11	2.85	10.51	41.42	3.83	1.53
ER 8	383449.78	4992449.78	6.84	8.25	47.27	14.14	5.66	7.83	60.69	16.07	6.43
ER 10	383610.48	4992534.82	6.30	10.77	40.13	4.53	1.81	18.05	34.34	3.38	1.35
ER 11	383499.03	4992548.66	6.29	7.56	55.47	7.29	2.92	9.36	69.49	7.19	2.88
ER 12	383799.03	4992254.61	6.49	9.62	45.22	6.17	2.47	11.88	39.89	4.39	1.76
ER 13	383458.59	4992524.02	6.20	6.04	65.02	6.71	2.69	7.07	84.59	9.12	3.65
ER 14	383694.21	4992450.29	6.45	8.36	45.91	6.86	2.74	9.17	58.33	6.34	2.54
ER 15	383787.24	4992226.18	6.50	12.97	37.33	5.04	2.02	13.73	40.80	4.40	1.76
ER 16	383657.09	4992482.97	6.48	7.79	49.94	6.22	2.49	8.30	57.15	7.08	2.83
ER 18	383511.22	4992525.75	6.30	7.91	59.07	6.90	2.76	10.50	62.28	6.29	2.52
ER 19	383674.51	4992491.89	6.12	7.07	59.12	7.28	2.91	11.05	66.70	5.77	2.31
ER 24	383692.16	4992464.16	6.43	6.61	29.29	3.19	1.28	12.56	44.26	5.29	2.12
ER 25	383765.78	4992260.26	6.79	11.26	30.37	6.11	2.44	9.08	48.05	10.75	4.30
ER 29	383658.69	4992476.93	6.62	10.90	33.16	6.49	2.60	7.51	53.11	6.65	2.66
ER 72	383444.21	4992576.27	6.19	8.33	56.85	6.45	2.58	10.39	66.19	6.70	2.68
ER 73	383612.62	4992512.62	6.54	13.29	40.63	5.32	2.13	17.52	36.87	3.45	1.38
ER 74	383613.59	4992484.53	6.68	11.13	31.19	6.45	2.58	12.24	45.40	5.42	2.17
ER 75	383613.76	4992465.75	6.41	10.30	40.25	6.33	2.53	18.17	36.71	3.63	1.45
ER 76	383692.27	4992404.59	6.79	19.05	25.46	4.79	1.92	12.86	45.15	5.01	2.00
ER 77	383716.59	4992356.60	6.69	11.07	52.36	5.15	2.06	11.28	79.29	7.74	3.10
ER 78	383850.30	4992264.82	5.99	10.29	48.08	6.21	2.49	10.40	50.19	4.83	1.93
T2S4	383491.28	4992540.15	6.27	7.69	54.55	6.50	2.60	8.19	59.74	6.00	2.40
T2S5	383483.96	4992511.95	6.32	18.66	52.48	7.09	2.84	8.03	63.22	6.90	2.76
T2S6	383474.07	4992485.70	6.29	6.09	63.97	7.30	2.92	7.28	79.97	8.38	3.35
T2S6 pink	383471.78	4992489.14	6.32	6.31	61.98	6.92	2.77	6.86	65.14	6.59	2.64
T3S4	383591.69	4992496.15	6.33	12.89	42.40	5.40	2.16	22.39	35.41	2.86	1.14
T4S3	383685.95	4992469.28	6.54	10.13	34.81	4.64	1.86	8.52	57.00	6.11	2.45

Table A.2 Sediment characteristics for the Converse Marsh

Station ID	**easting**	**northing**	**elevation**	**August**				**November**			
				Mean Grain Size (µm)	**H2O %**	**OM %**	**C %**	**Mean Grain Size (µm)**	**H2O %**	**OM %**	**C %**
ER 00	401117.82	5077320.11	6.38	15.89	31.59	5.08	2.03	16.63	36.90	6.97	2.79
ER 01	401563.23	5077262.77	5.87	11.31	38.39	5.73	2.29	8.93	60.96	6.42	2.57
ER 02	401461.38	5077207.13	6.17	11.11	29.82	2.73	1.09	5.56	34.23	3.36	1.34
ER 04	401309.29	5077234.35	5.89	17.79	29.95	4.40	1.76	18.68	34.86	4.10	1.64
ER 06	401146.68	5077071.43	5.79	8.83	65.03	7.39	2.96	9.46	64.83	7.08	2.83
ER 07	401478.00	5077068.46	5.89	9.35	50.23	6.02	2.41	10.83	53.54	6.15	2.46
ER 12	401525.31	5077248.73	5.81	13.43	33.37	4.43	1.77	13.00	65.88	6.20	2.48
ER 13	401369.63	5077020.07	6.15	8.61	44.90	10.89	4.36	7.84	52.14	7.41	2.97
ER 14	401440.76	5077349.25	6.23	13.09	37.02	6.73	2.69	9.95	49.03	6.96	2.78
ER 16	401509.51	5077385.08	6.06	9.73	41.67	5.78	2.31	9.28	41.77	5.67	2.27
ER 17	401463.93	5077411.24	6.44	11.99	33.20	4.86	1.94	15.48	32.06	4.20	1.68
ER 18	401463.93	5077411.24	6.44	11.55	53.12	6.32	2.53	11.08	58.16	6.58	2.63
ER 22	401145.46	5077171.57	6.02	11.67	35.54	4.81	1.92	10.16	44.98	5.46	2.18
ER 27	401183.19	5077074.66	5.74	7.67	59.30	7.02	2.81	7.53	77.32	8.64	3.46
ER 28	401291.20	5077161.64	6.01	12.79	45.25	5.51	2.20	15.82	52.69	5.22	2.09
MH2	401166.76	5077158.05	5.79	9.84	56.07	6.37	2.55	10.02	60.49	7.07	2.83
MH3	401236.53	5077141.12	5.73	9.68	43.39	6.59	2.64	12.37	46.99	5.58	2.23
MH05	401099.68	5077346.37	6.34	11.64	51.25	6.40	2.56	9.12	50.85	9.73	3.89
MH8	401478.17	5077033.37	5.74	8.62	50.76	6.05	2.42	8.61	68.60	6.89	2.76
MH9	401402.12	5077078.33	6.36	8.64	37.93	5.88	2.35	8.05	43.43	8.27	3.31
MH11	401354.34	5077175.03	5.68	10.65	52.10	6.34	2.54	9.09	70.42	8.73	3.49
MH17	401540.99	5077292.43	5.63	11.12	38.13	5.49	2.20	9.55	65.65	6.95	2.78
MH18	401488.12	5077315.10	5.70	12.70	53.12	6.32	2.22	11.41	57.04	6.35	2.54
T1S2	401227.36	5077160.92	5.57	9.89	46.63	6.23	2.49	9.12	56.51	7.95	3.18
T1S4	401186.42	5077207.43	5.80	13.70	46.15	90.71	36.34	11.76	61.41	6.22	2.49
T1S6	401148.74	5077255.08	5.64	11.38	56.39	5.21	2.09	8.70	73.27	6.95	2.78
T2S4	401493.55	5077145.49	5.91	10.70	31.11	4.29	1.71	11.29	48.61	5.21	2.08
T2S6	401476.24	5077201.02	6.26	11.16	31.19	5.00	2.00	14.47	28.17	3.91	1.56
T2S7	401467.94	5077227.04	6.06	15.52	27.92	3.90	1.56	16.56	27.63	2.96	1.18
T3S4	401514.82	5077435.81	5.21	9.88	63.79	6.64	2.66	9.71	68.15	7.27	2.91

APPENDIX B

Results of Regression Analyses

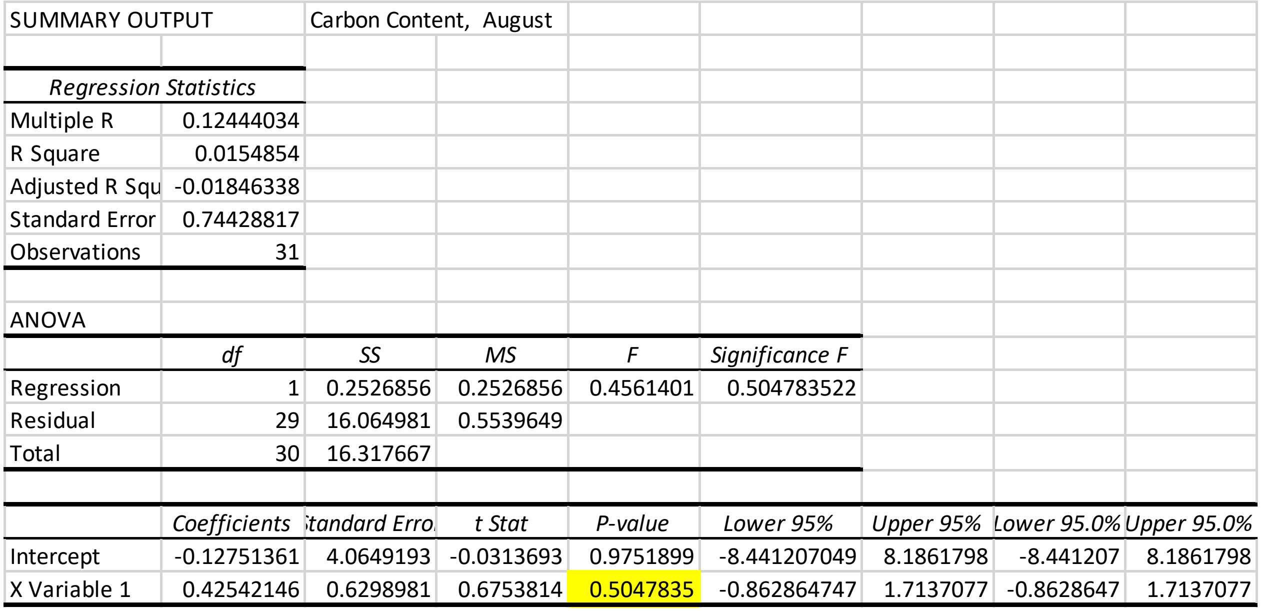
Table B.1 Regression summary output for mean grain size in August at the Belcher Street Marsh

SUMMARY OUTPUT		Mean Grain Size, August						
Regression Statistics								
Multiple R	0.33049669							
R Square	0.10922806							
Adjusted R Squ	0.07851179							
Standard Error	3.04153889							
Observations	31							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	32.896709	32.896709	3.5560323	0.069382493			
Residual	29	268.27781	9.2509588					
Total	30	301.17451						
	Coefficients	*Standard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-21.5538621	16.611322	-1.2975405	0.2046724	-55.52782942	12.420105	-55.527829	12.420105
X Variable 1	4.85406276	2.5740829	1.8857445	0.0693825	-0.410527981	10.118654	-0.410528	10.118654

Table B.2 Regression summary output for mean grain size in November at the Belcher Street Marsh

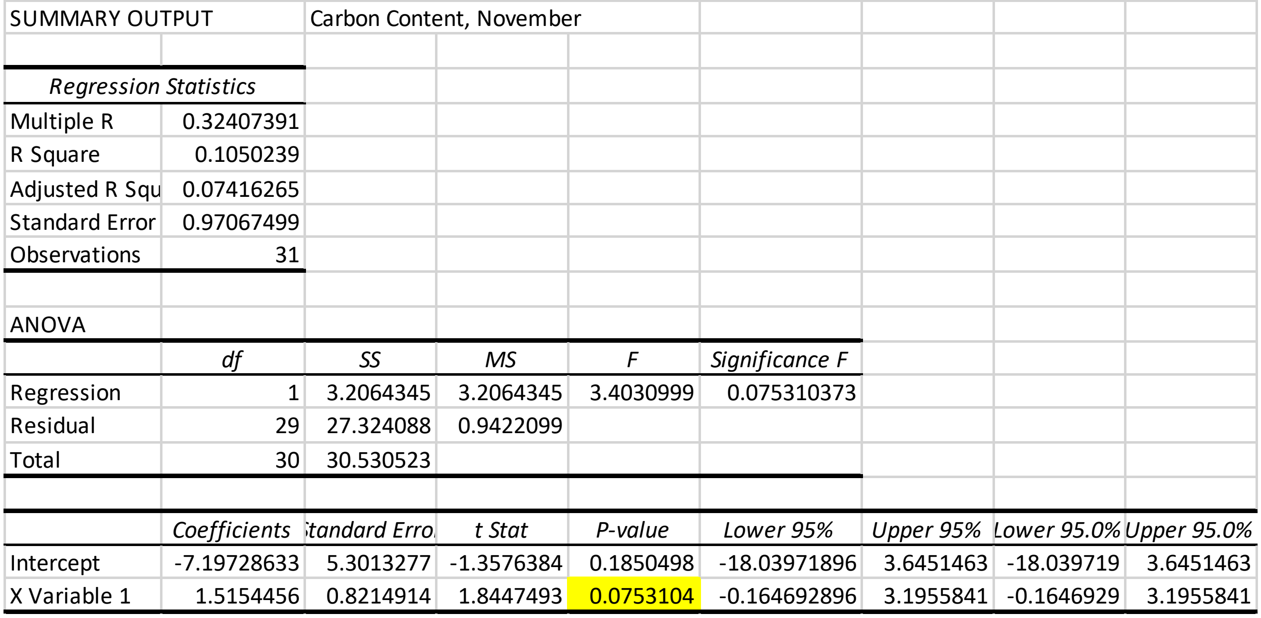
SUMMARY OUTPUT		Mean Grain Size, November						
Regression Statistics								
Multiple R	0.05983939							
R Square	0.00358075							
Adjusted R Squ	-0.03077853							
Standard Error	3.89410713							
Observations	31							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	1.5803236	1.5803236	0.104215	0.749145049			
Residual	29	439.75804	15.16407					
Total	30	441.33836						
	Coefficients	*Standard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	17.8713901	21.267611	0.8403102	0.4076095	-25.62575825	61.368538	-25.625758	61.368538
X Variable 1	-1.06390336	3.2956195	-0.3228235	0.749145	-7.804201965	5.6763952	-7.804202	5.6763952

Table B.3 Regression summary output for organic carbon content in August at the Belcher Street Marsh



SUMMARY OUTPUT		Carbon Content, August						
Regression Statistics								
Multiple R	0.12444034							
R Square	0.0154854							
Adjusted R Squ	-0.01846338							
Standard Error	0.74428817							
Observations	31							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	0.2526856	0.2526856	0.4561401	0.504783522			
Residual	29	16.064981	0.5539649					
Total	30	16.317667						
	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.12751361	4.0649193	-0.0313693	0.9751899	-8.441207049	8.1861798	-8.441207	8.1861798
X Variable 1	0.42542146	0.6298981	0.6753814	0.5047835	-0.862864747	1.7137077	-0.8628647	1.7137077

Table B.4 Regression summary output for organic carbon content in November at the Belcher Street Marsh



SUMMARY OUTPUT		Carbon Content, November						
Regression Statistics								
Multiple R	0.32407391							
R Square	0.1050239							
Adjusted R Squ	0.07416265							
Standard Error	0.97067499							
Observations	31							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	3.2064345	3.2064345	3.4030999	0.075310373			
Residual	29	27.324088	0.9422099					
Total	30	30.530523						
	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-7.19728633	5.3013277	-1.3576384	0.1850498	-18.03971896	3.6451463	-18.039719	3.6451463
X Variable 1	1.5154456	0.8214914	1.8447493	0.0753104	-0.164692896	3.1955841	-0.1646929	3.1955841

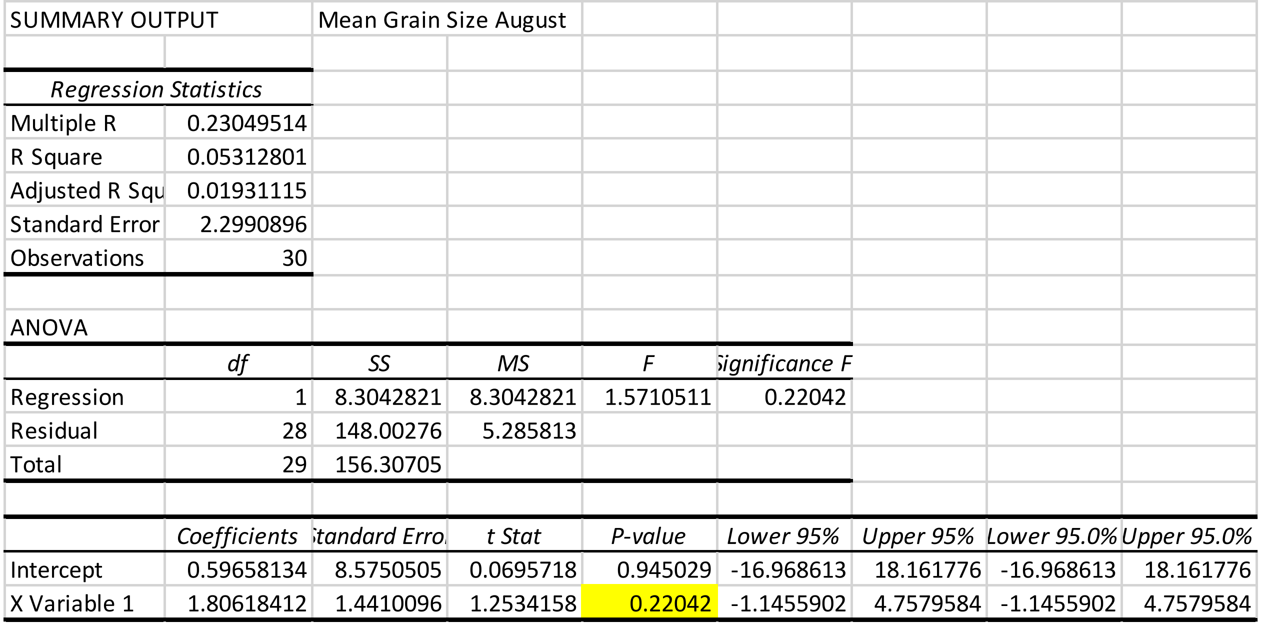
Table B.5 Regression summary output for water content in August at the Belcher Street Marsh

SUMMARY OUTPUT		H2O% August						
Regression Statistics								
Multiple R	0.66928865							
R Square	0.44794729							
Adjusted R Squ	0.42891099							
Standard Error	8.5899756							
Observations	31							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	1736.3139	1736.3139	23.531216	3.83889E-05			
Residual	29	2139.8427	73.787681					
Total	30	3876.1566						
	Coefficients	*Standard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	273.563723	46.91403	5.8311708	2.534E-06	177.613758	369.51369	177.61376	369.51369
X Variable 1	-35.2649505	7.2697771	-4.8508985	3.839E-05	-50.13331411	-20.396587	-50.133314	-20.396587

Table B.6 Regression summary output for water content in November at the Belcher Street Marsh

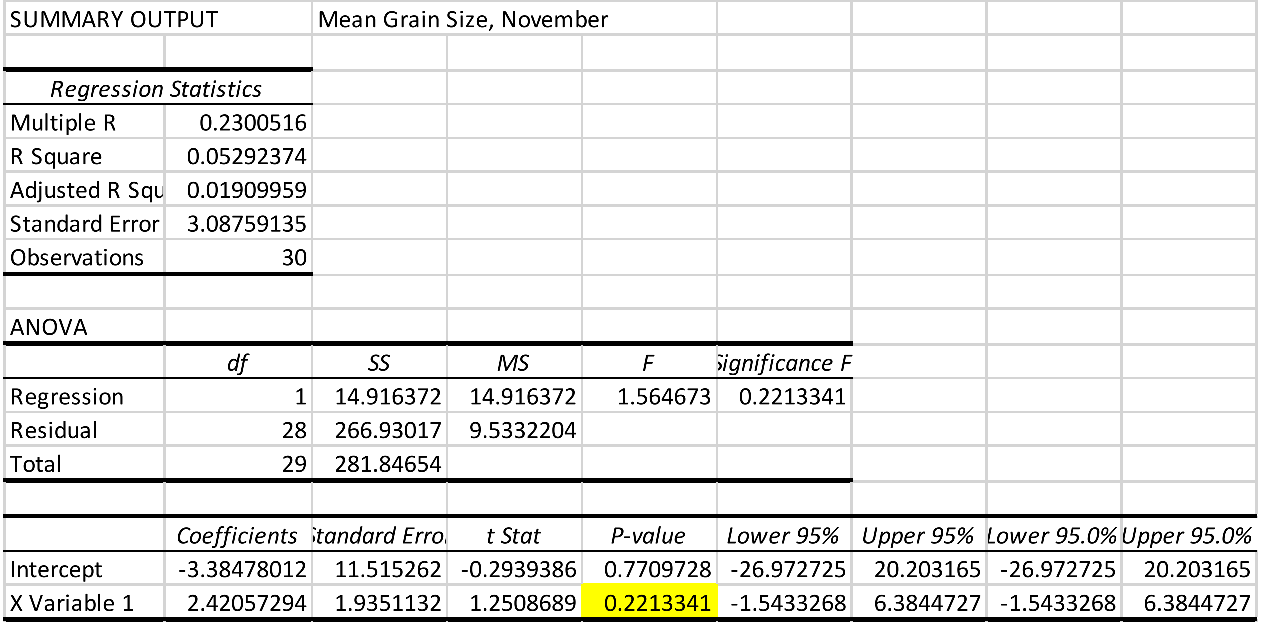
SUMMARY OUTPUT		H2O% November						
Regression Statistics								
Multiple R	0.27121754							
R Square	0.07355895							
Adjusted R Squ	0.04161271							
Standard Error	13.4767998							
Observations	31							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	418.20509	418.20509	2.3025854	0.139985675			
Residual	29	5267.0999	181.62413					
Total	30	5685.305						
	Coefficients	*Standard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	167.266397	73.603351	2.2725378	0.0306461	16.73064142	317.80215	16.730641	317.80215
X Variable 1	-17.3070807	11.405542	-1.5174272	0.1399857	-40.63403396	6.0198726	-40.634034	6.0198726

Table B.7 Regression summary output for mean grain size in August at the Converse Marsh



SUMMARY OUTPUT		Mean Grain Size August						
Regression Statistics								
Multiple R	0.23049514							
R Square	0.05312801							
Adjusted R Squ	0.01931115							
Standard Error	2.2990896							
Observations	30							
ANOVA								
	df	*SS*	*MS*	*F*	*ignificance F*			
Regression	1	8.3042821	8.3042821	1.5710511	0.22042			
Residual	28	148.00276	5.285813					
Total	29	156.30705						
	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.59658134	8.5750505	0.0695718	0.945029	-16.968613	18.161776	-16.968613	18.161776
X Variable 1	1.80618412	1.4410096	1.2534158	0.22042	-1.1455902	4.7579584	-1.1455902	4.7579584

Table B.8 Regression summary output for mean grain size in November at the Converse Marsh



SUMMARY OUTPUT		Mean Grain Size, November						
Regression Statistics								
Multiple R	0.2300516							
R Square	0.05292374							
Adjusted R Squ	0.01909959							
Standard Error	3.08759135							
Observations	30							
ANOVA								
	df	*SS*	*MS*	*F*	*ignificance F*			
Regression	1	14.916372	14.916372	1.564673	0.2213341			
Residual	28	266.93017	9.5332204					
Total	29	281.84654						
	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-3.38478012	11.515262	-0.2939386	0.7709728	-26.972725	20.203165	-26.972725	20.203165
X Variable 1	2.42057294	1.9351132	1.2508689	0.2213341	-1.5433268	6.3844727	-1.5433268	6.3844727

Table B.9 Regression summary output for organic carbon content in August at the Converse Marsh

SUMMARY OUTPUT		Carbon Content, August						
Regression Statistics								
Multiple R	0.1069251							
R Square	0.01143298							
Adjusted R Squ	-0.02518062							
Standard Error	0.57502036							
Observations	29							
ANOVA								
	df	*SS*	*MS*	*F*	*ignificance F*			
Regression	1	0.1032484	0.1032484	0.3122604	0.5809019			
Residual	27	8.9275073	0.3306484					
Total	28	9.0307557						
	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	3.51566611	2.1554475	1.6310609	0.114489	-0.9069469	7.9382791	-0.9069469	7.9382791
X Variable 1	-0.20223409	0.3619061	-0.5588027	0.5809019	-0.944804	0.5403359	-0.944804	0.5403359

Table B.10 Regression summary output for organic carbon content in November at the Converse Marsh

SUMMARY OUTPUT		Carbon Content, November						
Regression Statistics								
Multiple R	0.21292253							
R Square	0.045336							
Adjusted R Squ	0.01124086							
Standard Error	0.63571294							
Observations	30							
ANOVA								
	df	*SS*	*MS*	*F*	*ignificance F*			
Regression	1	0.5373693	0.5373693	1.3296909	0.2586094			
Residual	28	11.315666	0.4041309					
Total	29	11.853036						
	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	5.27042977	2.37091	2.2229565	0.0344666	0.4138408	10.127019	0.4138408	10.127019
X Variable 1	-0.45943383	0.3984259	-1.1531223	0.2586094	-1.2755724	0.3567047	-1.2755724	0.3567047

Table B.11 Regression summary output for water content in August at the Converse Marsh

SUMMARY OUTPUT		H2O% August						
Regression Statistics								
Multiple R	0.50380816							
R Square	0.25382267							
Adjusted R Squ	0.22717348							
Standard Error	9.44717317							
Observations	30							
ANOVA								
	df	*SS*	*MS*	*F*	*ignificance F*			
Regression	1	850.06108	850.06108	9.524592	0.0045336			
Residual	28	2498.9743	89.249081					
Total	29	3349.0353						
	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	152.417862	35.233508	4.3259349	0.0001744	80.245292	224.59043	80.245292	224.59043
X Variable 1	-18.2730747	5.9209097	-3.0861938	0.0045336	-30.401508	-6.144641	-30.401508	-6.144641

Table B.12 Regression summary output for water content in November at the Converse Marsh

SUMMARY OUTPUT		H2O %, November						
Regression Statistics								
Multiple R	0.6616891							
R Square	0.43783246							
Adjusted R Squ	0.41775505							
Standard Error	10.497676							
Observations	30							
ANOVA								
	df	*SS*	*MS*	*F*	*ignificance F*			
Regression	1	2403.1814	2403.1814	21.807216	6.838E-05			
Residual	28	3085.6336	110.2012					
Total	29	5488.815						
	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	235.496561	39.151389	6.0150244	1.758E-06	155.29858	315.69455	155.29858	315.69455
X Variable 1	-30.7241472	6.5793006	-4.6698197	6.838E-05	-44.201233	-17.247061	-44.201233	-17.247061

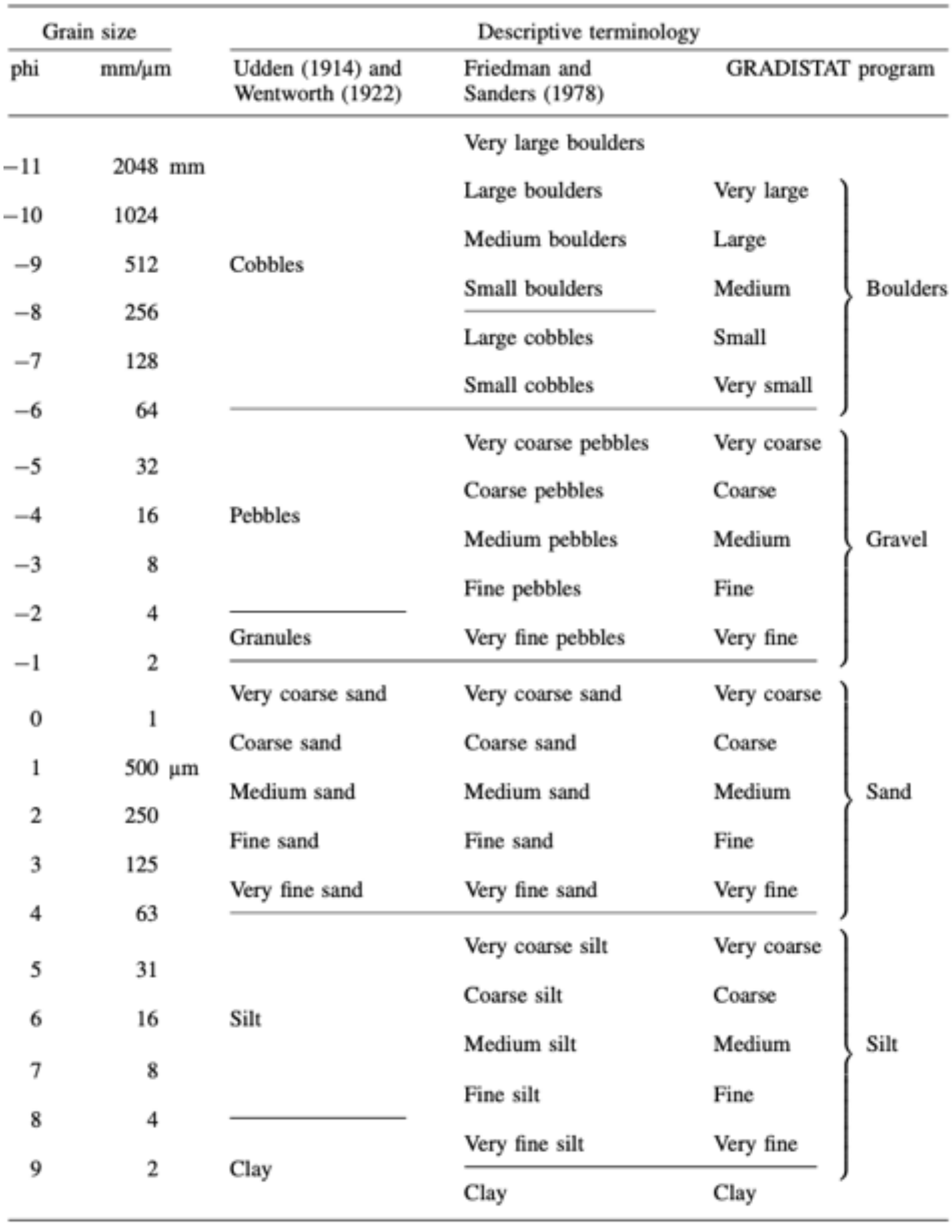
APPENDIX C

Folk and Ward Method

Table C.1 Mean Grain Size (µm) using the Folk and Ward Method

Belcher Aug		Belcher Nov		Converse Aug		Converse Nov	
Sample ID	Mean Grain Size (µm)	Sample ID	Mean Grain Size (µm)	Sample ID	Mean Grain Size (µm)	Sample ID	Mean Grain Size (µm)
ER0	9.317	**ER0**	6.949	**ER0**	15.89	**ER0**	16.63
ER1	6.932	**ER1**	15.36	**ER1**	11.31	**ER1**	8.933
ER3	7.497	**ER3**	9.161	**ER2**	11.11	**ER2**	5.563
ER6	9.876	**ER6**	9.101	**ER4**	17.79	**ER4**	18.68
ER7	8.411	**ER7**	10.51	**ER6**	8.829	**ER6**	9.456
ER8	8.252	**ER8**	7.826	**ER7**	9.351	**ER7**	10.83
ER10	10.77	**ER10**	18.05	**ER12**	13.43	**ER12**	13.00
ER11	7.555	**ER11**	9.364	**ER13**	8.609	**ER13**	7.835
ER12	9.618	**ER12**	11.88	**ER14**	13.09	**ER14**	9.947
ER13	6.041	**ER13**	7.065	**ER16**	9.731	**ER16**	9.277
ER14	8.358	**ER14**	9.168	**ER17**	11.99	**ER17**	15.48
ER15	12.97	**ER15**	13.73	**ER18**	11.55	**ER18**	11.08
ER16	7.786	**ER16**	8.303	**ER22**	11.67	**ER22**	10.16
ER18	7.913	**ER18**	10.50	**ER27**	7.665	**ER27**	7.532
ER19	7.072	**ER19**	11.05	**ER28**	12.79	**ER28**	15.82
ER24	6.614	**ER24**	12.56	**MH2**	9.838	**MH2**	10.02
ER25	11.26	**ER25**	9.079	**MH3**	9.683	**MH3**	12.37
ER29	10.90	**ER29**	7.508	**MH5**	11.64	**MH5**	9.121
ER72	8.326	**ER72**	10.39	**MH8**	8.616	**MH8**	8.612
ER73	13.29	**ER73**	17.52	**MH9**	8.637	**MH9**	8.045
ER74	11.13	**ER74**	12.24	**MH11**	10.65	**MH11**	9.093
ER75	10.30	**ER75**	18.17	**MH17**	11.12	**MH17**	9.551
ER76	19.05	**ER76**	12.86	**MH18**	12.70	**MH18**	11.41
ER77	11.07	**ER77**	11.28	**T1S2**	9.888	**T1S2**	9.125
ER78	10.29	**ER78**	10.40	**T1S4**	13.70	**T1S4**	11.76
T2S4	7.692	**T2S4**	8.191	**T1S6**	11.38	**T1S6**	8.704
T2S5	18.66	**T2S5**	8.033	**T2S4**	10.70	**T2S4**	11.29
T2S6	6.094	**T2S6**	7.280	**T2S6**	11.16	**T2S6**	14.47
T2S6Pink	6.307	**T2S6Pink**	6.855	**T2S7**	15.52	**T2S7**	16.56
T3S4	12.89	**T3S4**	22.39	**T3S4**	9.884	**T3S4**	9.709
T4S3	10.13	**T4S3**	8.519				

Table C.2 Size Scale Adopted in Gradistat. Reproduced from Blott & Pye (2001)

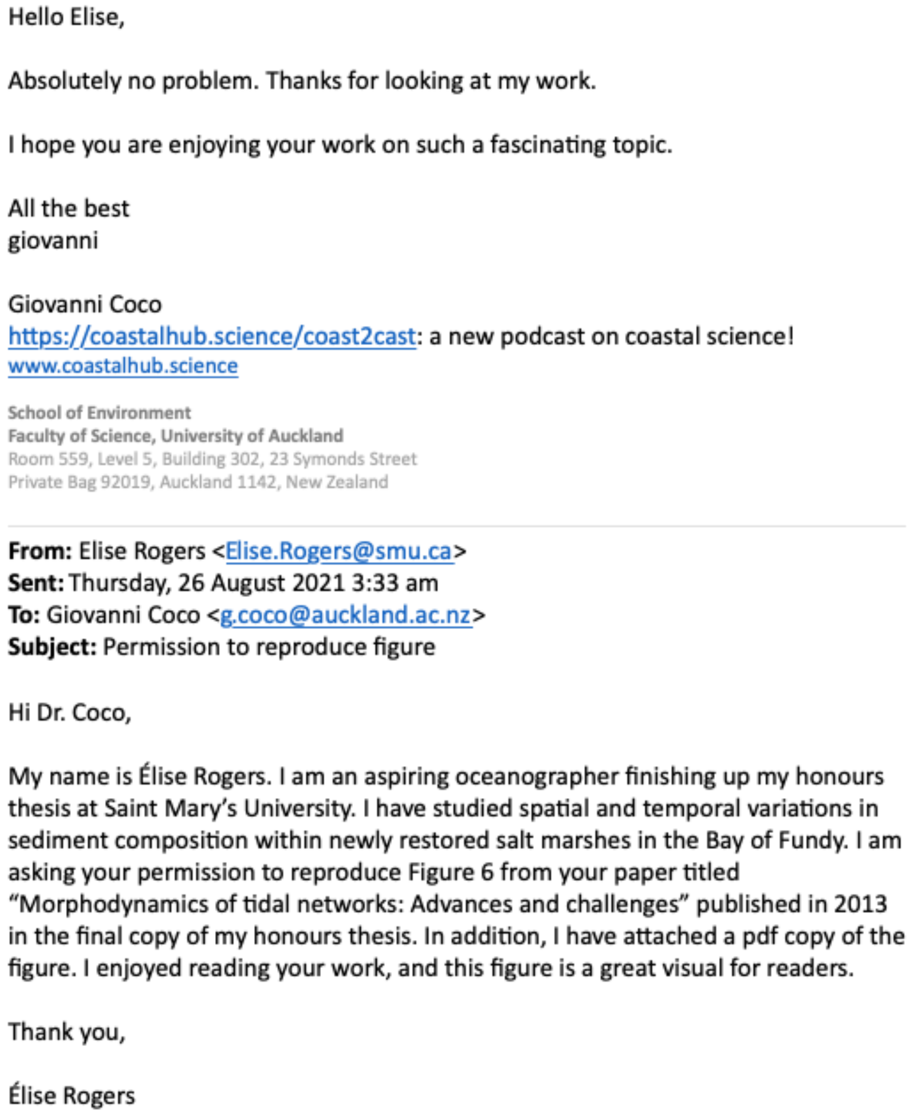


Grain size		Descriptive terminology			
phi	mm/µm	Udden (1914) and Wentworth (1922)	Friedman and Sanders (1978)	GRADISTAT program	
			Very large boulders		
−11	2048 mm				
			Large boulders	Very large	
−10	1024				
			Medium boulders	Large	
−9	512	Cobbles			
			Small boulders	Medium	Boulders
−8	256				
			Large cobbles	Small	
−7	128				
			Small cobbles	Very small	
−6	64				
			Very coarse pebbles	Very coarse	
−5	32				
			Coarse pebbles	Coarse	
−4	16	Pebbles			
			Medium pebbles	Medium	Gravel
−3	8				
			Fine pebbles	Fine	
−2	4				
		Granules	Very fine pebbles	Very fine	
−1	2				
		Very coarse sand	Very coarse sand	Very coarse	
0	1				
		Coarse sand	Coarse sand	Coarse	
1	500 µm				
		Medium sand	Medium sand	Medium	Sand
2	250				
		Fine sand	Fine sand	Fine	
3	125				
		Very fine sand	Very fine sand	Very fine	
4	63				
			Very coarse silt	Very coarse	
5	31				
			Coarse silt	Coarse	
6	16	Silt			
			Medium silt	Medium	Silt
7	8				
			Fine silt	Fine	
8	4				
			Very fine silt	Very fine	
9	2	Clay			
			Clay	Clay	

APPENDIX D

Permission to Reproduce Figures

Figure D.1. Screen capture of permission to reproduce the summary of the ecomorphodynamic processes occurring within a coastal wetland site obtained by Dr. Giovanni Coco.



Hello Elise,

Absolutely no problem. Thanks for looking at my work.

I hope you are enjoying your work on such a fascinating topic.

All the best
giovanni

Giovanni Coco
https://coastalhub.science/coast2cast: a new podcast on coastal science!
www.coastalhub.science

School of Environment
Faculty of Science, University of Auckland
Room 559, Level 5, Building 302, 23 Symonds Street
Private Bag 92019, Auckland 1142, New Zealand

From: Elise Rogers <Elise.Rogers@smu.ca>
Sent: Thursday, 26 August 2021 3:33 am
To: Giovanni Coco <g.coco@auckland.ac.nz>
Subject: Permission to reproduce figure

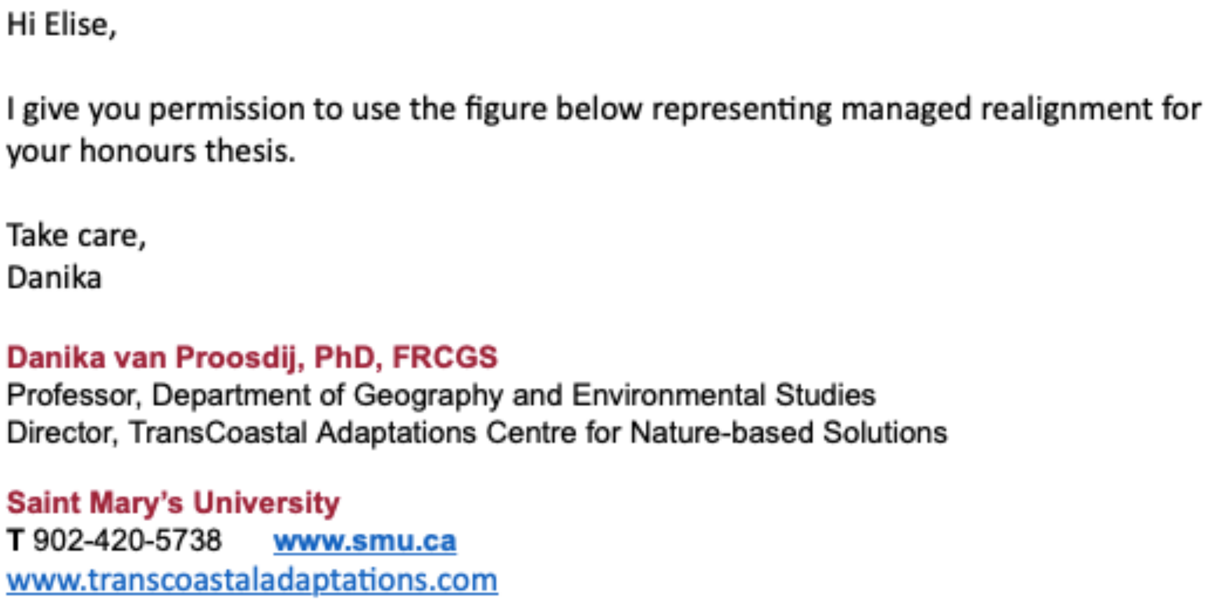
Hi Dr. Coco,

My name is Élise Rogers. I am an aspiring oceanographer finishing up my honours thesis at Saint Mary's University. I have studied spatial and temporal variations in sediment composition within newly restored salt marshes in the Bay of Fundy. I am asking your permission to reproduce Figure 6 from your paper titled "Morphodynamics of tidal networks: Advances and challenges" published in 2013 in the final copy of my honours thesis. In addition, I have attached a pdf copy of the figure. I enjoyed reading your work, and this figure is a great visual for readers.

Thank you,

Élise Rogers

Figure D.2. Screen capture of permission to reproduce figure representing managed realignment obtained by Dr. Danika van Proosdij.



Hi Elise,

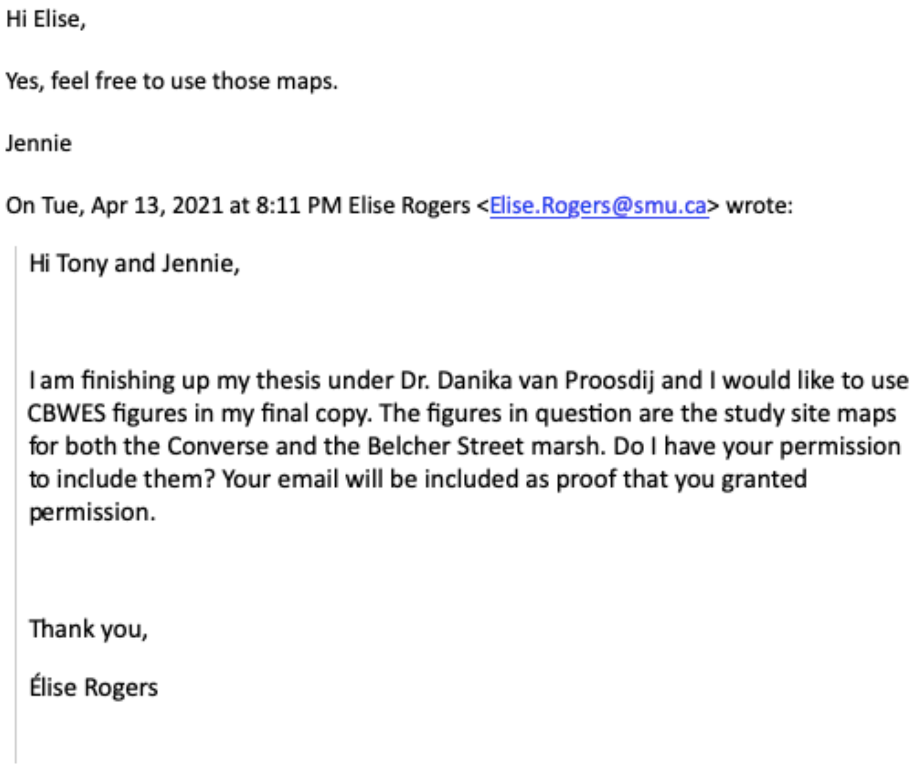
I give you permission to use the figure below representing managed realignment for your honours thesis.

Take care,
Danika

Danika van Proosdij, PhD, FRCGS
Professor, Department of Geography and Environmental Studies
Director, TransCoastal Adaptations Centre for Nature-based Solutions

Saint Mary's University
T 902-420-5738 www.smu.ca
www.transcoastaladaptations.com

Figure D.3. Screen capture of permission to reproduce study site maps for both the Converse Marsh and the Belcher Street Marsh obtained by Jennie Graham from CBWES.



Hi Elise,

Yes, feel free to use those maps.

Jennie

On Tue, Apr 13, 2021 at 8:11 PM Elise Rogers <Elise.Rogers@smu.ca> wrote:

> Hi Tony and Jennie,
>
> I am finishing up my thesis under Dr. Danika van Proosdij and I would like to use CBWES figures in my final copy. The figures in question are the study site maps for both the Converse and the Belcher Street marsh. Do I have your permission to include them? Your email will be included as proof that you granted permission.
>
> Thank you,
>
> Élise Rogers