Bathymetry, substratum and emergent vegetation distributions during an extreme flood event in Delta Marsh, Manitoba

by

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Abstract

In 2011 Manitoba experienced an extreme flood. The operation of the Assiniboine River Diversion resulted in the addition of approximately 1.72 million cubic decameters of water to Lake Manitoba amd an increase in water levels to 1.5 m above normal. Although this event resulted damage to farmland and many local homes, it also provided me the unique opportunity to utilize previously impractical methods of bathymetric and substrata distribution analysis in the adjoining Delta Marsh. Combined with satellite imagery taken in 2011 I was able to classify the vegetation classes within the study area and explore the relationship between vegetation distributions and water depth as well as those between water depth and substrata distribution. A seed bank study was carried out to explore the diversity of viable seeds in the area. In addition, satellite imagery taken in 2009 was used to evaluate the effects of the flood event experienced in 2011.

Table of Contents

Acknowledgements i

Abstract iii

List of Tables vii

List of Figures viii

1.0 – Introduction 1

1.1 - Organization of Thesis 1

1.2 – Preface 1

1.3 – Overview of Objectives and Hypotheses 3

2.0 – Literature Review 5

2.1 – Wetlands 5

2.1.1 - Function 6

2.1.2 - Wetland Loss 8

2.1.3 - Hydrology 9

2.1.4 - Wetland Vegetation 13

2.1.5 - Effects of Hydrology on Vegetation 14

2.1.6 - Invasive Species 16

2.2 - Study Area 20

2.2.1 - Lake Manitoba 20

2.2.2 - Delta Marsh 23

2.3 - Bathymetric Data 28

2.3.1 - Benefits and Uses 28

2.3.2 - Methods 29

3.0 – Bathymetry 41

3.1 - Introduction 41

3.1.1 - Study Area 43

3.1.2 - Current Study 45

3.2 – Materials and Methods 46

3.3 – Results 52

3.4 – Discussion 53

4.0 – Substrata Distribution 73

4.1 - Introduction 73
4.2 – Materials and Methods 76
4.3 - Results 80
4.4 - Discussion 83
5.0 – Vegetation Distribution 94
5.1 – Introduction 94
5.1.1 - Study Area 96
5.2 – Materials and Methods 97
5.3 – Results 101
5.4 – Discussion 107
6.0 - Seed Bank Analysis 118
6.1 - Introduction 118
6.2 – Materials and Methods 121
6.3 – Results 123
6.4 – Discussion 125
7.0 – Synthesis 147
7.1 – Introduction 147
7.2 – Materials and Methods 151
7.3. – Results 152
7.3.1 – Elevation vs Vegetation Distribution 152
7.3.2 – Elevation vs Substrata Distribution 155
7.4 – Discussion 157
7.4.1 – Elevation vs Vegetation Distribution 157
7.4.2 – Elevation vs Substratum Distribution 160
8.0 – Final Discussions and Recommendations 171
8.1 - Hypotheses 171
8.2 – Recommendations 174
8.2.1 – Bathymetry 174
8.2.2 – Substrata Distribution 174
8.2.3 – Vegetation Distribution 175
8.2.4 – Seed Bank Analysis 176
8.2.5 - Management 176

9.0 – References.. 178

List of Tables

Table 1. Error Matrix calculated for the classified substrata map of the eastern portion of Delta Marsh, Manitoba. 93

Table 2. Error Matrix calculated for the classified vegetation map of the eastern portion of Delta Marsh, Manitoba.. 112

Table 3. Coverage areas of cover classes within the eastern portion of Delta Marsh, Manitoba in 2009 and 2011 as determined by Quickbird satellite imagery. 116

Table 4. Coverage areas of condensed cover classes in the eastern portion of Delta Marsh, Manitoba in 2009 and 2011 as determined by Quickbird satellite imagery 117

Table 5. Distribution of wetland plant species as germinated from seedbank samples from the eastern portion of Delta Marsh, Manitoba in three saturation treatments.. 131

Table 6. Common plant species found in the Delta Marsh area seed bank. 146

Table 7. Summary of elevation data for SAS-identified vegetation classes in the eastern portion of Delta Marsh, Manitoba as determined by extrapolation of Quester Tangent Corporation (QTC) and Manitoba Land Initiative (MLI) elevation data and analysis of QuickBird satellite imagery. 163

Table 8. Summary of depth data for substratum classes identified by Quester Tangent Corporation (QTC) single beam sonar analysis and QTC IMPACT substrate analysis in the eastern portion of Delta Marsh, Manitoba. 166

Table 9. A summary of substratum classes identified through Quester Tangent Corporation (QTC) single beam sonar analysis and examination of ground-truth samples in the eastern portion of the Delta Marsh, Manitoba. 168

List of Figures

Figure 1. Annual and long term range of water levels seen on Lake Manitoba from 1932 – 2012. 37

Figure 2. Photo of *Typha latifolia* and *Typha angustiflia* at Delta Marsh, Manitoba.). 38

Figure 3. The eastern portion of Delta Marsh, located east of Highway 240 on the southern edge of Lake Manitoba. 39

Figure 4. Correlation of water level fluctuations on Lake Manitoba and in Delta Marsh. 40

Figure 5. Water levels recorded on Lake Manitoba (Near Steep Rock) in 2006, 2007, 2008 and 2011. 56

Figure 6. Transects and outline of vegetation fringe taken by the Quester Tangent Corporation (QTC) VIEW single beam sonar system during collection of bathymetric and substrate data in the eastern portion of Delta Marsh, Manitoba in 2011.. 57

Figure 7 Method of determining substrate elevation.. 58

Figure 8. Construction of a Digital Elevation Model (DEM) in AcrMap from depth points taken using QTC single beam sonar system in Cadham Bay in the eastern portion of Delta Marsh, Manitoba.. 59

Figure 9. Comparison of DEMs of Simpson Bay in the eastern portion of Delta Marsh, Manitoba before (A) and after (B) adjustment of bathymetric elevations due to seiche effects.. 60

Figure 10. Comparison of DEMs of Black Fox Bay in the eastern portion of Delta Marsh, Manitoba before (A) and after (B) adjustment of bathymetric elevations due to seiche effects.. 61

Figure 11. Outline of study area showing the 44 individual sections used for interpolation of bathymetric data in the eastern portion of Delta Marsh, Manitoba. Each bay and channel is separated into a unique section. 62

Figure 12. A mask, obtained from the features in Figure 10, which represents the survey area, is used to clip the entire DEM to include only those parts that had been surveyed by the QTC single beam sonar system 63

Figure 13 Final interpolated Digital Elevation Model (DEM) of the surveyed area of the eastern portion of Delta Marsh, Manitoba. 64

Figure 14. Digital Elevation Model (DEM) of the eastern portion of Delta Marsh, Manitoba. 65

Figure 15. 3D rendering of the eastern portion of Delta Marsh, Manitoba created using ArcScene. This model shows the approximate extent of flooded areas during a normal water year (water level of 247.47 mASL). 66

Figure 16. 3D rendering of the eastern portion of Delta Marsh, Manitoba created using ArcScene. This model shows the approximate extent of flooded areas during a normal water year (water level of 248.97 mASL). 67

Figure 17. Digital Elevation Model (DEM) of the eastern portion of Delta Marsh, Manitoba as determined by Quester Tangent Corporation (QTC) single beam sonar analysis as well as data obtained from the Manitoba Land Initiative (MLI) website.. 68

Figure 18. Distribution of elevations within the study are in the eastern portion of Delta Marsh, Manitoba as determined by Quester Tangent Corporation (QTC) single beam sonar analysis.. 69

Figure 19. Location of lowest elevations within the bathymetry study area in the eastern portion of Delta Marsh, Manitoba as determined by Quester Tangent Corporation (QTC) single beam sonar analysis... 70

Figure 20. Distribution of elevation measurements taken within several bays and channels within the eastern portion of Delta Marsh, Manitoba as determined by Quester Tangent Corporation (QTC) single beam echosounder analysis.. 71

Figure 21. Locations of bays and channels in Figure 20. A)Delta Channel, B) Delta Channel, C) Northeast Channel D) Channel Off of Clandeboye Bay E) Simpson Bay, F) Black Fox Bay, G) Waterhen Bay, H) Clandeboye Bay. 72

Figure 22. Distribution of six unclassified substratum categories as identified by Quester Tangent Corporation (QTC) single beam sonar and QTC IMPACT substrate analysis in the eastern portion of Delta Marsh, Manitoba in 2011. 86

Figure 23. Substrata distribution map of the eastern portion of Delta Marsh, Manitoba in 2011 as determined by Quester Tangent Corporation (QTC) IMPACT substrate analysis.. 87

Figure 24. Locations of 72 substratum samples taken in 2011 within the eastern portion of Delta Marsh, Manitoba in order to ground-truth substratum categories identified by Quester Tangent Corporation (QTC) single beam sonar analysis and QTC IMPACT substrate analysis... 88

Figure 25. Three substratum categories found within the eastern portion of Delta Marsh, Manitoba as determined by examination of ground-truthed samples from the study area. A) Plant Matter B) Clay/Silt C) Organic Matter. 89

Figure 26. Distribution of three classified substratum categories as identified by Quester tangent Corporation (QTC) IMPACT substrate analysis and examination of ground-truthed samples in the eastern portion of Delta Marsh, Manitoba in 2011. 90

Figure 27. Transition from point data collected by Quester Tangent Corporation (QTC) single beam sonar analysis and QTC IMPACT substrate analysis (A) to an interpolated substrata map as determined by interpolation of QTC data (B) and ground-truthed samples (C) in Cadham Bay, located in the eastern portion of Delta Marsh, Manitoba in 2011. 91

Figure 28. Interpolated distribution of three predominant substratum classes in the eastern portion of Delta Marsh, Manitoba in 2011 as determined by Quester Tangent Corporation (QTC) Impact substrate analysis and examination of ground-truthed samples. 92

Figure 29. Quickbird satellite imagery of the vegetation study area in the eastern portion of Delta Marsh, Manitoba obtained from DigitalGlobe Inc. on August 29th, 2011......................... 110

Figure 30. Vegetation study area in the eastern portion of Delta Marsh, Manitoba. 111

Figure 31. Distribution of cover classes in the eastern portion of Delta Marsh, Manitoba as determined by statistical analysis of ground-truthed and visually extrapolated cover areas within Quickbird satellite imagery obtained from DigitalGlobe Inc. on August 29, 2011. 113

Figure 32. Box plots displaying the range of values displayed by dominant cover classes in the eastern portion of Delta Marsh, Manitoba based on **A.** Mean reflectance in the red spectral band (630 – 690 nm) **B.** Mean reflectance in the near-infrared (NIR) spectral band (760 – 900 nm) **C.** Normalized Difference Vegetation Index (NDVI) **D.** Maximum difference between two pixels of a classified polygon and **E.** Standard deviation in the red spectral band (630 – 690 nm). 114

Figure 33. Comparison of cover distributions in the eastern portion of Delta Marsh, Manitoba in 2009 and 2011 as determined by statistical analysis of ground-truthing and visually extrapolated data from Quickbird satellite imagery. 115

Figure 34. Locations of ten seed bank samples taken from the eastern portion of Delta Marsh Manitoba in July 2011. 129

Figure 35. Handling of seedbank samples from the eastern portion of Delta Marsh, Manitoba included three unique treatments A) Moist soil B) Saturated soil C) Flooded soil. 130

Figure 36. Sample of dock (*Rumex sp.*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 132

Figure 37. Sample of Longstyle Rush (*Juncus longistylis*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 133

Figure 38. Sample of unknown grass #1 grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 134

Figure 39. Sample of Wild Mustard (*Sinapsis arvensis*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 135

Figure 40. Sample of unknown grass #2 grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 136

Figure 41. Sample of Red Goosefoot (*Chenopodium rubrum*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 137

Figure 42. Sample of Celery-leaved Buttercup (*Ranunculus scleratus*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 138

Figure 43. Sample of Rough Bugleweed (*Lycopus asper*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 139

Figure 44. Sample of Wild Mint (*Mentha canadensis*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 140

Figure 45. Sample of Salt Marsh Bulrush (*Scirpus paludosus*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 141

Figure 46. Sample of Northern Willowherb (*Epilobium ciliatum*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 142

Figure 47. Sample of Rayless Annual Aster (*Symphotrichium ciliatum*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 143

Figure 48. Sample of Common Duckweed (*Lemna minor*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 144

Figure 49. Sample of Star Duckweed (*Lemna trisulca*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 144

Figure 50. Sample of Common Bladderwort (*Utricularia vulgaris*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba. 145

Figure 51. Quartile box plots representing the elevational ranges of classified vegetation cover within the eastern portion of Delta Marsh, Manitoba as determined by Quester Tangent Corporation (QTC) and Manitoba Land Initiative (MLI) elevational data and analysis of QuickBird satellite imagery.. 164

Figure 52. Frequency distribution of elevations measured within the eastern portion of Delta Marsh, Manitoba as determine by Quester Tangent Corporation (QTC) single beam sonar analysis.. 165

Figure 53. Quartile boxplots describing the range of depth distributions among substratum classes identified by Quester Tangent Corporation (QTC) single beam sonar analysis and QTC IMPACT substrate analysis in the eastern portion of Delta Marsh, Manitoba. 167

Figure 54. Quartile boxplots describing the range of depth distributions among substratum classes as determined by Quester Tangent Corporation (QTC) single beam sonar analysis, QTC IMPACT substrate analysis and ground-truthed samples in the eastern portion of Delta Marsh, Manitoba. 169

Figure 55. Comparison of substrate categories, identified by Quester Tangent Corporation (QTC) single beam sonar analysis and QTC IMPACT substrate analysis ,within the clay and organic substrate classes identified by ground-truthed samples in the eastern Delta Marsh, Manitoba. 170

1.0 – Introduction

1.1 - Organization of Thesis

This thesis is organized into eight chapters. Chapter one will introduce the study and the major objectives and hypotheses. Chapter 2 will review the relevant and recent literature pertaining to the study location and the study. Chapters 3 will look at the creation and implications of the bathymetry created in 2011. Chapter 4 will look at the creation and implications of the substrata map created in 2011. Chapter 5 will look at the creation and implications of the vegetation map created in 2011 and compare it to similar data collected in 2009. Chapter 6 will look at the collection of seed bank data through seedling emergence experiments in 2011. Chapter 7 will explore the relationships existing between the vegetation and bathymetric data as well as those between the substrata and bathymetric data. Chapter 8 will explore the overall implications and recommendations resulting from this study.

1.2 – Preface

In the summer of 2010 I embarked on the first field season of my Master's thesis; an examination of the efficacy of a range of control methods for the invasive cattail *Typha x glauca* in Delta Marsh, Manitoba. I spent the summer taking baseline above and below ground biomass measurements and applying my control methods and the winter processing hundreds of samples and compiling my results. As the spring of 2011 began, high water levels on the Assiniboine River resulted in the operation of the Assiniboine River Diversion, which diverted the approaching flood water into Lake Manitoba. The Diversion continued to operate throughout the spring resulting in consistently rising water levels in Lake Manitoba and the adjacent Delta Marsh. The 2011 flood resulted in the inundation of cabins, homes, crop land and large portions of the marsh, including my experimental plots, which resulted in the senescence of all vegetation within them. Upon discussing the situation with my committee it was decided that this project should be abandoned, but fortunately the situation afforded me the opportunity to begin a new project. Satellite imagery, used to create distribution maps of the dominant emergent vegetation in the marsh had been taken in the past during normal water years. My new objective was to obtain satellite imagery of the eastern portion of Delta Marsh during the flood and compare it to the imagery taken during a normal water year. In addition, the Department of Fisheries and Oceans (DFO) was in possession of a single beam sonar system that could be used to take bathymetric measurements. A detailed bathymetry of the marsh had never been attempted due to the shallow nature of the area but the increased water levels meant that the operation of a single-beam sonar system, which requires approximately 1 meter of water for accurate data collection, became feasible. My objective was to utilize this sonar system to create a bathymetric map of the study area to be to examine the relationships expressed between vegetation and water depth distributions. Furthermore, while taking bathymetric measurements the sonar system simultaneously collected data on the substrata of the marsh, allowing me to create a distribution map of the dominant sediments in the marsh.

The 2011 flood has been described as a 1 in 300 year event. Due to the extreme nature of this incident I expected that the high water levels would gradually recede leaving in their wake newly exposed mudflats, which had the potential to become colonized by a wide variety of plants from the seed bank. Since Delta Marsh has been prominently dominated by *Typha* in the past several decades this could mean the reintroduction of uncommon species to the area. In order to explore the potential results of the eventual drawdown I also set out to conduct several experiments which would demonstrate what species remained viable in the seed bank.

1.3 – Overview of Objectives and Hypotheses

This study was undertaken in order to expand our knowledge of the bathymetry of Delta Marsh as well as to explore the affects and implications of said bathymetry on multiple environmental characteristics of the marsh including substrata and vegetation distributions. I also set out to determine the effects of high water levels, as exemplified by the flood of 2011, on the vegetation in the marsh. My main objectives were to:

- Create a bathymetry of the eastern portion of Delta Marsh (Chapter 3)
- Create a substrata distribution map of the eastern portion of Delta Marsh (Chapter 4)
- Create a cover map of the dominant emergent vegetation species in Delta Marsh representative of the conditions resulting from high water (Chapter 5)
- Compare the distributions of dominant emergent vegetation species between normal water and high water years (Chapter 5)
- Examine the viable seed bank in Delta Marsh (Chapter 6)
- Explore the relationship between elevation/water depth and the distribution of dominant emergent vegetation species in Delta Marsh (Chapter 7)
- Explore the relationship between the elevation/water depth and the distribution of substrata in Delta Marsh (Chapter 7)

Based on these objectives the following hypotheses were put forward:

- Due to the large amount of vegetative material and highly productive nature of the marsh I expected that sediments in the marsh will be dominated by organic substrata.
- Substrata within the marsh would be distributed in a homogenous manner due to resuspension as a result of the shallow nature of the area and disturbance from wind and wave action.
- Due to the shallow slope in the marsh and surrounding areas and the drastic increase in water levels I expected that coverage of open water throughout the marsh in 2011 would increase in comparison to 2009 while the coverage of emergent vegetation would decrease significantly due to flooding and senescence
- *Typha* would remain the dominant emergent species due to its preference of flooded conditions and its ability to form floating mats
- Due to its historical and present dominance in the marsh I expected that *Typha* would also be the dominant presence in the viable seed bank
- As many wetland plants require the presence of moist or saturated soils for germination, yet are not capable of germinating in flooded soils I expected that the diversity of germinating seeds would be lower in flooded emergence experiments than in moist or saturated experiments
- Due to its preference for flooded conditions *Typha* would be associated with relatively low elevations, while *Phragmites* would be associated with relatively high elevations.

2.0 – Literature Review

2.1 – Wetlands

Wetlands are transition zones between terrestrial and aquatic environments and provide a wide range of ecosystem functions and exhibit a wide range of conditions (Mitsch and Gosselink, 2007). Despite this there are several characteristics which can be attributed to all wetland ecosystems. All wetlands possess either flooded zones, or at the very least saturated soil, for some part of the year. They accumulate organic litter from plants, which decomposes slowly and supports a variety of plants and animals which are adapted to these wet conditions (Lewis and Cowardin, 1979; National Wetlands Working Group, 1988; Campbell and Rubec, 2003). Within this set of characteristics there is still a very wide range of conditions in which a wetland may exist. Although all wetlands experience flooded or saturated conditions the depth and extent of flooded areas and duration of flooding varies widely; some wetlands are flooded year round, where others may only experience minimal flooding or saturated soil conditions for a portion of the year. In addition, flooding within a wetland may not be annually consistent; the extent of flooding is based on the inflow and outflow of water (precipitation, groundwater, runoff, evapotranspiration, etc.) so the location of flooded or saturated areas may change significantly from year to year. Because wetlands experience flooded or saturated condition for at least part of the year we find that the vegetation in wetlands is adapted to these conditions. Wetland plants range from those that are able to survive in extended flooded or wet conditions, to those that may only be able to tolerate them for a short time. In addition to the wide range of conditions within wetlands, they are found all over the world in many different environments including coastal or inland, and may be directly connected to a larger water body or completely isolated.

Due to their ambiguous nature many definitions have been produced. For my purposes the definition used by the U.S. Fish and Wildlife Service will suffice: "Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water… Wetlands must have more than one of the following three attributes: (1) at least periodically, the land supports primarily hydrophytes; (2) the substratum is predominantly undrained hydric soil; and (3) the substratum is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year." (Cowardin et al., 1979).

2.1.1 - Function

Wetlands provide us with many important ecosystem services; from nutrient and sediment retention to provision of recreational areas. They play a major role in mitigating the impacts of excessive nutrient and toxicant loads to downstream aquatic ecosystems. They are important for removing excess nitrogen (N), phosphorus (P) and suspended sediments from water thereby protecting nearby water bodies from eutrophication and sediment loading (van der Valk, 1989; Mayer et al., 1999; Casey and Klaine, 2001). Runoff from urban areas and agricultural lands is a major source of nutrients and sediments as well as toxins such as pesticides and fertilizers. Processes within wetlands are capable of neutralizing and breaking down many toxins that enter through these means (Cowan, 1979; Mitsch and Gosselink, 2007).

N is often a limiting nutrient in anaerobic soils such as those found in wetlands; such is the case in Delta Marsh (personal observation; Bortoluzzi, 2013). N enters wetlands in runoff and is also produced in the form of ammonium as organic matter, such as plant litter, breaks down. N is removed from the water and soil in the wetland through denitrification by bacteria, assimilation by plants and algae, dissimilatory reduction to ammonia and volatilization (van der Valk, 1989; Tomaszek et al., 1997; Bachand and Horne, 1999; Whitmore and Hamilton, 2005; Mitsch and Gosselink, 2007; Scott et al., 2008).

P comes mainly from the breakdown of organic materials and as input from runoff in the surrounding area; it can also be a limiting nutrient in wetlands. A large portion of the total P in a wetland is tied up in organic litter, which is released upon decomposition. P is removed through uptake by vascular plants, algae and bacteria, adsorption to clay particles, peat and ferric and aluminum hydroxides and oxides, and precipitation with ferric iron, calcium and aluminum under aerobic conditions (van der Valk, 1989; Kadlec and Knight, 1996; Dierberg et al., 2002; Mitsch and Gosselink, 2007; Gu, 2008)

Sediments enter into wetlands mainly through inflowing water and tend to settle out as the water slows down due to the increase in vegetation cover (Johnson et al., 1984; Fennessey et al., 1994; Murkin, 1998; Cronk and Fennessey, 2001). The settling of suspended sediments results in clearer water, which in turn results in increased light penetration into the water column. This also results in the removal of nutrients (as well as metals and organic chemicals) which are bound to the sediment particles (Kadlec and Knight, 1996).

2.1.2 - Wetland Loss

Wetlands are some of the most productive ecosystems on Earth but unfortunately they are becoming increasingly rare habitats; a very small portion of the Earth's surface is covered by wetland habitat; an estimated 4 – 7.5% (Maltby and Turner, 1983; Mathews and Fung, 1987; Aselmann and Crutzen, 1989; Lehner and Doll, 2004; Mitsch and Gosselink, 2007). Wetlands in North America, and all over the world, are being destroyed at an alarming rate. In 1985 it was estimated that 56 – 65% of wetlands in North America and Europe had been drained, mainly for agricultural purposes. Similarly it is estimated that 27% of wetlands in Asia have been drained (Ramsar Convention Secretariat, 2004). Canada has experienced relatively low rates of wetland loss, seeing an estimated 15% loss across the country. There are, however, several regions that have experienced particularly high wetland losses, such as those seen in southern Ontario (68%), the Atlantic Coast (65% of salt marshes) and the in prairies (over 1,000,000 ha - >50%). It is estimated that approximately 85% of the total wetland loss in Canada is due to conversion for agricultural purposes (North American Wetlands Conservation Council of Canada, 1993). In Manitoba, one of the hardest hit regions in Canada, it is estimated that wetlands make up approximately 2.5% (13,532 km^2) of the total area of the province, which is most highly concentrated in the southern portion of the province, often referred to as the prairie pothole region (Halsey et al., 1997). It has been estimated that six hectares of wetlands are lost every day in this relatively concentrated area, adding up to approximately 2,185 ha lost every year, again mainly due to drainage for agricultural processes (Ducks Unlimited Canada, 2009). With the loss of these precious wetland environments also comes the loss of the ecosystem services provided by them such as the removal of nutrients, toxins and sediment.

2.1.3 - Hydrology

The health of a wetland can be greatly impacted by its water regime (van der Valk et al., 1994; Baldwin et al., 2001; Cronk and Fennesey, 2001; Haag et al., 2005). Changes in water level may occur on a day to day or seasonal basis, or may not change significantly for many years. The hydrology of a wetland is influenced by climate, basin morphology and subsurface conditions such as soil composition and geology as well as inputs and outputs such as precipitation, surface runoff, groundwater, tides, flooding and evapotranspiration. Surface flow occurs directly following precipitation events and spring thaw. Many wetlands receive flow from connections to other water bodies and may also receive water input from unconnected water bodies during flood events from overflowing waters. Groundwater is only a large influence on hydroperiod in certain circumstances; namely where the wetland is situated either higher or lower than the level of the water table, causing water to flow out of or into the wetland respectively. Many wetlands are not greatly influenced by groundwater and experience the majority of water inflow through runoff and precipitation and the majority of water loss through surface outflow and through evaporation and uptake by plants (evapotranspiration) (Cronk and Fennessey, 2001; Mitsch and Gosselink, 2007). Evapotranspiration increases as atmospheric temperature increase and can be the largest source of water loss in a wetland, especially during summer months (Gillman, 1994; Owen, 1998). Changes in these characteristics will result in changes in water depth distributions, water flow patterns as well as flooding duration and frequency, which combine to create a completely unique wetland ecosystem.

Some wetlands, such as coastal salt marshes and tidal marshes, are also influenced by tides. Although this is generally experienced by wetlands that are directly connected to the ocean, some inland wetlands which are adjacent to large water bodies experience a similar occurrence. One such wetland, Delta Marsh, the focus of this thesis, is located on the southern end of Lake Manitoba and is directly connected to the lake through several channels. Changes in water level may be experienced during periods of extended, strong northerly winds. The huge surface area and shallow depth of the lake allows water to pile up in the south end of the basin during periods of extended high wind, which can then move into the marsh; this occurrence is called a seiche.

A normal succession from wet to dry and back again may occur over 5 – 20 years and is often highly influenced by patterns of precipitation (Kiel et al., 1972; van der Valk and Davis, 1980). This cycle consists of four main stages:

1. Dry marsh stage – during drought conditions the wetland will experience a drawdown (partial or complete) that exposes part of the wetland bottom. Seeds present in the seedbank germinate on this newly exposed soil (Walker, 1959; Kadlec, 1962; Walker, 1965). Seeds of many emergent and mudflat plant species that are found in the seedbank require mudflat conditions for germination (Kadlec, 1962; Pederson, 1981; van der Valk, 1981). Exposure of mudflats also promotes faster decomposition of organic materials which have accumulated during flood years and creates the opportunity for soil aeration (Kadlec, 1962; Christensen et al., 2009). Nutrients released from decomposing materials promote the growth of newly germinated plant seedlings.

2. Regeneration Stage – previously dry areas are flooded; this usually results in the senescence of annual plant species. Many emergent species survive and spread, generally through vegetative reproduction (Mitsch and Gosselink, 2007). This vegetation serves as valuable habitat for aquatic vertebrates and invertebrates (Weller and Fredrickson, 1974; Wrubleski, 1991; Murkin et al., 1997). Prolonged flooding may however result in the senescence of emergent vegetation, with the rate of senescence being positively correlated with water depth (McDonald, 1955; Harris and Marshall, 1963; Millar, 1973).

3. Degeneration Stage – reduction of emergent vegetation due to prolonged flooding reduces the amount of food and cover available to marsh organisms, thereby reducing the number of organisms and diversity of species that can be supported (Weller and Fredrickson, 1974). This occurrence was observed in all emergent plant species at Delta Marsh in the 1950's (Walker, 1959; Harris and Marshall, 1963; Walker, 1965; Bossenmaier et al., 1968; Millar, 1973).

4. Lake Marsh Stage – vegetation in the deepest areas is eliminated and is reduced to a band around the fringe of the basin. Emergent species are unable to become reestablished due to the continuous deep water conditions. Reduced levels of emergent vegetation result in decreased litter production and cover, which reduces habitat for those species that utilize it (Weller and Fredrickson, 1974). The water's surface is more exposed to high winds, which may stir the water and sediment and create turbid conditions, reducing light availability within the water column, which may reduce growth and survival of submersed plants

(Nelson and Kadlec, 1984). The marsh will remain in this stage until another drawdown occurs, causing a return to the Dry Marsh stage.

Although many wetlands experience varied water regimes this is not always the case. Many wetlands, especially those connected to large water bodies, are often managed to create more stable water conditions. This may be done through the use of levees, dikes and other water control structures in order to reduce changes in water level. In stagnant, unchanging water conditions, like those found in artificially stabilized wetlands, primary productivity decreases; contrastingly it is enhanced in areas where water levels change frequently and flow is present (Mitsch and Ewel, 1979; Conner et al., 1981; Mitsch and Reader, 1991). This was seen with the installation of the Fairford River Control Structure (FRCS) on Lake Manitoba in 1961, which reduced water level fluctuations on the lake. Fluctuations have been reported to measure 1.93 m pre-regulation to 1.06 m post-regulation (Lake Manitoba Regulation Review Advisory Committee, 2003; Lake Manitoba Regulation Review Committee, 2013; Water Office of Canada, 2014) and from 2.2 m to less than 0.6 m (Crowe, 1974; de Geus, 1987) (Figure 1). Although the total variation before the construction of the control structure was much larger than the variation post construction, the annual variation remained relatively constant, decreasing from an average of 0.433 m to 0.401 m annually. Because the Delta Marsh is directly connected to Lake Manitoba it has experienced similar patterns in water level stabilization.

2.1.4 - Wetland Vegetation

Hydrology is greatly influential on the structure and health of wetlands and is particularly significant to its distribution and diversity of vegetation (van der Valk and Davis, 1978; Spence, 1982; Keddy and Ellis, 1985; Squires and van der Valk, 1992; van der Valk et al., 1994; Grosshans and Kenkel, 1997; Shay et al., 1999; Batzer, 2006) Wetland vegetation is an important source of food for invertebrates, waterfowl and other wetland organisms and provides important habitat to many organisms. It is also an important substratum for algae growth, which acts as an additional food source to wetland fauna (Kaminski and Prince, 1984; Murkin et al., 1992; Ross and Murkin, 1993; Murkin et al., 1997; Cronk and Fennessey, 2001). Wetland plants are often known as hydrophytes - plants that grow in water or in soil that is at least periodically saturated by water, though not all plants growing in wetlands are tolerant of flooded conditions (Cowardin et al., 1979). Many terrestrial species can be found in upland areas that are not normally water saturated or may grow temporarily in dry areas created by drawdown conditions. Flood intolerant species may grow in areas that experience small amounts of flooding but will not survive long when the soil becomes saturated or flooding occurs. Wetlands that experience longer periods of flooding will generally have lower species diversity than one with intermittent flooding (van der Valk et al., 1994; Shay et al., 1999; Casanova and Brock, 2000). Experiments in the Marsh Ecology Research Program (MERP) cells in Delta Marsh showed increased open water cover and lower species diversity following 2-3 years of continuous flooding. Emergent vegetation decreased by approximately 40% over this time; emergent vegetation also experienced decreases in species richness, species diversity and total shoot density (van der Valk and Davis, 1978; van der Valk et al., 1994). Wetlands that experience flowing water and water level fluctuations tend to have relatively high species diversity; these continually changing environments offer constantly fluctuating habitats, which are colonized by those plants within the soil seed bank which are best adapted to them. (Keddy, 1992). Seeds within the seedbank may have been dispersed years before but remain viable within the soil (Keddy, 2000). Colonization events in wetlands are often the result of a drawdown, which reveals previously uncolonized mudflat areas (van der Valk and Davis, 1978)

2.1.5 - Effects of Hydrology on Vegetation

Many wetland plants are hydrophytes, meaning that they are tolerant of wet conditions, but even flood tolerant species have their limits. Plant death may occur during flooding due to the anoxic conditions that develop in the soil. Water fills spaces between soil particles (interstitial spaces) which would normally contain air. Since oxygen diffuses through water at a much slower speed than air, oxygen concentrations within the soil drop quickly and are unable to support many plant species. Signs of oxygen stress include a wilted appearance (due to decreased ability to transport water), decreased photosynthesis (due to closure of stomata to decrease water loss) and swelling of the stem base (due to expansion of gaseous spaces to increase diffusion to the roots) (Cronk and Fennessey, 2001). When oxygen is unavailable through normal avenues plants must obtain it through other means or tolerate the low oxygen levels. Adaptations which aid in this include utilization of aerobic soil near the surface, development of expanded gas spaces within the plant to increase gas diffusion and rapid extension of the shoot in order to remain above the water line (Armstrong, 1978; Armstrong et al., 1994; Vartapetian and Jackson, 1997; Visser et al., 1997).

While much of the soil becomes anoxic during flooded conditions a thin layer near the surface may continue to exhibit higher oxygen concentrations. Plants have developed several strategies to take advantage of this oxygen-rich portion of the soil including adventitious roots, pneumatophores and aerenchyma which aid in gas exchange (Brown, 1981; Koncalova, 1990; Vartepetian and Jackson, 1997). Some species also exhibit shoot extension – increased growth that brings the plant closer to or above the water's surface, increasing exposure to light and required gases and to keep flowering portions of the plant above water (Jackson, 1990; Waters and Shay, 1990; Vartepetian and Jackson, 1997).

Due to the wide range of water depth and soil saturation tolerances of wetland plants, water level changes often result in the redistribution of emergent and submergent vegetation along an elevation/water depth gradient (Pearsall, 1920; Gleason, 1926; Spence, 1967; Keddy, 1983; Keddy and Ellis, 1985). Since unique plant species have unique responses to the environment each will develop in a particular niche; in the case that the niche of two species overlaps they may coexist or one species may out-compete the other for that particular zone. Other factors such as elevation will also affect the distributions of species; a steeply sloped basin will result in very distinct zonation of plant species based on flood tolerance while a shallow slope might result in a mosaic-like pattern of species distributions (Walker, 1965; de Geus, 1987). In a natural environment hydrological changes are common, resulting in cycles of flooding and drawdowns, which produce dynamic changes in vegetation distributions and high species diversity (Wilcox, 2004). Stabilized conditions, however, often result in decreases in introduction of new species and the domination of vegetation communities by aggressive species over time (Wilcox and Meeker, 1991).

2.1.6 - Invasive Species

Non-native plant species, also known as invasive species, can have large negative impacts on native plants. Invasive species are often introduced by human actions including migration and disturbances. Although the introduction of new species in not uncommon it is estimated that very few introduced species become established or detrimental to their environments (Williamson and Fitter, 1996). An introduced species will become invasive if it is observed to have a negative impact on native species and/or the surrounding environment. This may include the alteration of environmental features such as reduced species diversity as well as changes in plant productivity, hydrology and nutrient cycling. In recent years, one particular invader has detrimentally affected the wetlands of North America, including several significant wetlands here in Manitoba. *Typha angustifolia* L., and more importantly its hybrid *Typha x glauca* Godr., have spread throughout Manitoba wetlands such as Delta Marsh and Netley-Libau Marsh, displacing native plant species, resulting in reduced species diversity and the loss of important habitat for waterfowl and other wetland organisms (Goldsborough, 1984, 1987; Pederson and van der Valk, 1985; Shay et al., 1999)

2.1.6.1 - Typha

Cattails are a common emergent wetland plants that are found throughout the world. A common species is the temperate *Typha latifolia* L. (the common cattail), which is found throughout North America, including in Canada. In the 1800s, around the time of widespread

European settlement in North America, a European species of cattail, *Typha angustifolia* (narrow-leaved cattail), was introduced (Grace and Harrison, 1986). Both *T. latifolia* and *T. angustifolia* have an optimal water depth of approximately 50 cm but *T. latifolia* tends to outcompete *T. angustifolia* due to its aggressive nature, causing *T. angustifolia* to grow in deeper water than is optimal (50 – 90 cm water depths). *Typha angustifolia* is more tolerant of deep water conditions which may be due to the fact that it produces larger rhizomes (Grace and Wetzel 1981, 82). Differentiation between the two species can be difficult as the range of expression of many traits, such as shoot height, distance between spikes and leaf width, height and thickness, overlap in both species (Hotchkiss and Dozier, 1949; Fassett and Calhoun, 1952; Smith, 1967; Marcinko-Kuehn and White, 1999; Finkelstein, 2003; Selbo and Snow, 2004) (Figure 2).

The two species have interbred to create a fertile hybrid, *Typha x glauca*, whose characteristics have a wide range overlapping those of the two parent species. This species has been known in Europe from as far back as the 1880s (Kronfeld, 1889) and was first described in North America by several authors around the 1950's (Hotchkiss and Dozier, 1949; Fernald, 1950). *Typha x glauca* is an aggressive cattail species (Kuehn and White, 1999) which can survive in a wider range of water depths than either parent species and out-competes both *T. latifolia* and *T. angustifolia* in their preferred water depths (Smith, 1967; Waters and Shay, 1992; Kuehn and White, 1999). Like *T. angustifolia*, *T. x glauca* is tolerant of deep water (Waters and Shay, 1990)*;* being able to survive for two years in 70 cm of water, though experiencing reductions in both stand biomass and density (Squires and van der Valk, 1992), and in 60 cm of water over four years of continuous flooding (Harris and Marshall 1963). It has been shown that shoot density and shoot length in *T. x glauca* is greatest when growing in water depths between 20 and 70 cm, while both above and below-ground biomass is highest at depths between 45 and 70 cm (Squires and van der Valk, 1992). In experiments conducted by van der Valk (1994) one year of flooding at a depth of one meter eliminated most or all stands of *Carex atherodes* Spreng. (wheat sedge), *Scolochloa festuceae* Willd. (whitetop) and *Schoenoplectus tabernaemontani* (syn. *Scirpus lacustris* L.) (softstem bulrush). Only *T. x glauca* and *Phragmites australis* Cav. remained (40% and 25% of original stands respectively). Both above and belowground biomasses were reduced significantly during the first year of flooding but did not change significantly during the second year. *Typha spp*. are known to produce extensive root and rhizome networks which allow them to survive anaerobic conditions for longer periods of time than plants with small rhizomes (Barclay and Crawford, 1982; Braendle and Crawford, 1987). Since ATP production in anaerobic conditions requires more glucose, plants with a larger supply of carbohydrates (stored in rhizomes) can survive longer (Studer and Braendle, 1987).

Another advantage exhibited by *T. glauca* is its ability to germinate under flooded conditions (Bedish, 1967; Waters and Shay, 1990). Bedish (1967) found that *T. x glauca* had the highest growth rates when germination occurred in one inch of water, though germination was still relatively high in saturated soil an in up to six inches of water. It is therefore capable of establishing itself before mudflats become exposed, whereas the seeds of many other wetland plants require exposed soil for germination (Harris and Marshall, 1963; Pederson, 1981; Smith, 1967; Smith, 1972). *Typha x glauca* naturally grows in dense monodominant stands (Boers, 2006). *T. latifolia* has been known to grow in dense stands as well but only in high nutrient conditions (Day et al., 1988). The dense arrangement of *T. x glauca* stands results in large amounts of both standing and fallen litter from dead stems, leaves, roots and rhizomes; this reduces water depth and creates habitat in which new cattail can grow (usually vegetatively) but which is not useful to other plants due to reduced light availability (Boorman and Fuller, 1971; Haslam, 1971; Yeo, 1964). Rose and Crumpton (1996) showed that in *Typha* dominated emergent stands litter accumulation resulted in less than 2% of available light being present in the water column. Accumulated litter can also insulate the ground during winter, preventing freezing. Because of this, root systems that would have frozen and died over winter survive and grow new vegetation quickly in the spring, making the stand even more dense. Litter production in *Typha* stands is often highest during flooded conditions; furthermore, decomposition is relatively slow in flooded environments which can cause litter to remain present for several years (Davis and van der Valk, 1978; Christensen et al., 2009). Because of this slow rate of decomposition litter tends to build up, effectively reducing water depth and acting as a substratum for vegetative colonization by new stalks. Wave and wind action has been known to lift these dense rhizome/litter networks off of the wetland bottom, creating floating mats which are capable of moving around open water areas, creating the opportunity to colonize new areas (Krusi and Wein, 1988). It is believed that flotation originally occurs due to the gaseous spaces located within the stems and roots of the plant (aerenchyma) (Curtis, 1959) and is continued, as the mat increases in size and weight, by the accumulation of methane bubbles during the decomposition process which become trapped within the mat (Hogg and Wein, 1988). This ability may allow *Typha* to survive periods of extreme or extended flooding.

Not only do these dense monotypic stands reduce species diversity, they are poor habitat for waterfowl as they do not provide a desirable cover : water ratio nor do they provide proper food sources (Weller, 1994). Marsh birds prefer a 50:50 cover to water ratio, also known as a hemi-marsh (Weller and Spatcher, 1965; Weller and Fredrickson, 1974; Kaminski and Prince, 1981) while diving ducks prefer deeper water with a higher proportion of open water (Murkin et al., 1997). Due to its ability to grow in relatively deep water and produce floating mats *Typha* tends to reduce the percent cover of open water areas, thereby reducing suitable water bird habitat.

2.2 - Study Area

2.2.1 - Lake Manitoba

Lake Manitoba, located in south central Manitoba, is one of the largest freshwater lakes in the world, ranking 14th largest in Canada and 3rd largest in Manitoba (Statistics Canada, 2005). At approximately 180 km in length and 52 km in width (4624 km^2), but with depths not exceeding 8 m, it is relatively shallow (Love and Love, 1954). Lake Manitoba is a remnant of glacial Lake Agassiz, which was formed approximately 12,000 years ago as glaciers covering the northern portion of the continent retreated. Approximately 6,400 years ago what we now know as the Assiniboine River emptied directly into the southern end of Lake Manitoba, carrying with it large amounts of sediment which were deposited at the mouth of the river, forming a large Delta (Teller and Last, 1981). The building up of this delta and movement of sediments through wind and wave action eventually resulted in the creation of a beach ridge along the southern end of the lake. This ridge allowed for the formation of Delta Marsh, which is protected from the wind and wave action on Lake Manitoba. Some 2500 to 2000 years ago the Assiniboine River became disconnected from Lake Manitoba and water levels on the lake began to stabilize

(Rannie et al., 1989). Today the main hydrological inputs to Lake Manitoba are the Waterhen River, fed by Lake Winnipegosis to the north, the Whitemud River in the southwest and the Assiniboine River Diversion in the south. The only point of outflow in the lake is the Fairford River in the northern basin of the lake which drains into Lake St. Martin and eventually Lake Winnipeg.

2.2.1.1 Water Levels

Historically, water levels on Lake Manitoba have fluctuated an average of approximately 1.93 m annually (Water Office of Canada, 2014). As unstable water levels and extreme flood events such as those observed in 1954 and 1955 (Shay et al., 1999) presented problems for agriculture (flooding of farm land), the environment (drying out of wetland habitat) and recreation in the area (loss of boat launch and beach areas), attempts to control the water levels in the lake began, culminating in the construction of a water control structure on the Fairford River in 1961. The control structure is operated through the use of stop logs (adding logs to maintain/increase water levels in the lake and removing logs to decrease water levels) and is used to maintain an optimal water level of 247.6 mASL. Prior to the flood of 2011 the operation of this control structure had effectively reduced the annual water level fluctuations on Lake Manitoba from approximately 1.93 m to 1.06 m annually (Lake Manitoba Regulation Review Committee, 2003; Water Office of Canada, 2014).

In 1969 a new inflow to Lake Manitoba was created by reconnecting the Assiniboine River back to the lake; this diversion channel connects to the Assiniboine River just west of Portage la Prairie and travels north 25 km to the southern end of Lake Manitoba at Delta Marsh. The diversion was meant to reduce flooding along the low lying Red River Valley, preventing flood damage in high population areas such as in the City of Winnipeg. Construction was completed in 1970 and has had a significant impact on both the lake and marsh during its operation. The diversion is capable of carrying flows of up to 25,000 cubic feet per second (Last, 1984) which includes high levels of sediment that are directed into the lake (Kenny, 1985). In 2011 the diversion contributed approximately 87% of the total suspended solids entering Lake Manitoba (Berke, 2012). Fortunately the operation of the FRCS allows for the displacement of some of this input. A failsafe in the diversion was also built, which causes a portion of the channels embankment near the lake to collapse once 15,000 cubic feet per second of flow is reached, diverting water directly into the western unit of Delta Marsh. This failsafe was built to minimize damage to the west dike of the diversion, but in reality diverting water into the marsh also results in the flooding of agricultural lands in the surrounding area. Use of the failsafe in 1976 resulted in the deposition of large amounts of sediments in the marsh (an estimated 15 to 45 cm) and extensive flooding to the surrounding agricultural lands (Ducks Unlimited, 1981). Approximately 61,855,200,890 cubic feet of water flowed through the diversion which resulted in a rise in water level of approximately 10 inches. The diversion has also been shown to be a leading source of phosphorus input, contributing 62% of the total P loading in the lake and 25% of the total N loading (Lake Manitoba Regulation Review Advisory Committee, 2003; Berke, 2012).

The Province of Manitoba has recently accepted the recommendations of the Lake Manitoba Regulation Review Committee to reintroduce water level fluctuations, though not to the extent observed before installation of the FRCS.

2.2.2 - Delta Marsh

Delta Marsh is located at 50° 11' N, 98° 19' W on the southern shore of Lake Manitoba, (Figure 3). Covering approximately 18,500 ha (Watchorn et al., 2012) it is one of the largest freshwater marshes in North America and has existed for over 2,500 years. It has been classified as a slightly brackish lacustrine wetland (Anderson, 1978; Goldsborough, 1994). The marsh is made up of a collection of generally shallow, open bays, which are connected by channels and is directly connected to Lake Manitoba through four channels: Cram Creek and Deep Creek on the western side of the marsh and Clandeboye Channel and Delta Channel on the eastern side. The marsh can be broken up into an eastern and western region separated by the Assiniboine River Diversion. The eastern portion of the marsh is larger than the west and tends to have larger, more open water bodies. Water depths within the marsh range from less than one meter up to three meters (Shay et al., 1999; Walker, 1965), with most areas following a gentle slope, though the elevation gradient of some channels is relatively steep (personal observation). This gentle slope continues in many areas south of the marsh, which is why the area is so sensitive to water level changes.

Delta Marsh has a negative water budget, meaning that the amount of water lost through evapotranspiration is greater than the amount gained through precipitation in a given year. Since precipitation levels are low the largest water input to the marsh is through water flow from Lake Manitoba. Without the water input from Lake Manitoba it is estimated that the marsh water level would decrease by approximately 18 cm each year (Millar, 1969; Jones, 1978; Greenall, 1995). As previously mentioned Delta Marsh is directly connected to Lake Manitoba allowing for free movement of water in and out of the marsh; water levels within the marsh are highly correlated to water levels in the lake (de Geus, 1987; Bortoluzzi, 2013; personal obs.) (Figure 4).

2.2.2.1 Water Level Stabilization

Construction of the FRCS in 1961 has resulted in stabilization of lake water levels to an average of 0.40 m annually with an average water level of 247.47 mASL compared to pre-regulation water level fluctuations of up to 0.43 m annually with an average water level of 247.55 mASL (Lake Manitoba Regulation Review Advisory Committee, 2003; Water Office of Canada, 2014). Since water levels in the marsh are highly correlated with those in Lake Manitoba the stabilization of the lake has had a large impact on the adjoining marsh, reducing the water level variation that would normally result in changes between wet and dry conditions that are essential to the maintenance of health and species diversity (van der Valk, 1981; Keddy and Fraser, 2000; Wilcox and Nichols, 2008). Wet dry cycles are also important in preventing the dominance of particularly competitive plants by allowing other species to grow from the seedbank (van der Valk and Davis, 1980; Grosshans and Kenkel. 1997).

Reduced water level variation in wetlands can often result in increased monotypicity in emergent vegetation (Grace and Wetzel, 1981; Keddy and Reznicek, 1986; Wilcox et al., 1992) This has been seen in one of the largest wetlands in Manitoba; Netley-Libau marsh, located at the south end of Lake Winnipeg, which is in poor health due to the spread of *Typha x glauca* following water level stabilization (Grosshans et al., 2004). Delta Marsh is also under pressure from artificially stabilized water levels and expanding invasion of *T. x glauca.* From 1964 to

1997 cattail cover in Center Marsh increased by 819% while exhibiting a 97% decline in bulrush cover and 19% decline in open water (Goldsborough and Wrubleski, 2001). These changes not only reduce diversity within the marsh but may also have negatively affecting waterfowl populations due to habitat loss (Ould, 1980; Bond, 1996; Goldsborough and Wrubleski, 2001; Laporte, 2012). Stabilization of water levels has resulted in much of the marsh reaching a lake marsh stage of development, which is relatively unproductive (van der Valk and Davis, 1978).

2.2.2.2 Geology and Substrata

Delta Marsh is underlain by bedrock, which is covered by up to 100 m of sediment deposited by glaciers, rivers, streams and lake water (Last, 1984). Wetland soils are hydric, meaning that that they are saturated or flooded for a long enough period of time in order for anaerobic conditions to occur during the growing season. Anaerobic conditions develop during periods of extended flooding by filling the spaces between soil particles, which are usually occupied by air. Oxygen diffuses through water at a much slower rate than it does through air meaning that soil oxygen concentrations are much lower than in dry conditions. Anaerobic conditions can develop within hours of flooding and will occur at a faster rate when ambient temperatures are high (Turner and Patrick, 1968).

Soils in the marsh have been described as ranging from sandy loam to silty clay with characteristics of gleysolic and regosolic soils (Walker, 1965). Gleysols are hydric soils, saturated with water and exhibiting anaerobic conditions for at least part of the year while regosols are classified as mineral soils in which distinct sediment layers have not developed (Soil Classification Working Group, 1998). Sediments in the marsh are generally covered by 5 – 10 cm of organic materials (Zbigniewicz, 1982) though highly vegetated areas may have a much thicker layer of decomposing materials and organic litter from emergent plants. Decomposition of plant materials in flooded areas is relatively slow due to anaerobic conditions so there may be a significant layer of decomposing and senesced plant material over top of the actual soil.

2.2.2.3 Changes in Emergent Vegetation

The hydrologic regime of a wetland is a main influence on the distribution and composition of wetland vegetation. A fluctuating hydroperiod will result in a diverse plant community, while stabilized water levels often result in the dominance of several highly competitive species, resulting in lowered species diversity (Kantrud et al., 1989). Prior to regulation of water levels in Delta Marsh, the dominant emergent vegetation consisted of giant reed grass (*Phragmites australis*) and white-top (*Scolochloa festucacea*) in higher elevations (shallow or damp areas) and bulrush (*Schoenoplectus acutus var. acutus* and *Schoenoplectus tabernaemontani*) and cattail (*T. latifolia* and *T. angustifolia*) at lower elevations (deep water environments) (Love and Love, 1954; Rayner, 1978; Shay et al., 1999; Batt, 2000). Post regulation, significant changes in vegetation were observed.

As water levels change emergent plant species are redistributed along a water depth gradient dependent on their flood tolerances. With decreased water level fluctuations dynamic changes in vegetation that once occurred in Delta Marsh were no longer observed (de Geus, 1987). Water level stabilization resulted in the expansion and domination of *T. x glauca*. Shorelines are now fringed by *Schoenoplectus spp.* and extensive monodominant stands of *T. x glauca*, backed by *P. australis* (syn. *Phragmites communis*) (Walker, 1965) which are generally associated with areas that are flooded during the growing season (Millar, 1976). Whitetop (*Scolochloa festuceae*) and sedges (*Carex spp.)* may also be found in higher elevation zones (Batt, 2000).

2.2.2.4 - Typha Invasion

Typha spp. have been the dominant emergent species in Delta Marsh since.at least 1972 (de Geus, 1987). Hybridization between the native *T. latifolia* and the invasive *T. angustifolia* was first reported in the Delta Marsh after the construction of the FRCS (Shay and Shay 1986) but it may have been present as early as the 1950's (Figure 2). Love and Love (1954) described great variation among individuals of *T. latifolia*, but did not believe this was due to hybridization. *Typha x glauca* has since spread rapidly throughout Delta Marsh, out-competing and displacing native vegetation. Continuously stabilized water levels have also lead to the infilling of small, shallow bays by cattail (Shay et al., 1999). Shay (1986) described a shift from *Phragmites* to *Tyhpa* domination within the marsh around 1980, which coincided with a shift in domination from *T. latifolia* and *T. angustifolia* to *T. x glauca* which was noted to be the dominant *Typha* species during a field survey in 1984 (de Geus, 1987). Following controlled burns in the early 1990's revegetated areas also seemed to be dominated by *T. x glauca* as well (Greenall, 1995). A recent study of the distribution of cattail species in southern Manitoba and southeastern Saskatchewan (Wasko, 2013) found that *T. x glauca* is by far the most dominant species in the province, followed by *T. latifolia*, while *T. angustifolia* was relatively rare. The same study found that within the Delta Marsh region, while *T. x glauca* remained the dominant species and *T. angustifolia* remained relatively rare, *T. latifolia* was completely absent from sample transects (Wasko, 2013).

Dominance of *Typha x glauca* and *Typha spp*. in general, is attributed to its reproductive advantage. Although both *Typha* and *Phragmites* produce extensive rhizome networks *Typha* also produces huge quantities of seeds and has a large seed bank, allowing it to quickly colonize newly exposed mudflats. Areas dominated by *Typha x glauca* tend to lack species diversity, which is important in the maintenance of a healthy marsh system (Weller, 1978; Weller, 1981; Kaminski and Prince, 1981; Murkin et al., 1982)

2.3 - Bathymetric Data

2.3.1 - Benefits and Uses

Knowing the importance of hydrology in regards to the health and species diversity of a wetland it stands to reason that knowledge of the elevational distribution of these wetlands would be enormously beneficial for developing management strategies. This data, known as a bathymetry, can be used to create elevational maps that can assist in predicting the extent of flooded areas during either high or low water events. Three-dimensional maps can be used to effectively visualize the distribution of water depths and to observe how the distribution of water itself would be altered as water levels change. Increased knowledge about the bathymetry of these areas can aid in our understanding of their hydrology, geology and biology. Although topographic data for terrestrial areas and bathymetric data for larger lakes are often readily +difficult to attain.

Throughout the years several methods have been used in creating bathymetries; the most antiquated being the use of poles or ropes to take individual depth measurements from a boat. This method is not only time-consuming but accurate depths may be difficult to obtain due to wave and wind action, especially in deep open water. Today most bathymetric data are collected through the use of remote sensing equipment or sonar devices. Remote sensing can be done in two ways: imaging and non-imaging. Non-imaging methods, such as light detection and ranging (LiDAR), are limited to relatively shallow or clear water bodies as it is dependent on light penetration in order to be effective (Gao, 2009; Brown et al., 2011). Data from imaging methods, such as optical analysis, are extracted directly from images or video and is once again affected by water quality and often requires ground-truthing for accurate analysis (Gao, 2009). Sonar surveys are a much more accurate method of obtaining bathymetric data in deeper water systems (de Moustier, 2001; Bjork et al., 2007; Bloomer et al., 2007) It is even possible to obtain both bathymetric and substrata composition data from one sonar survey, which makes it a very useful and efficient system. These data can be used in a wide range of fields, contributing to our knowledge of geology, hydrology and the ecosystem as a whole. Three forms of acoustic survey methods are quite common in bathymetric and substrata mapping; single-beam sonar (or single beam echosounder – SBES), multi-beam sonar (or multi-beam echosounder – MBES) and sidescan sonar (SSS), all of which have their own strengths and weaknesses.

2.3.2 - Methods

Historically sonar has been used to map marine benthic habitats but they have been used in freshwater ecosystems as well (USGS, 2002; Waples et al., 2005; Athearn et al., 2010). All sonar techniques have several similarities. Surveying takes place in a series of parallel and/or perpendicular transects and involves the creation of an acoustic signal, whose echo is picked up by a transducer and examined for unique characteristics that allow us to retrieve information about the benthic habitat. Water depth is a measure of the time it takes for the transducer to record an echo after the original signal has been sent. Substratum classes are distinguished by comparing characteristics of the echo such as the shape, amplitude and strength of the returning signal (Heald and Pace, 1996; Siwabessy et al., 2000; QTC VIEW Series V User Manual, 2004). A soft substratum will tend to absorb more of the acoustic signal resulting in a relatively weak echo while a hard bottom such as gravel or rock will reflect more of the signal resulting in a relatively strong echo. A smooth substratum will result in a relatively simple echo while a rough substratum such as gravel or cobble may result in a complex echo. In regards to substratum determination, some form of ground-truthing is always required in combination with echosounder data. Ground-truthing may include underwater photography or video, dredging or coring. Echosounder data are then used in statistical analyses that group similar echoes into unique substratum classes, which are then compared to ground-truthed data to determine the composition of said classes. Common statistical analyses of echo data include k-means clustering (Legendre et al., 2002) and discriminant analysis (Hutin et al., 2005). This manner of analysis, where sonar identification is carried out on a large scale, followed by in-field ground truthing on a much smaller scale is known as a “top-down” method. A “bottom-up” method also exists where ground-truthing is completed prior to the acoustic survey; however, it is not guaranteed that all identified substratum classes will be represented when sampling in this manner (Eastwood et al., 2006; Shumenchia and King, 2010). Since data from these acoustic systems is collected by boat the accuracy of retrieved data can be greatly affected by conditions on the water's surface, namely wave action; it is necessary to survey during calm periods when this will not be an issue.

Single-beam sonar devices use backscatter from acoustic signals, or "pings" to determine water depth and substrata composition. Backscatter is also known as an echo and is the result of the original acoustic signal being reflected off of the substrate. Characteristics of each echo, such as amplitude, duration and shape, are used to identify unique substrata classes. SBES usually operate within the 30 – 2000 kHz range (Brown, 2007). Some systems can operate over a range of frequencies depending on water depth and substrata composition, while some systems are equipped with a single standard frequency. Substrata composition cannot be identified solely on echo characteristics but the number of unique substratum classes can be predicted through the use of a clustering algorithm; these results combined with ground-truthing samples taken from the survey area can be used to identify the composition of each identified class. It has been shown that there is a strong correlation between the strength of a returning echo and the composition of the substratum (Collier and Brown, 2005; Ferrini and Flood, 2006; Fonseca and Mayer, 2007; Brown and Collier, 2008). The system used by SBES is much simpler than those used by multi-beam and sidescan sonar simply because one signal is used in the analysis. It is limited, however, by the fact that it only collects data from directly below the sonar device. Unsurveyed portions of the area must be interpolated to create a comprehensive map. Even when survey lines are close together there is a chance of missing out on unique features. It is therefore best to use SBES in areas where elevational changes are gradual (Biffard et al., 2005). Another issue with single-beam sonar is that the footprint of the acoustic signal increases with increasing water depth; a single signal with a large footprint may contain multiple substratum classes but it can only be classified as one, which may result in low class confidence or probability. Single-beam systems are relatively small and lightweight and therefore have the advantage of being usable on smaller vessels. They are also relatively inexpensive and easy to use (Brown, 2007). Common SBES include the QTC-View and RoxAnn systems.

Multi-beam sonar operates in a similar manner to single-beam sonar in that it records backscatter data in order to determine the structure of the substratum and is also capable of measuring water depth (Schimel et al., 2010). It differs in that it is able to record the entire footprint of the sonar signal as opposed to a single point. By determining the footprint of the signal it is relatively straightforward to determine how far apart transects should be in order to collect a continuous series of data with no need for interpolation. Determining different substratum categories can be more difficult than for a SBES as the data are more complicated due to the increased level of information in each echo. Interpretation of the MBES data can be done manually by examination of the backscatter data or through the use of algorithms (Marsh and Brown, 2009; Preston, 2009; Brown et al., 2011). Areas with similar backscatter patterns are considered to be in the same class and the composition of each class is again determined by ground-truthing samples. MBES are much larger and heavier than single-beam sonar which means that their usage is restricted to larger vessels.

Sidescan sonar collects data in the same way as multibeam sonar though it is not able to collect bathymetric data (Blondel, 2009). Like MBES, SSS substrata data can be processed manually though there are now interpretation algorithms to assist in classification, which reduce potential sources of error (Brown and Collier, 2008; Lucieer, 2008; van Overmeeren et al., 2009). As with multi-beam sonar, sidescan systems are relatively large, which limits their usage to larger vessels.

Due to its ease of use and relatively low price SBES are very commonly used for acoustic surveys. These systems have been used for a wide range of purposes over a variety of different habitats. SBES have been used for creating bathymetric maps (USGS, 2002; Athearn et al., 2010) as well as substrata distribution maps (Hamilton et al., 1999; Anderson et al., 2002; Freitas et al., 2003; Waples et al., 2005), for coastal areas (Hamilton et al., 1999; Smith et al., 2001; Anderson et al., 2002; Ellingsen et al., 2002; Freitas et al., 2003) as well as for lakes (USGS, 2002; Waples et al., 2005) and even wetlands (Athearn et al., 2010). SBES collect both bathymetric and substrata data simultaneously, however the majority of surveys tend to be directed towards obtaining substrata data as opposed to bathymetries. The number of published surveys examining wetlands is relatively low; this may be due to the fact that sonar systems require sufficient water depth for operation. Flooded areas must be deep enough to allow for navigation by boat; as well the transducer must be submerged in the water column for proper operation while allowing enough room between the transducer and the substrate surface for accurate data collection. As wetland water levels can fluctuate greatly and water depths may be quite low it can be difficult to survey in many areas. In order to take accurate bathymetric and substrata data at shallow depths acoustic signals must be sent quickly, yet the amount of time between signals must be great enough that returning echoes do not overlap. It has been shown that certain SBES, such as the QTC VIEW, are capable of obtaining accurate bathymetric data in as little as 0.9 m of water (Preston and Collins 2000, QTC VIEW Series V Manual 2004).

2.3.2.1 - QTC-VIEW

One of the most commonly used single-beam systems is the QTC VIEW, developed by the Quester Tangent Corporation in Sydney BC (no longer in operation). The QTC VIEW system is comprised of an echo sounder, a transducer, a GPS unit and a laptop with Quester Tangent Real-Time Seabed Classification (QTRT) software installed. The system components are connected through a QTC sounder interface and are powered by a battery or generator. The transducer is suspended from the boat and must be completely submerged for proper operation. The QTC system may be equipped with either a 50 or 200 kHz transducer or a dual frequency transducer which is capable of either frequency. It has been shown that lower frequency signals penetrate deeper into the substrate, which may provide more data to the transducer (Madricardo et al., 2012). A higher frequency signal will have relatively shallow penetration into the substrate and may reflect off of vegetation above the substrate resulting in a poorly defined bottom (Collins and Rhynas, 1998). Freitas et al. (2008) observed that in shallow water (< 5 m in depth) the 50 kHz frequency was more accurate at determining substratum classes than the 200 kHz frequency.

Upon receiving the returning echo, the transducer transforms the acoustic signal into an electrical signal that is sent through the interface, which sends the signal to both the depth finder for visual interpretation and to the laptop where it is read and recorded by the QTRT software. Global positioning system (GPS) data are recorded in tandem with the sonar data so that each data point has an individual GPS location. Once surveying is complete the data can be transferred to another program, QTC IMPACT, which further processes the waveforms. In this program each waveform can be inspected; data that is deemed to be outlying or misshapen can be removed manually. Alternatively, several automated programs allow for the removal of specified data in a much faster, though less deliberate manner. After data cleanup is complete, the IMPACT program “stacks” a series of echoes into one waveform; five consecutive pings are grouped together and averaged in order to eliminate slight variations between echoes and to enlarge the footprint of each data point. This results in more reliable classifications. In order to obtain useful substrata data from the waveforms collected during the survey, they must be processed using multivariate statistics. Each waveform created by the QTC software is evaluated based on 166 unique characteristics, which are used in a principal component analysis (PCA) based on a covariance matrix. In this manner the number of features (or Q-values) is reduced to three. The final classes are determined by an automatic clustering engine (ACE) within the QTC IMPACT program that uses a k-means clustering algorithm to group the data points into n categories based on their position in the three dimensional Q-Space (QTC VIEW Series V User Manual, 2004) . Following classification QTC IMPACT data can be compared to ground-truthed samples in order to verify the composition or substratum type of each class.

The information gathered from an acoustic survey can be very beneficial in management terms; as previously mentioned knowledge of the bathymetry of an area can help us better understand hydrology. Water depth is extremely influential in the distribution of wetland vegetation; some species may dominate in particular depth ranges based on their tolerance to or preference for flooding and some species are only able to germinate on exposed soil while others require a minimum water depth. By knowing the depth distributions of a wetland we can predict the most likely areas to find these plants. Using a bathymetry of a given wetland we would be able to model the distribution of water depths at any given water level. This data could be used to determine the likely areas of colonization by particular plant species based on their germination requirements and flood tolerances. Areas where water is too deep for vegetation growth can also be identified in this manner. As waterfowl are often attracted to specific open water to vegetation cover ratios this is important information for management as well. A bathymetric model would also be useful in examining the water budget of the wetland based on the volume of the basin.

Substrata data obtained from the acoustic survey can also be used for a variety of purposes. Substratum composition is influential for hydrology; drainage and retention patterns may be different based on particle size. In addition, some aquatic organisms have habitat preferences. While some organisms are habitat generalists some may be specialized to a very particular habitat niche. Habitat specialization may be based on a variety of characteristics such as water depth, sediment type, turbidity and current. In cases such as this knowledge of the benthic substrata can be important for maintaining and protecting habitat for endangered species.

Figure 1. Annual and long term range of water levels seen on Lake Manitoba from 1932 – 2012. In 1961 the Fairfor River Control Structure (FRCS) was installed on Lake Manitoba resulting in a drastic decrease in overall water level fluctuations with the exception of an extreme flooding event in 2011. Data obtained from the Government of Canada Wateroffice https://wateroffice.ec.gc.ca/report/report_e.html?mode=Table&type=h2oArc&stn=05LK002&dataType=Daily&parameterType=Level&year=2014&y1Max=1&y1Min=1

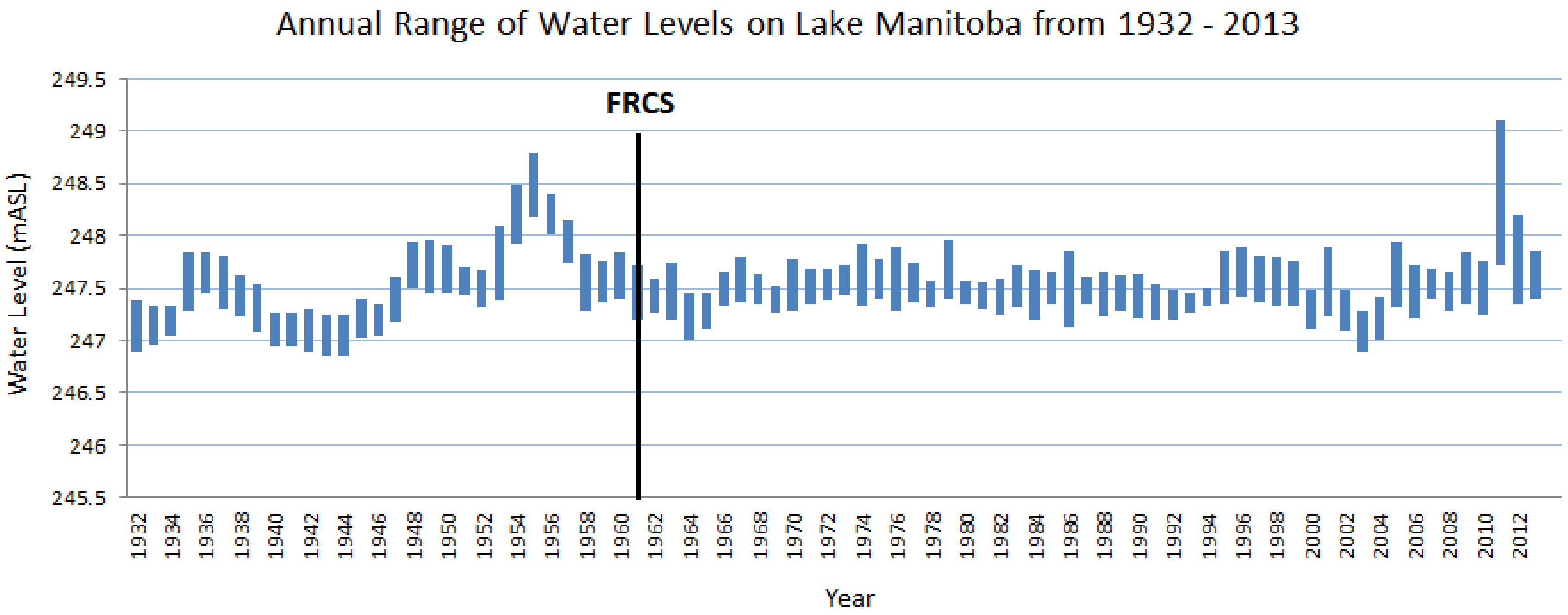


Figure 2. Photo of *Typha latifolia* and *Typha angustiflia* at Delta Marsh, Manitoba. The distance between the pistillate and staminate spikes is one of the ways to visually distinguish *T.latifolia* (left) and *T. angustifolia* (right), although the introduction of the hybrid *Typha x glauca* which displays spike distances equal and intermediate to these two species makes field identification very difficult. Photo: G. F. Bondar (McLeod et al.,1949).

Figure 3. The eastern portion of Delta Marsh, located east of Highway 240 on the southern edge of Lake Manitoba.

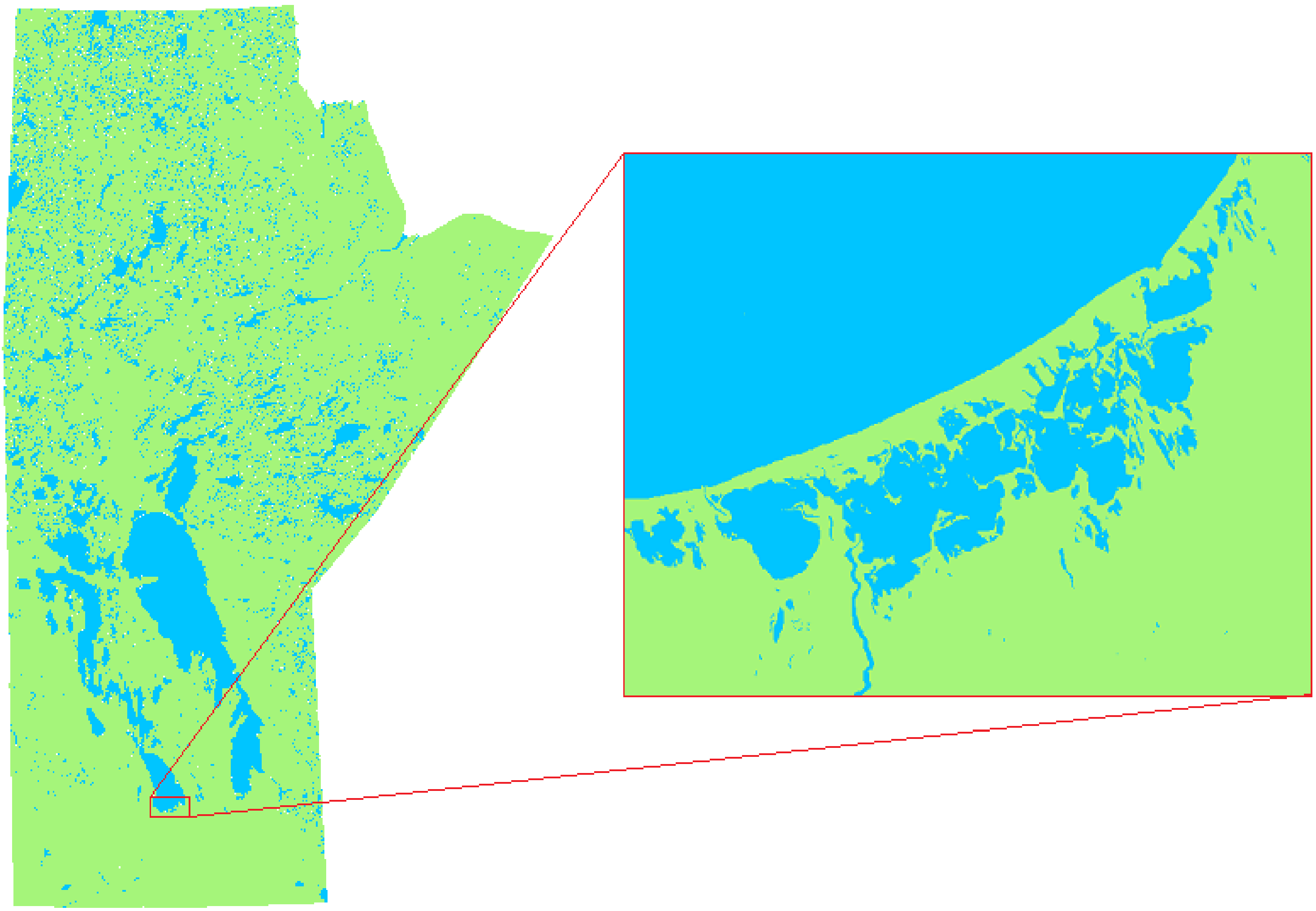
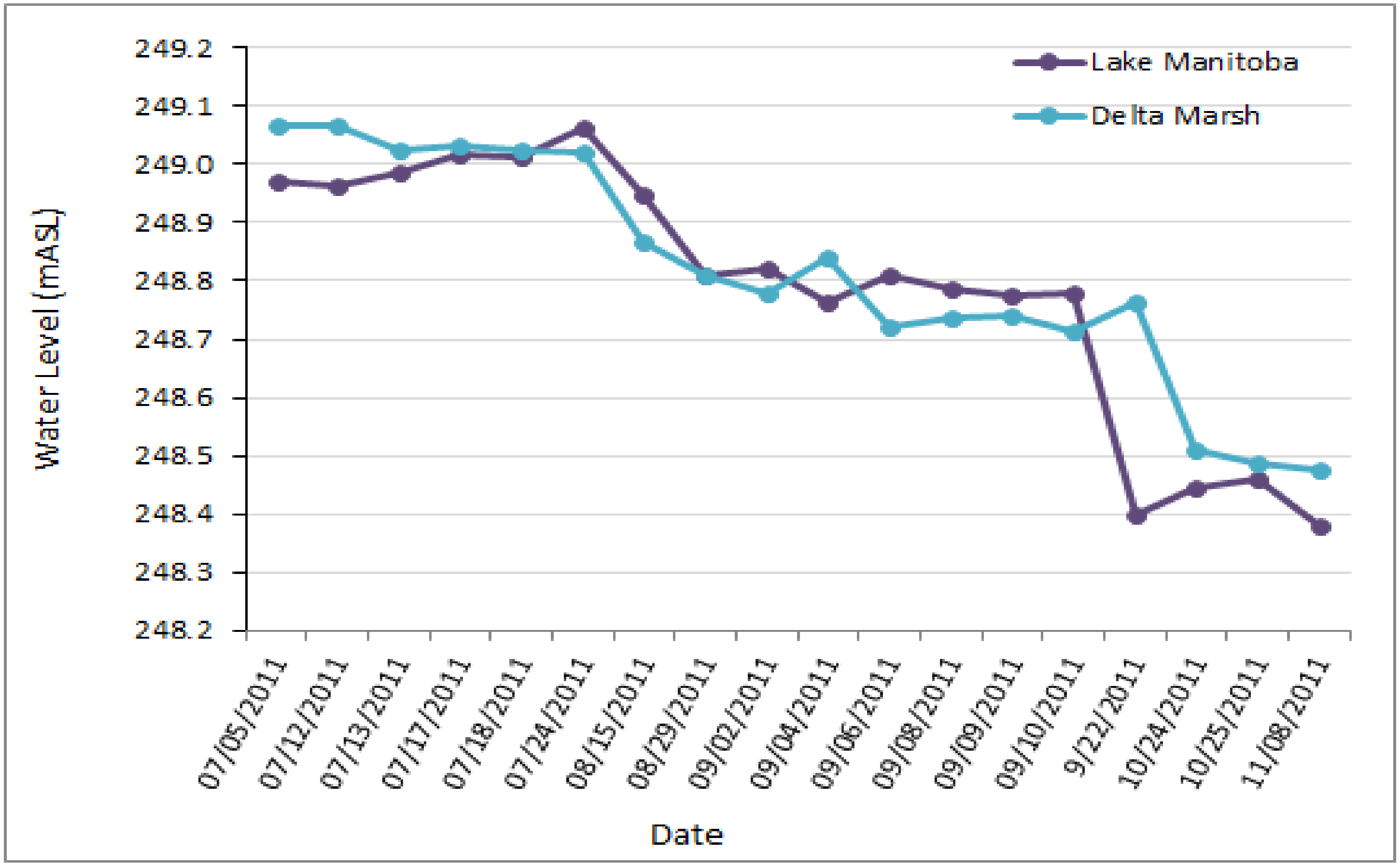


Figure 4. Correlation of water level fluctuations on Lake Manitoba and in Delta Marsh. Data for Delta Marsh obtained during bathymetric survey in 2011. Data for Lake Manitoba obtained from the Government of Canada Wateroffice https://wateroffice.ec.gc.ca/report/report_e.html?mode=Table&type=h2oArc&stn=05LK002&dataType=Daily&parameterType=Level&year=2014&y1Max=1&y1Min=1



3.0 – Bathymetry

3.1 - Introduction

Hydrology is influential in many aspects of the biology and chemistry of wetlands; water depth and distribution and the duration of flood or drought periods can greatly affect plant species abundance and diversity, the distribution of plant species as well as rates of decomposition and nutrient cycling within a wetland. It has been shown that water depth is one of the most influential factors in determining the distribution of plant species in wetlands (Harris, 1963; Spence, 1982; Schalles and Shure, 1989; Squires and van der Valk, 1992). Plants have differing tolerances to flooding and anoxic conditions, which allows some species to outcompete others at particular depths or saturation levels. This results in a distribution of species along a water depth gradient. Knowledge of a wetland's elevational contouring, known as a bathymetry, could be helpful in forming management strategies to deal with changing vegetation patterns in response to changes in hydrology, such as those resulting from lake regulation. Topographic data of terrestrial environments as well as bathymetric data of large waterbodies is relatively common but data on shallow water bodies such as wetlands are less so, partly because it is more difficult to obtain. Turbid waters make remote sensing difficult and shallow waters are detrimental to acoustic data collection. Despite the difficulties in obtaining these data it could be beneficial for determining and predicting not only the extent of flooded areas during water level fluctuations but also the distribution of water depths within the wetland. We would also therefore be able to better predict changes in vegetation zonation succeeding these water level fluctuations. The distribution of vegetation in a wetland can affect water flow, sedimentation processes and how organisms use these disturbed habitats.

A detailed bathymetry for the Delta Marsh had never been developed due to the large extent and shallow nature of the area. Several portions of the marsh, such as the Marsh Ecology Research Program (MERP) cells, constructed in 1979, have been mapped but this is only a small area relative to the marsh as a whole (Murkin et al., 2000). Bathymetric techniques have improved over the recent years and now include much more efficient and accurate methods including remote sensing techniques, such as LiDAR, and sonar techniques, such as single-beam and multi-beam systems. Sonar surveys are capable of collecting data from greater depths than LiDAR and can collect both bathymetric and substrata data at the same time, which means a large amount of information about the waterbody can be obtained simultaneously (de Moustier, 2001; Bjork et al., 2007; Bloomer et al., 2007; Gao 2009; Brown et al., 2011). These data can contribute to our knowledge of the ecosystem as a whole.

Acoustic telemetry has been used for years in measuring depth and creating imagery in deep water marine environments such as the ocean floor and coral reefs (Ellingsen et al., 2002; Bloomer et al., 2007; Vertino et al., 2010) which can be difficult to reach with sampling equipment. Until recently, acoustic telemetry methods required these depths for accurate operation and for this reason had not been used in shallow water environments such as those found in wetlands. Recent developments in acoustic technologies have made it possible to conduct sampling and analysis of much shallower settings with accurate measurements in as little as one meter of water (Preston and Collins, 2000); it is becoming more common for this type of analysis to be used (USGS, 2002; Freitas et al., 2008; Madricardo et al., 2012). Three forms of acoustic survey methods are common in bathymetric and substrata mapping: single-beam sonar (or single beam echosounder – SBES), multi-beam sonar (or multi-beam echosounder – MBES) and sidescan sonar (SSS), which all have inherent strengths and weaknesses. Whatever the method, surveying takes place in a series of parallel and/or perpendicular transects and involves the creation of acoustic signals, whose echoes are picked up by a transducer and examined for unique characteristics, such as duration, amplitude and shape, which allow us to retrieve information about the benthic habitat. Water depth is measured by the time it takes for the transducer to record an echo after the original signal has been sent. The large size of MBES and SSS relegates their use to relatively large vessels which makes them impractical for use in small or shallow water environments. Single beam echosounders have been the most common means of data collection in these settings (Preston and Collins, 2000; Takekawa et al., 2005; Athearn et al., 2010).

3.1.1 - Study Area

The Delta Marsh, located on the southern end of Lake Manitoba, is the largest coastal wetland in the Lake Manitoba basin covering approximately 15,000 ha (Hochbaum, 1971; Watchorn et al., 2012). Comprised of a series of relatively shallow bays and channels, the marsh generally does not exceed depths of two meters, with most areas measuring less than one meter and a maximum depth of three meters (Walker, 1965; Shay et al., 1999). The marsh is connected to Lake Manitoba through four channels and breaks in the protective beach ridge along the south end of the lake: Deep Creek and Cram Creek (on the extreme west side of the marsh), Delta Channel (at the village of Delta), and Clandeboye Channel (on the far eastern edge of the marsh). Through these channels, water is able to flow freely between the lake and the marsh; water levels in the marsh are directly correlated to those in the southern end of the lake (de Geus, 1987). Water levels are mainly influenced by runoff from surrounding agricultural lands and influxes from the Portage Diversion, which began operating in 1969 as a way to divert large amounts of snow melt water away from urban areas in the Red River Valley and into Lake Manitoba. The construction of a control structure on the Fairford River in 1961 resulted in the stabilization of water levels on the lake; reducing fluctuations from 1.93 m pre-construction to 0.95 m post-construction (Lake Manitoba Regulation Review Advisory Committee, 2003). Water levels on the lake and within the marsh are greatly influenced by runoff from surrounding agricultural lands as well as inputs from the Portage Diversion during high water in the spring (Lake Manitoba Regulation Review Advisory Committee, 2003; Page, 2011). A flooding event in 1976 caused the water levels in Lake Manitoba to rise approximately 25 cm and the flooding event in 2011 caused an increase in water levels to 1.5 m above the average level (Province of Manitoba, 2011) (Figure 5). In 2011 the diversion operated for a record breaking 126 days, resulting in the diversion of approximately 1.72 million cubic decameters of water into Lake Manitoba (Province of Manitoba, 2013). Since distributions of wetland vegetation are largely influenced by water depth, dramatic changes in water level, like those seen during these flooding events, can be expected to cause a significant redistribution of emergent plant species (van der Valk and Welling, 1988). This was seen at Delta Marsh by de Geus (1987) and Shay et al. (1999) over relatively large time spans (between 1948 – 1980 and 1948 – 1997, respectively). If we are able to produce an accurate bathymetry of the Delta Marsh area, we will be able to better examine water depth gradients and, in the case of flooding or drought, determine what changes in vegetation we may expect to occur as well as the effects these changes will have on the marsh as a whole. Although several small-scale bathymetric surveys have been conducted throughout the marsh, including one conducted in the Marsh Ecology Research Program (MERP) cells during the 1980s (Murkin et al., 2000), no large scale bathymetric studies had yet taken place in the area.

3.1.2 - Current Study

The flood event in the summer of 2011 around Lake Manitoba resulted in an increase in water level of approximately 1.5 m in Lake Manitoba and Delta Marsh (Water Office of Canada, 2014, personal obs). Previous to this water level increase, a bathymetric study of the marsh would have been too time-consuming and costly, being limited to manual collection of data due to the large amount of shallow water areas or remote sensing which would not be feasible due to the turbid nature of the marsh water. With higher water levels came the opportunity to use sonar as a means of determining water depth over a large area in a more efficient way. Sonar mapping can accurately determine water depth in as little as one meter of water (Preston and Collins, 2000). My goal was to create an accurate bathymetry of the study area, which could be used in conjunction with vegetation data to determine and predict patterns of vegetation distribution as relating to water depth. This information could also be used in the future to predict changes in vegetation distribution based on fluctuations in water levels throughout the marsh. The study area consisted of the portion of Delta Marsh east of highway 240 (Chapter 2, Figure 3). This area was chosen as the study site as satellite imagery was available from previous years (to provide a comparison to satellite imagery from 2011) and because this portion of the marsh contains larger, deeper bays, which are ideal for bathymetric analysis.

3.2 – Materials and Methods

Data were collected between June and November of 2011 through the use of Quester Tangent Corporation (QTC) seabed classification equipment and software. The QTC system requires a minimum water depth of approximately 1 m to operate accurately which, prior to the flood of 2011, had not existed in many areas of the Delta Marsh. Water depths were standardized each day by measuring the water depth at a culvert near the boat launch (N50.176160, W98.313898) before and after the day's survey. These data were used to interpolate the change in water depth for the entire data set over the course of the day. An overall change of 32 cm was observed over the course of the survey period but the change in water levels did not exceed 4 cm on any given day. The elevation of the culvert was determined by surveying from a known elevational marker.

The data collection system used a Suzuki ES-2025 50 kHz echo sounder. The transducer was mounted on an aluminum pole, which was suspended approximately 60 cm from the side of a 14-foot aluminum fishing boat from a modified outboard motor mount on a 20 cm by 20 cm post measuring approximately 2.4 m in length. The post was secured across the middle of the boat by a series of ropes, as was the aluminum pole, to eliminate movement of the transducer during data collection. The transducer was secured at a minimum depth of 25 cm below the water surface to eliminate noise interference from the boat motor and electrical equipment. The equipment was powered by a 12 V deep-cycle battery and a 120 V portable Honda generator. Sonar data were collected by the transducer, which was then sent via cable to a QTC interface module. The cable then split at the interface module, going to the echo sounder's display and to the system laptop which possessed the QTC data acquisition and processing software, Quester Tangent Real-Time

Seabed Classification (QTRT). The QTRT software allows the user to monitor the data acquisition for real-time depth and to reset the system in case of problems such as loss of the bottom substrate due to interference from underwater vegetation and structures. I observed that when collecting data in highly vegetated areas, the pick (the depth at which the substrate occurs) would become confused, often mistaking the top of the vegetation with the top of the substrate. In such cases, the pick needed to be reset manually. The laptop was directly connected to a Trimble 5800 GPS unit whose receiver was mounted at the top of the aluminum pole which suspended the echo sounder transducer. The receiver was used to communicate with a secondary Trimble base receiver at a known location to increase the accuracy of the GPS data. The IMPACT software collected the data sent to laptop from the GPS unit in real time, giving each data point XYZ coordinates.

The echo sounder sent out approximately seven pulses per second at a 50 kHz frequency; moving at roughly 9 km/hour, the system collected approximately 25,200 echoes per hour or 2,800 echoes per km. Sonar data were collected in a grid-like pattern with transects separated by approximately 100 – 200 m (Figure 6). The presence of dense submerged macrophytes prevented surveying in some areas due to poor quality echo returns and, in some cases, vegetation became caught on the transducer causing signal interference and data loss. The greatest obstacle to surveying, however, was the presence of emergent vegetation such as cattail and common reed; however, the presence of these plants often coincided with water depths of approximately one meter which also would have restricted data collection. In addition to the data collected from transects, an outline of the unvegetated portion of the marsh was collected by following the fringe of emergent vegetation surrounding the marsh. These measurements were taken as close to the fringe as possible and where depth permitted.

The survey occurred over approximately four months, mainly due to high winds which resulted in extended periods of wave action. The shallow bathymetry and great surface area of the larger marsh bays often resulted in high wave amplitude during minimal winds. Winds over 10 km/hour created wave action which made data collection impossible as accurate depth determination relied on transducer stability. Data recorded during unstable conditions would fluctuate visibly on both the depth finder and within the QTC program and resulted in inaccurate data due to the vertical movement of the transducer. Unfortunately, the density of data samples was limited by the aforementioned weather-related obstacles as well as the formation of ice towards the end of the survey period.

After collection was complete the acoustic data were uploaded into Quester Tangent's IMPACT software. Data were processed manually by removing outliers and wave forms which appeared misshapen. After the completion of this process, the remaining dataset was compressed. As individual echoes can be variable the IMPACT program takes sets of five consecutive echoes (known as a stack) and averages them. This creates a smoother waveform with a larger footprint, which is more accurate. The data then undergoes a series of multivariate statistical analyses including a Principal Components Analysis (PCA) using a K-Means Clustering Algorithm, which identifies possible unique substratum categories. This will be further discussed in Chapter 4. The final dataset consisted of over 400,000 unique depth points represented by XYZ coordinates.

The depth measurements taken by the QTC system on different days could not always be directly compared as water levels within the marsh fluctuated on a regular basis. To standardize the daily depth measurements taken by the QTC system, I used a known benchmark elevation at a culvert near the boat launch location. Measurements were taken at the beginning and end of each survey day. Water levels exceeded the level of the culvert throughout the majority of July and declined below the culvert for the remaining survey period. In the case where the water level declined or increased during a single day, the difference between the two measurements was calculated and extrapolated evenly across all measurements taken that day. The elevation of the substrate surface for each data point was calculated by taking the benchmark culvert elevation (249.021 mASL), adding the depth at which the daily water level was measured at the benchmark culvert, then subtracting the depth between the water surface and the bottom surface of the transducer, as well as the depth measured by the QTC program (Figure 7).

The elevation data were uploaded to ArcMAP to interpolate the data points into a continuous bathymetry of the study area. Since Delta Marsh consists of many bays and interconnecting channels it was determined that applying a single interpolation to the entire area was not sufficient to capture all of the detail in the area. Consequently, I broke the marsh into 44 separate sections, generally dividing the bays and the channels into individual data sets, which were then interpolated separately using the Radial Basis Function – Multiquadratic analysis in ArcMap. This resulted in the creation of 44 individual digital elevation models (DEMs) such as the one seen in Figure 8. Each DEM was then converted into a raster image. Each section was created so that it overlapped to a small degree with each adjacent section. In this way, it was assured that no gaps between sections would occur in the final bathymetry. Upon interpolating several of the larger bays, I observed that, in some cases, the sampling transects were conspicuous (Figure 9). On closer inspection, I saw that at some transect intersections where perpendicular transects were surveyed on different days the measured depths on each day were unequal. As previously mentioned, the shallow nature and large surface area of the marsh, especially in large bays, resulted in high intensity wave action, especially during periods of extended wind. During these periods, the larger bays in the marsh experienced seiches. The constant force of the wind pushed water to the opposite end of the basin, causing unequal water distributions. The side of the basin opposite the direction of wind origin experienced deeper water conditions than the end closest to the direction of wind origin. This was probably the cause of depth differences seen at intersecting transects (Wrubleski, Personal Comm.; Aminian, Personal Comm.). To correct for this problem, a baseline day was selected during a period of low wind activity and all separate transects crossing that particular set of data points were adjusted accordingly. At least one set of intersections, and as many as five, was used to determine an average difference in elevations, which was then added or subtracted from the original data. This process was repeated until all survey dates had been adjusted to offset the observed depth differences and the interpolation was run again (Figures 9 and 10). The adjusted data resulted in the removal of several transect artifacts, though all issues could not be fixed completely.

An outline of the un-vegetated portion of the marsh, collected during the bathymetric survey, was used to create a polygon of the surveyed area. This was then broken down into the 44 separate polygons, representing the 44 areas that were individually interpolated (Figure 11). Again, each adjacent polygon overlapped to eliminate gaps between sections. Since interpolation always resulted in the creation of data outside of the surveyed area, these polygons were used as analysis masks to clip only those portions of the DEM that had been surveyed (Figure 12). The 44 extracted raster images were then combined using the raster “Mosaic” tool; where two sets of data overlapped, the elevation values were averaged. The result of the final mosaic was a complete DEM of the entire survey area (Figure 13). Although this provided me with important information, I was still missing data from the vegetated areas surrounding the deeper portions of the marsh.

Due to the fact that dense emergent vegetation and shallow water prevented data collection in large portions of the marsh, additional data from the surrounding area were obtained from the Manitoba Land Initiative (MLI; http://mli2.gov.mb.ca/t20k/index.html). The MLI data and the QTC data were combined to create a larger DEM of the eastern Delta Marsh. This was done in the same way that the DEM of the survey area was created. First, the MLI and QTC datasets were combined into one layer. An interpolation of this data using Radial Basis Function – Multiquadratic analysis was created. In the same way that the individual sections of the survey area were combined using the mosaic tool, the new DEM of the entire eastern portion of the marsh was combined with the original DEM (Figure 14). Unfortunately, the MLI data had a much more coarse resolution that the QTC data which reduced the accuracy of the interpolation outside of the study area. In order to retain the accuracy of the original DEM only values from the QTC data were expressed in overlapping areas. Again, it must be mentioned that the data obtained from the MLI website was of a much lower resolution than that of the QTC survey and because of this areas outside of the QTC survey were less detailed and less accurate than the area within the survey zone.

The completed DEM was used to create a 3D rendering of the survey area using ArcScene. which could be used to simulate the approximate extent of flooded areas in a normal water year (Figure 15) or in a high water year, such as that seen in 2011 (Figure 16).

3.3 – Results

From the final DEM, it can be seen that much of the study area has a gradual slope, especially when contours are added to the map (Figure 17). The distribution of elevations within the study area, approximately 44.71 km², was relatively normal (Figure 18), with an average elevation of 246.437 mASL. The maximum elevation within the area was 247.818 mASL, located in the northeastern portion of Cadham Bay near the vegetation fringe. At the time of the survey, the depth at this site was approximately 1.25 m. Areas measuring over 247 mASL tended to be located near this fringe or near islands within the larger bays. The deepest areas tended to be found in channels between the larger bays, such as the channel between Waterhen and Clandeboye bays, which was measured to be 243.883 mASL (4.9 m deep at the time of the survey). Additional deep sites included the channel between Simpson and Cadham Bays, whose lowest elevation was 244.146 mASL (4.88 m deep at the time of survey) and the Delta Channel, at 244.503 mASL (4.62 m at the time of survey) (Figure 19).

Looking at the bays and channels separately, one can see that although the distribution of elevations within the channels seemed to remain relatively normal, a bimodal distribution was observable within the depth distributions of the bays (Figures 19 and 20). This was likely due to the large number of depth measurements taken around the vegetation fringe which tended to be relatively shallow. The elevations in channel B (the ditch south the MERP cells) averaged 246.598 mASL with a range of 1.2 m (Figures 20 and 21). Channel C (a channel located in the northeastern portion of the marsh, approximately 2 km west of Clandeboye Bay) had a slightly smaller range of approximately 0.89 m with an average elevation of 246.722 mASL, while channel D (located just west of Clandeboye Bay) had a relatively large elevational range (1.76 m) and relatively low average of 256.213 mASL. Channel A (the Delta Channel, which connects the marsh to Lake Manitoba near the town of Delta) had the deepest surveyed areas (244.503 mASL) and exhibited a larger range of elevations that the other channels (3.14) with an average close to that of channel B (246.598 mASL).

The bays tended to have slightly lower average elevations and relatively larger ranges. Bays E and F (Simpson Bay and Blackfox Bays), the largest examined bays, had the lowest ranges (1.82 and 1.81 m respectively) and the highest average elevations (246.401 and 246.430 mASL respectively). The average elevations found in the smaller bays (Bay G – Waterhen Bay and Bay H – Clandeboye Bay) were relatively low at 246.257 and 246.234 m ASL, respectively and had higher ranges than the larger bays (2.807 and 3.593 m, respectively).

3.4 – Discussion

With a complete bathymetry of the eastern portion of the study area, we can now extrapolate the water depth at any given site within the entire marsh based on a single water depth measurement. By using the bathymetric map in a three-dimensional display, such as that found in ArcScene, we can overlay a layer to represent water of any depth. With this we will be able to obtain a fairly accurate visualization of the extent of flooded or dry areas throughout this area of the marsh, which will be useful for a wide range of purposes.

Our hydrological knowledge of the area can be much improved with this data. As mentioned previously, a single water depth measurement in the marsh can be extrapolated to predict and approximate the extent of flooding throughout the entire study area, as well as the distribution of water depths. Flow patterns throughout the area may also be predicted by determining which areas may become connected or isolated based on water level as well as where water will tend to flow based on slope analysis.

With the knowledge that emergent vegetation species often exist along a water depth gradient, we may be able to determine the probable distributions of these species in the event of flood or drought conditions (Adams, 1988; Stewart and Kantrud, 1971). In future years of high or low water, we will be able to predict which areas may be flooded or dry. The distribution of emergent vegetation will change dependent on these water level variations; flood conditions will cause many emergent species to senesce, while drought conditions will result in the exposure of mud flats, which are required for seed germination of many wetland species. Exposure of new mud flat areas often results in the germination of a wide variety of species from the seedbank.

Many aquatic organisms choose their habitat based on the proportion of open and closed water areas, or on water depth, so we may be able to predict where these organisms will occur in high or low numbers. Diving ducks, for example, are generally found in higher numbers in open, deeper water areas. Dabbling ducks, on the other hand, are most commonly found in areas where open water and vegetated areas are found in equal coverage (Murkin et al., 1982). Wetland organisms may also be influenced by water depth, whether as a function of depth itself or perhaps by water temperature, which will be heavily influenced by water depth. Knowledge of these factors may assist in predicting distributions of these organisms.

Bathymetric data can be used of a wide variety of purposes. Although the regions surrounding the study site are not as accurate as those within, this data can still be useful in predicting and approximating water distributions. A more detailed survey of the surrounding area would be useful but may also be much more difficult and time-consuming to obtain. Future projects might benefit by taking baseline measurements at multiple points in the marsh in order to make the issue of seiches more manageable. If time allows, manual collection of depth data within shallow of vegetated areas would result in more accurate bathymetric data.

Figure 5. Water levels recorded on Lake Manitoba (Near Steep Rock) in 2006, 2007, 2008 and 2011. Flood waters diverted into the Lake by the Assiniboine River Diversion in 2011 resulted in an increase in water levels of approximately 1.5 m from normal water years. Data obtained from the Government of Canada Wateroffice https://wateroffice.ec.gc.ca/report/report_e.html?mode=Table&type=h2oArc&stn=05LK002&dataType=Daily&parameterType=Level&year=2014&y1Max=1&y1Min=1

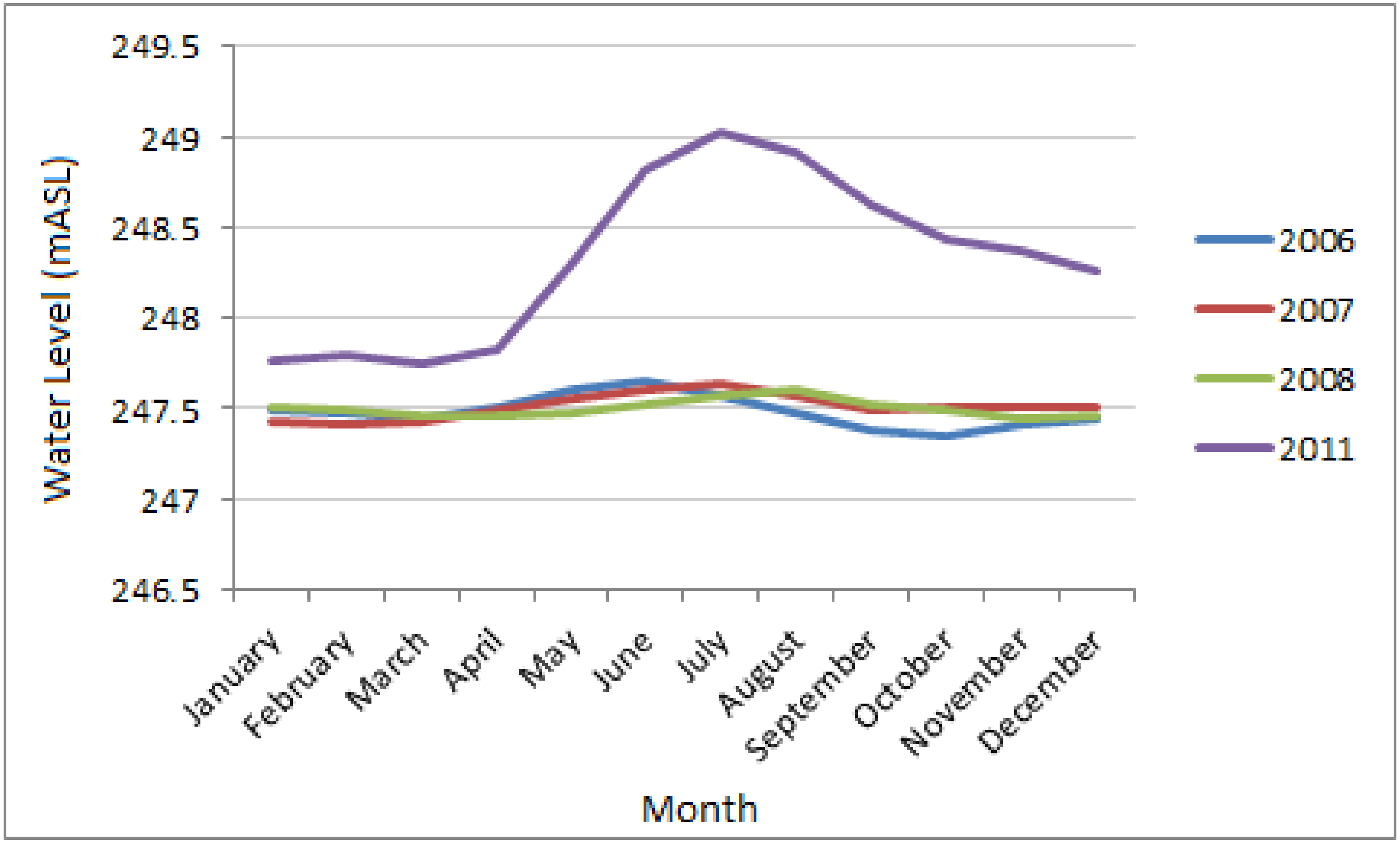


Figure 6. Transects and outline of vegetation fringe taken by the Quester Tangent Corporation (QTC) VIEW single beam sonar system during collection of bathymetric and substrate data in the eastern portion of Delta Marsh, Manitoba in 2011.

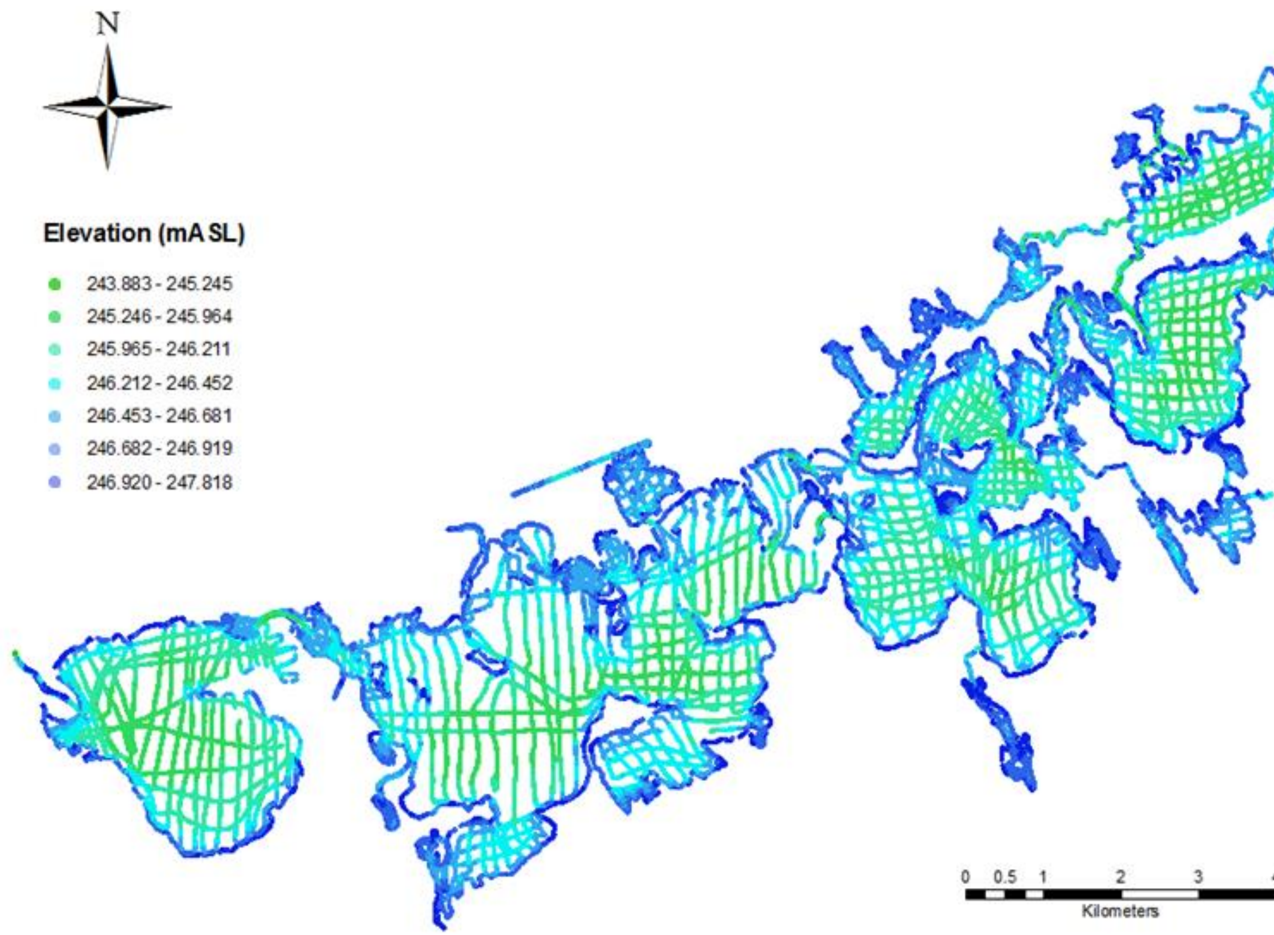


Figure 7 Method of determining substrate elevation. A known elevational benchmark at a culvert (A) is used. The depth of the water above the culvert (B) is added to the benchmark elevation; the distance between the water's surface and the bottom of the acoustic transducer (C), as well as the distance from transducer to the substrate (D), are then subtracted.

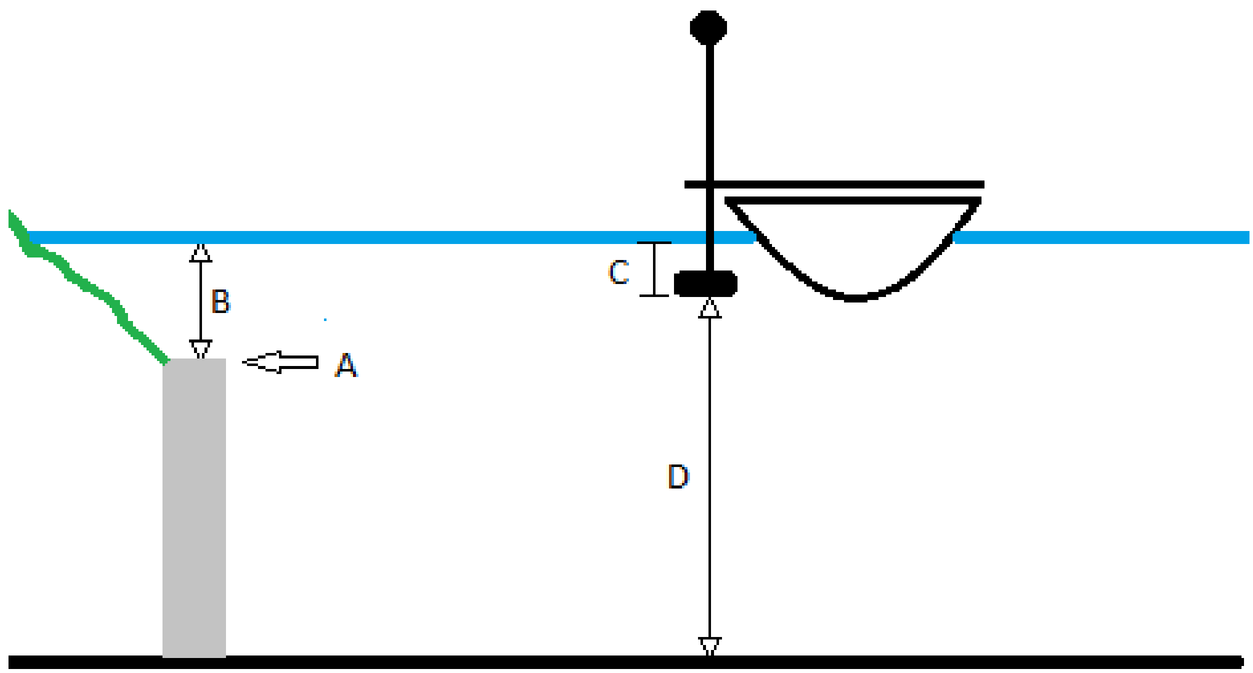


Figure 8. Construction of a Digital Elevation Model (DEM) in AcrMap from depth points taken using QTC single beam sonar system in Cadham Bay in the eastern portion of Delta Marsh, Manitoba. A displays the original depth data collected by the QTC system while B displays the DEM created using ArcMap.

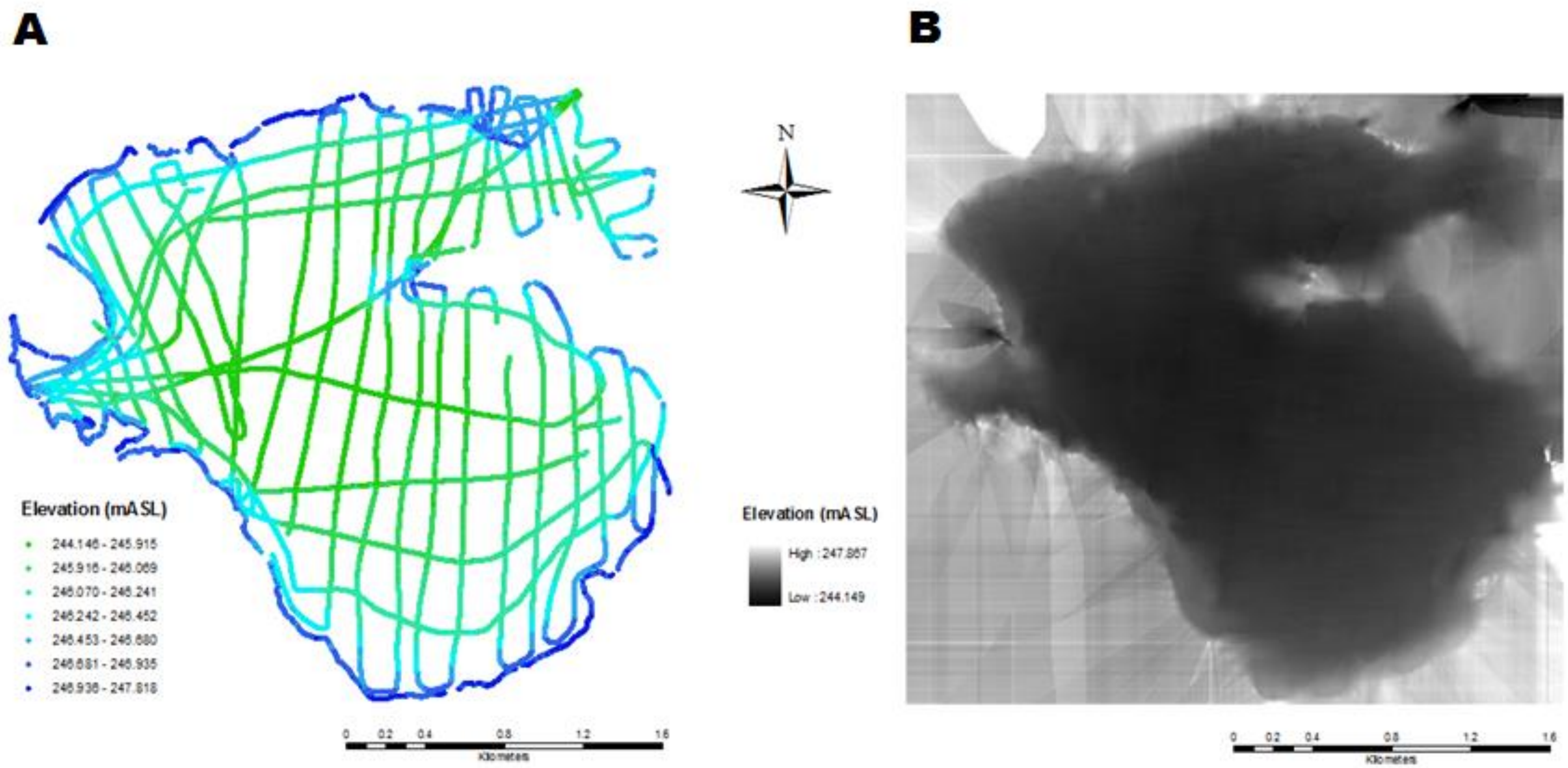


Figure 9. Comparison of DEMs of Simpson Bay in the eastern portion of Delta Marsh, Manitoba before (A) and after (B) adjustment of bathymetric elevations due to seiche effects. Note the multiple transect lines in the original versus the adjusted version; most transects have been eliminated and the remaining line has been relatively toned down.

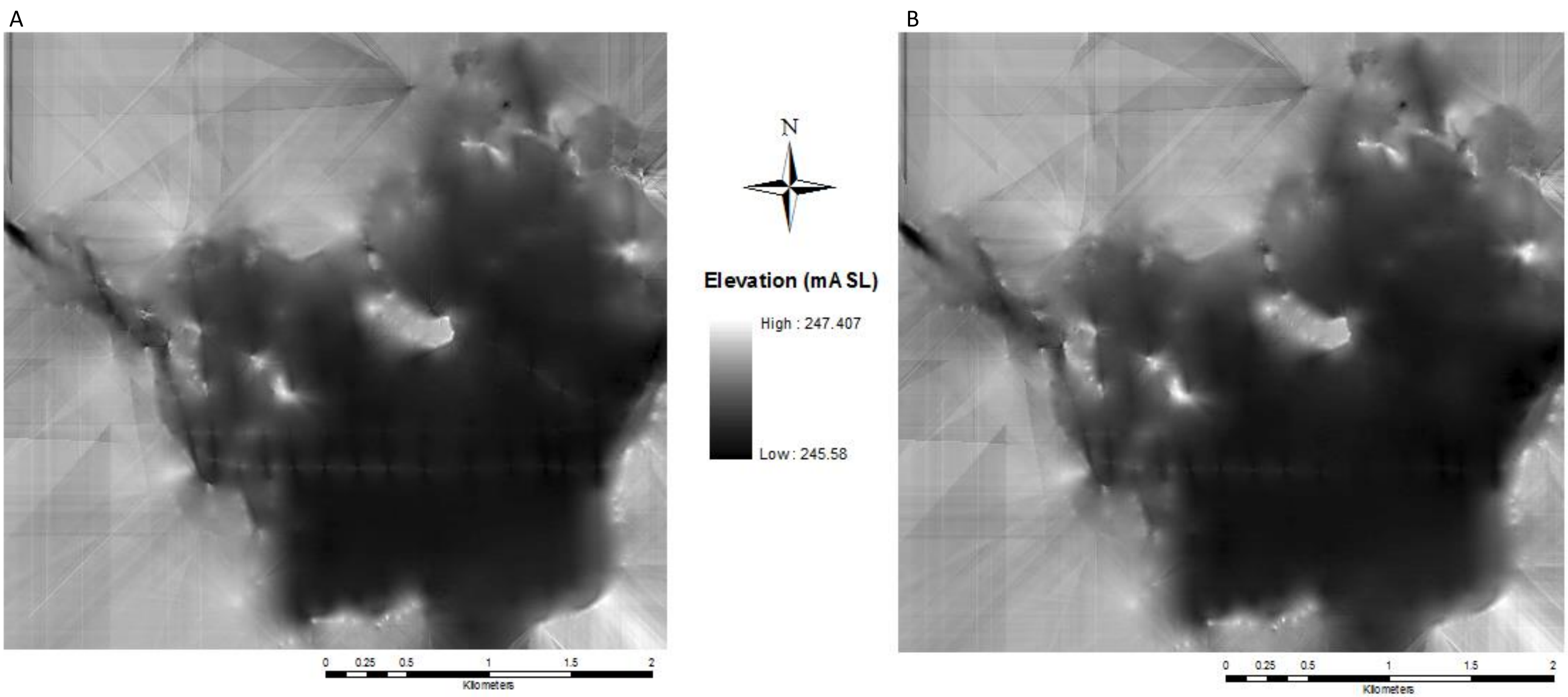


Figure 10. Comparison of DEMs of Black Fox Bay in the eastern portion of Delta Marsh, Manitoba before (A) and after (B) adjustment of bathymetric elevations due to seiche effects. Note the marked difference in elevations between the east and west portions of the bay in A.

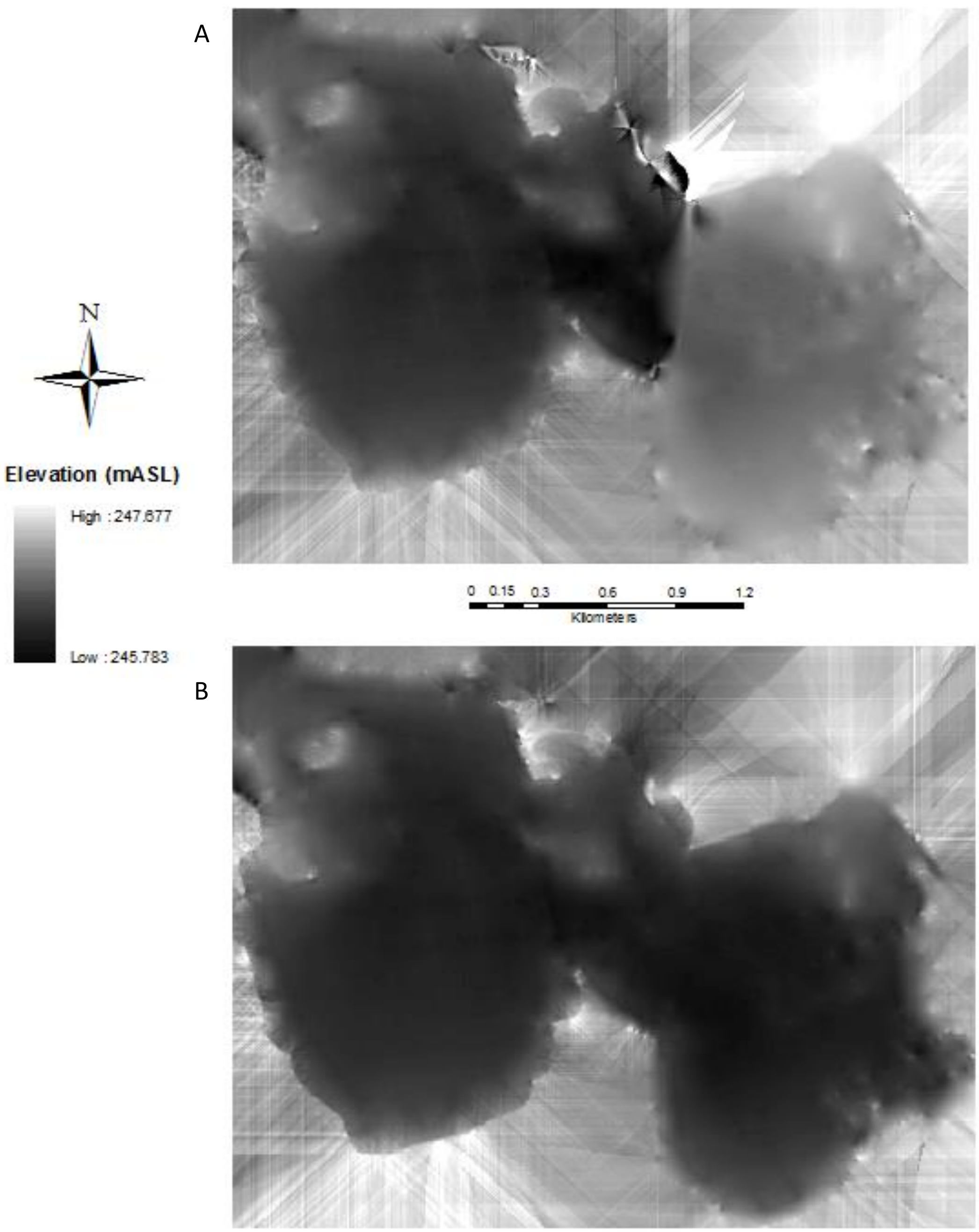


Figure 11. Outline of study area showing the 44 individual sections used for interpolation of bathymetric data in the eastern portion of Delta Marsh, Manitoba. Each bay and channel is separated into a unique section.

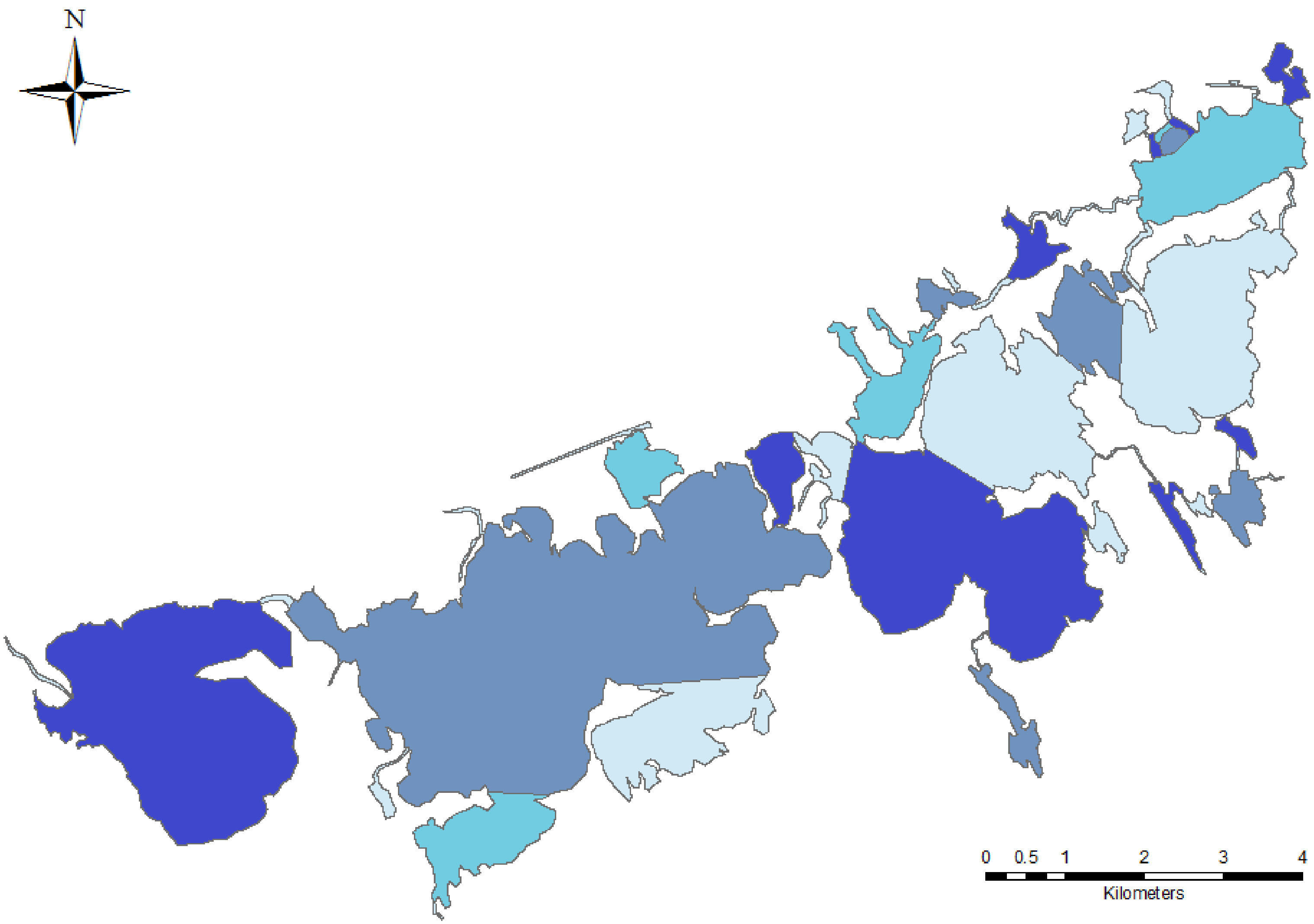


Figure 12. A mask, obtained from the features in Figure 10, which represents the survey area, is used to clip the entire DEM to include only those parts that had been surveyed by the QTC single beam sonar system

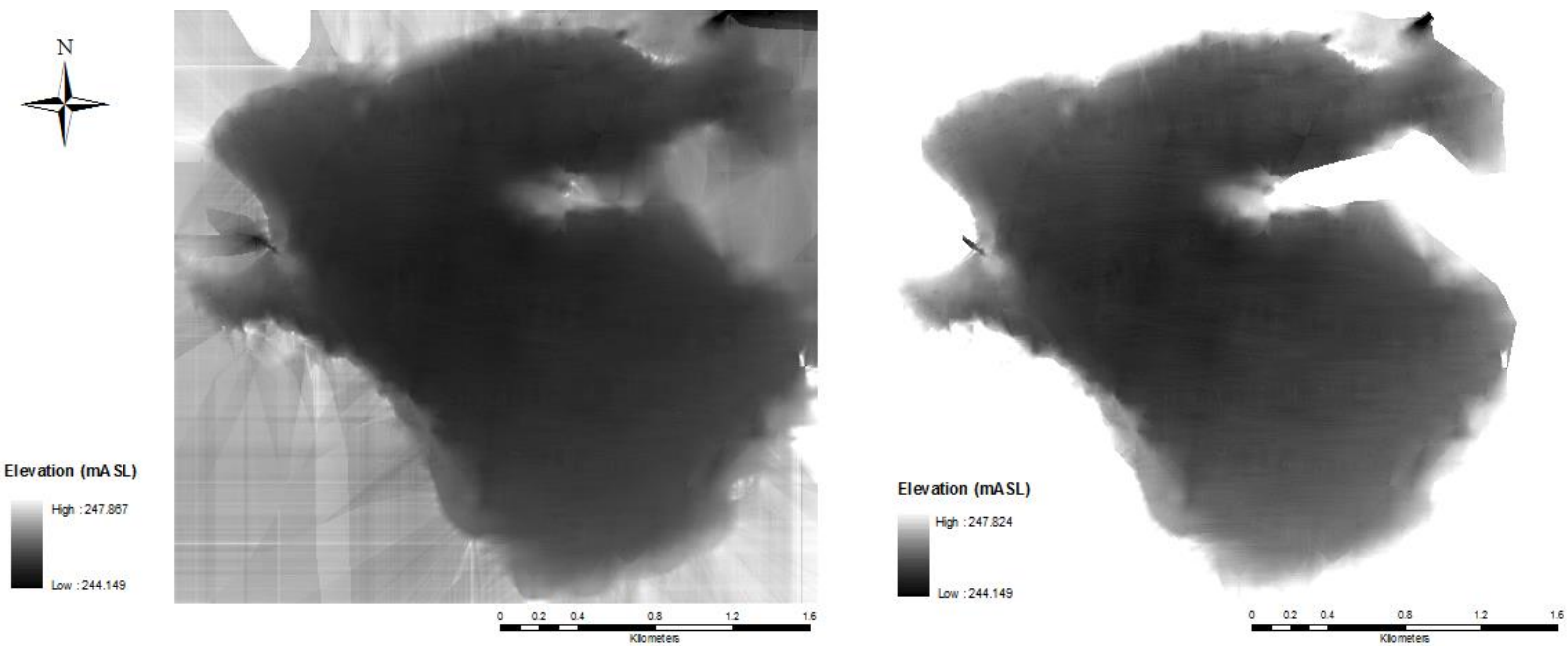


Figure 13 Final interpolated Digital Elevation Model (DEM) of the surveyed area of the eastern portion of Delta Marsh, Manitoba.

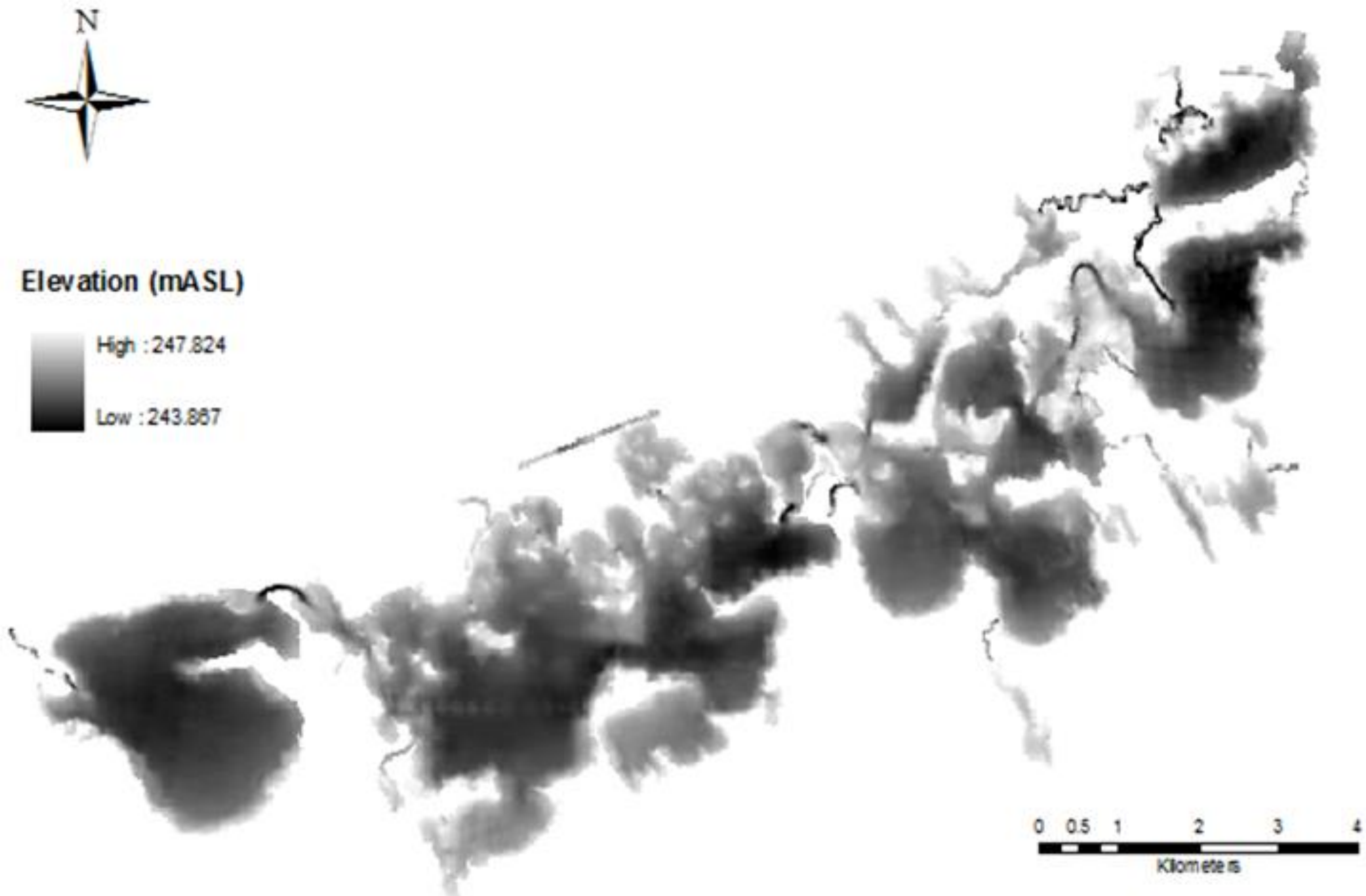


Figure 14. Digital Elevation Model (DEM) of the eastern portion of Delta Marsh, Manitoba.

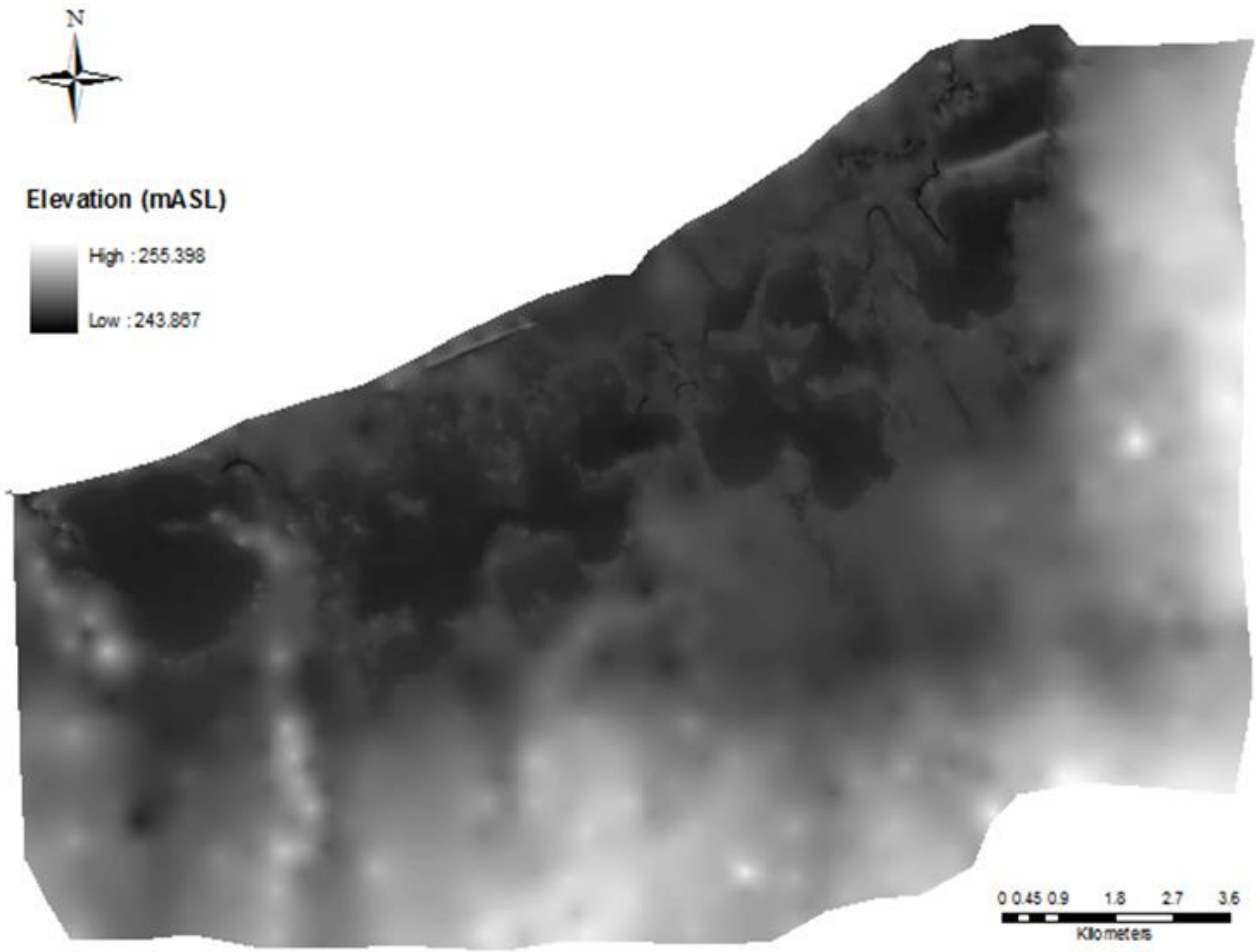


Figure 15. 3D rendering of the eastern portion of Delta Marsh, Manitoba created using ArcScene. This model shows the approximate extent of flooded areas during a normal water year (water level of 247.47 mASL).

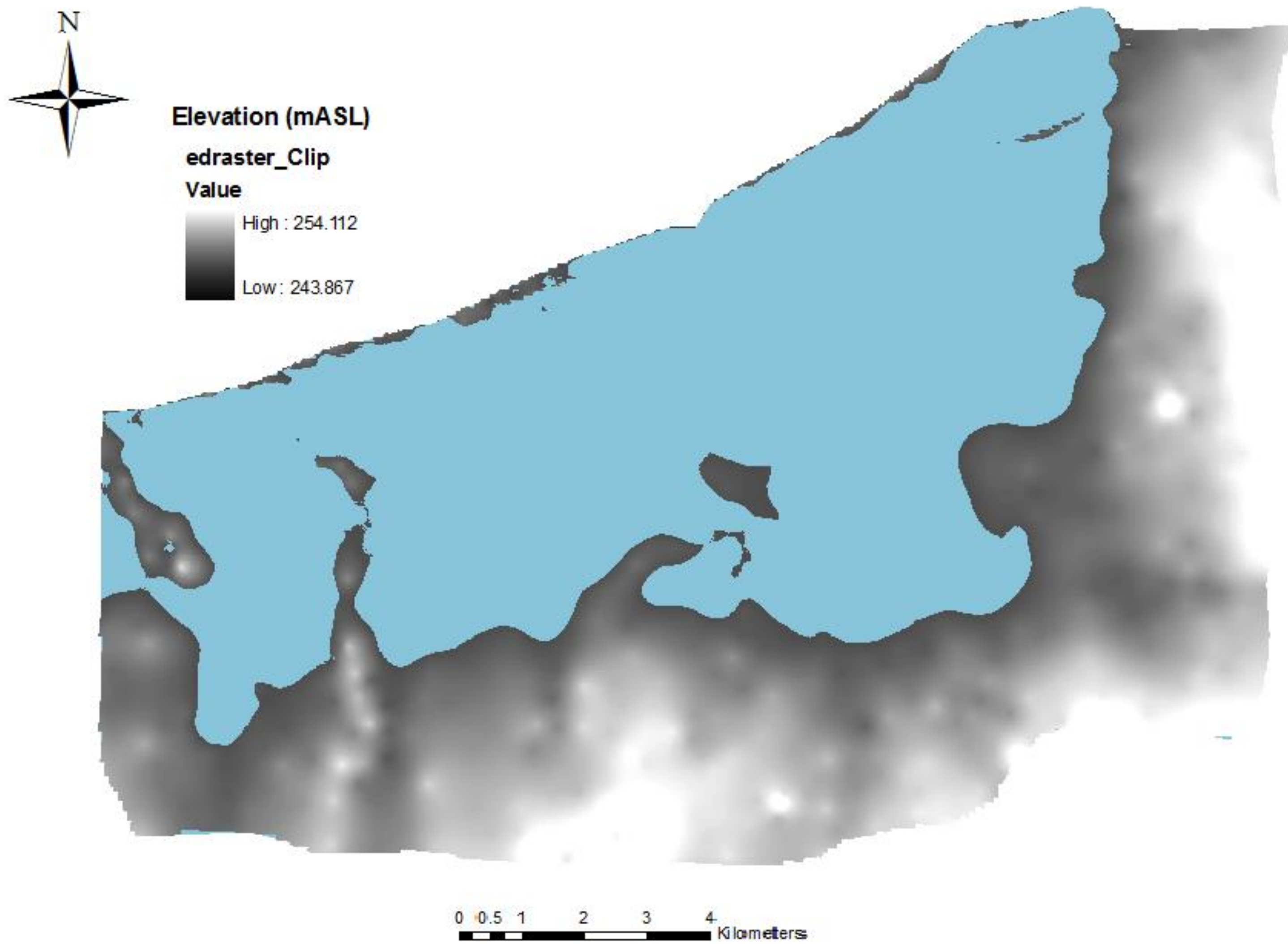


Figure 16. 3D rendering of the eastern portion of Delta Marsh, Manitoba created using ArcScene. This model shows the approximate extent of flooded areas during a normal water year (water level of 248.97 mASL).

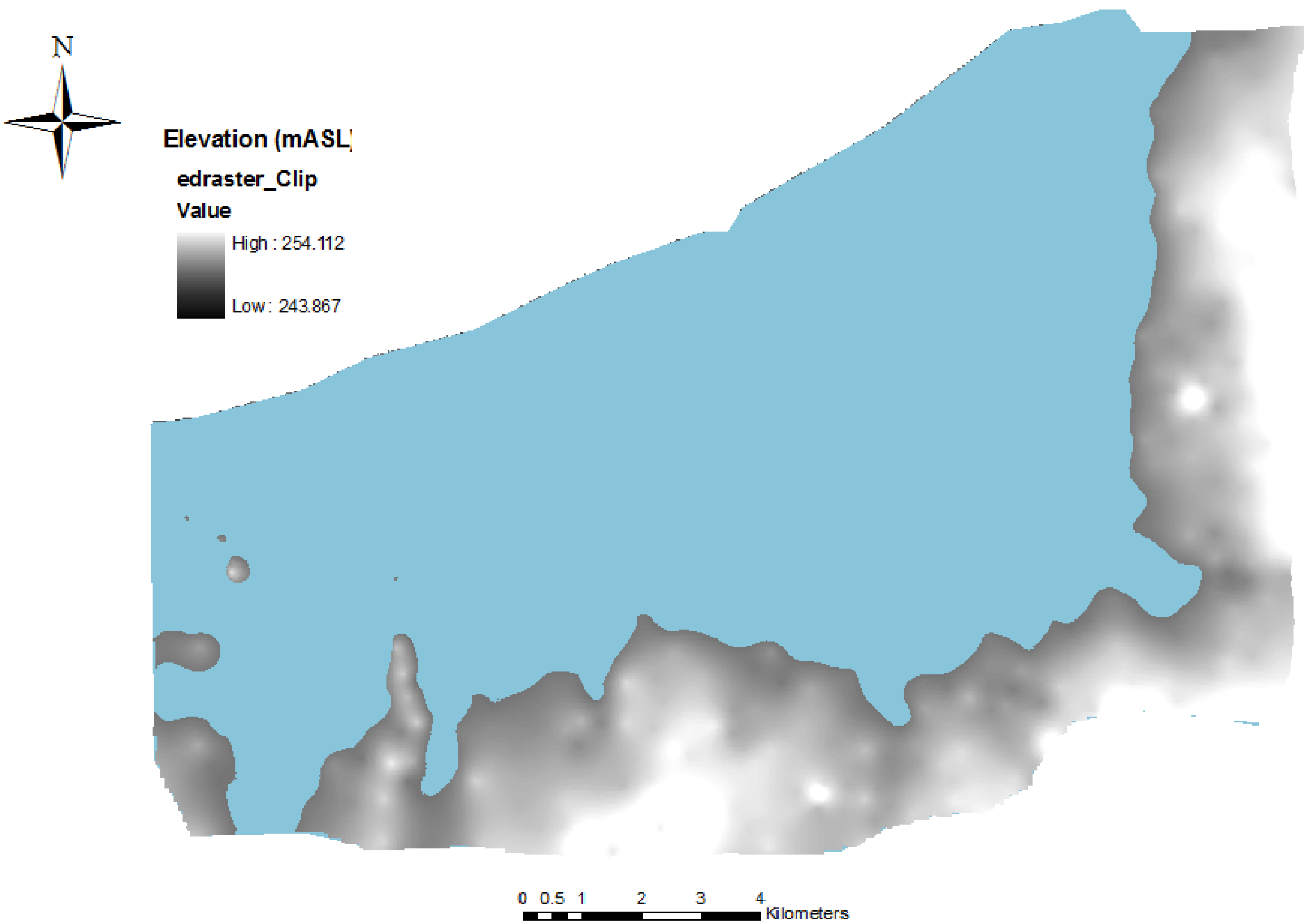


Figure 17. Digital Elevation Model (DEM) of the eastern portion of Delta Marsh, Manitoba as determined by Quester Tangent Corporation (QTC) single beam sonar analysis as well as data obtained from the Manitoba Land Initiative (MLI) website. Contours are set at intervals of 0.5 m.

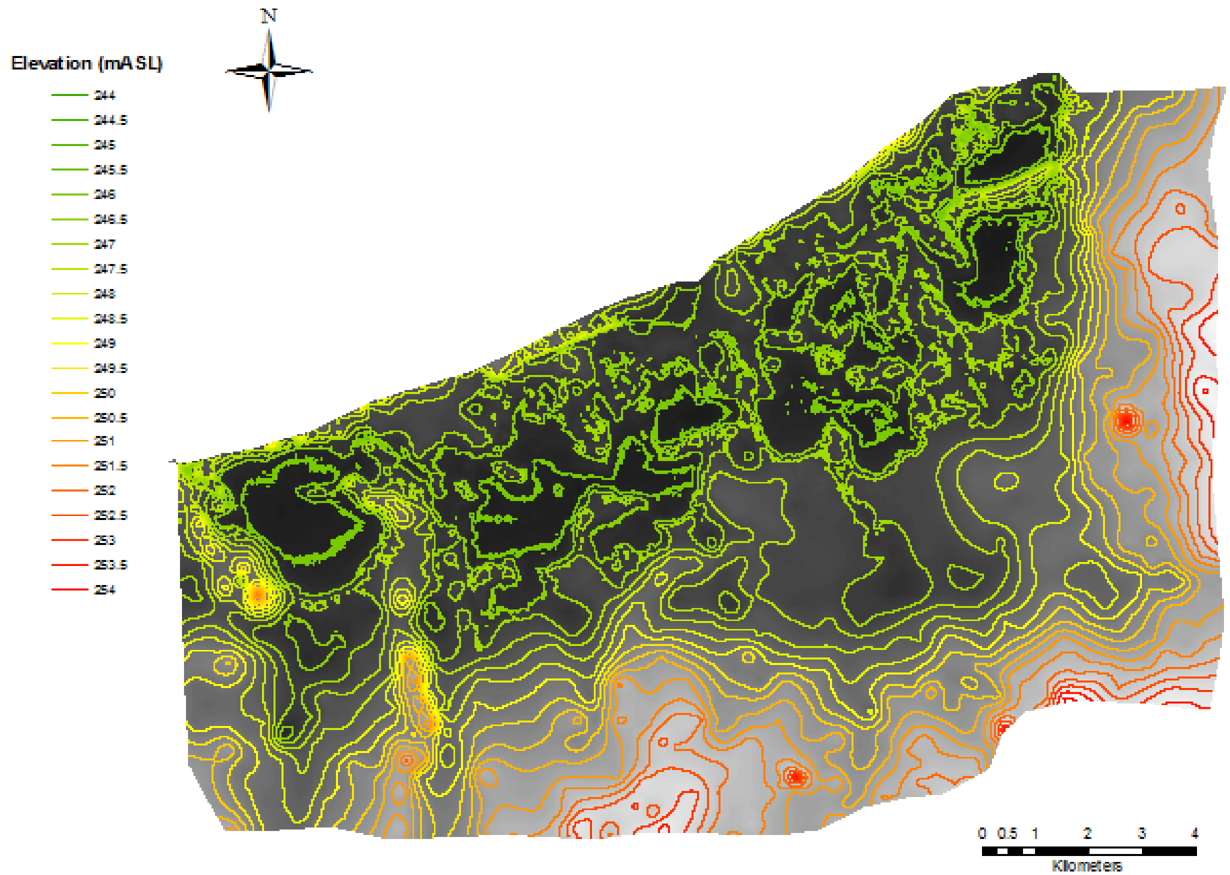


Figure 18. Distribution of elevations within the study are in the eastern portion of Delta Marsh, Manitoba as determined by Quester Tangent Corporation (QTC) single beam sonar analysis.

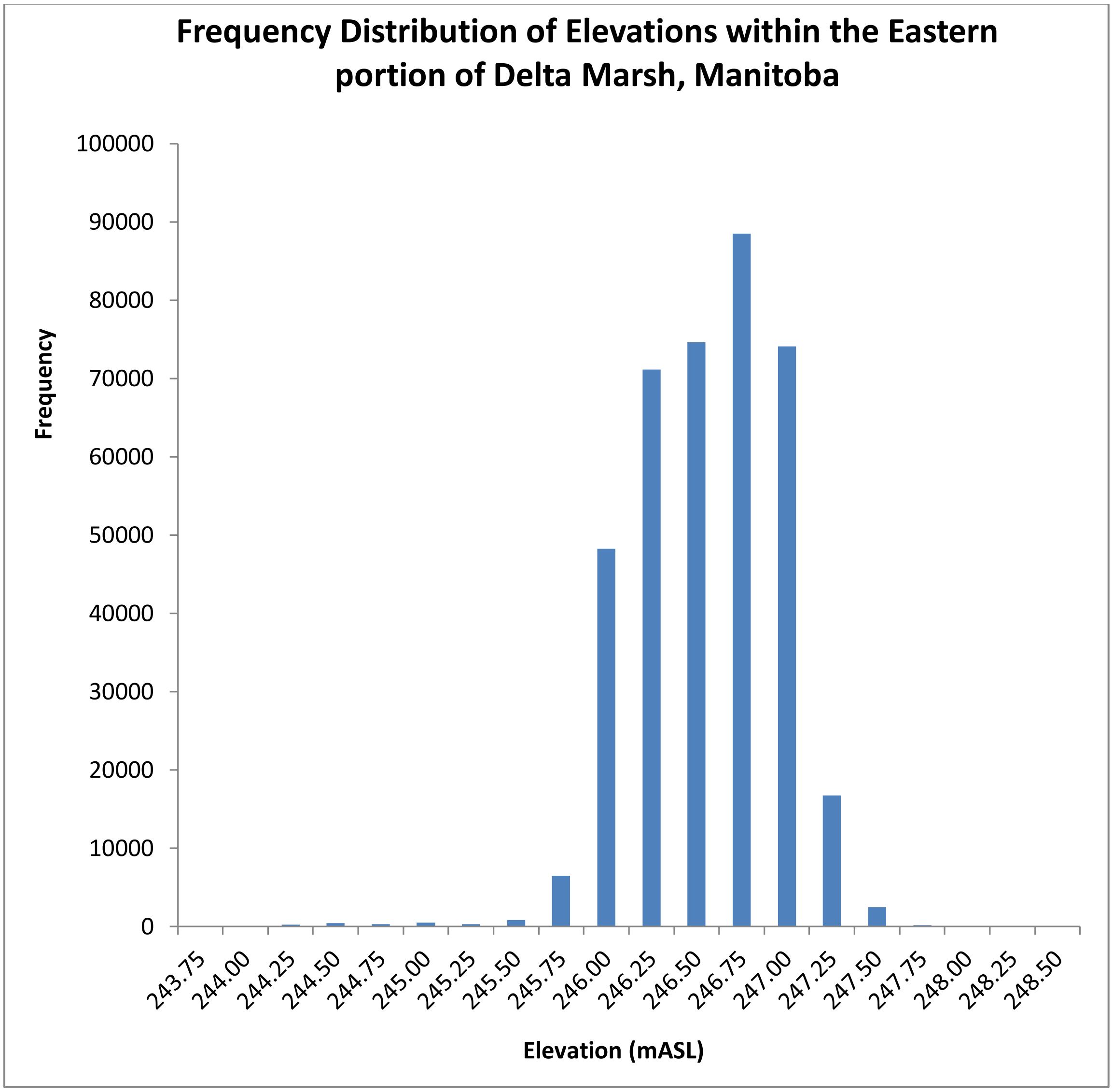


Figure 19. Location of lowest elevations within the bathymetry study area in the eastern portion of Delta Marsh, Manitoba as determined by Quester Tangent Corporation (QTC) single beam sonar analysis. A) Delta Channel, connecting the marsh to Lake Manitoba near the town of Delta. B) Channel between Cadham and Simpson Bays. C) Channel between Waterhen and Clandeboye Bays.

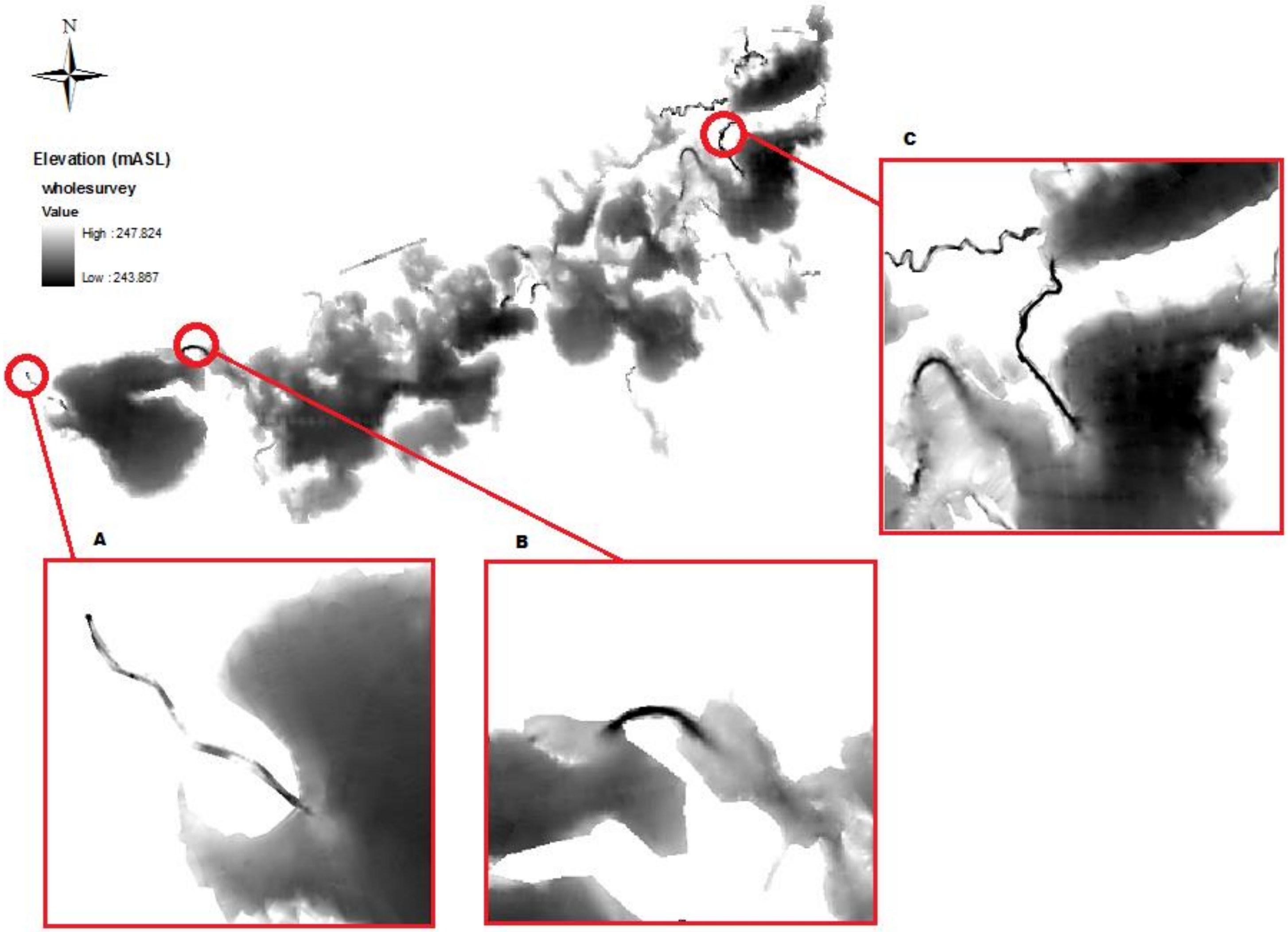


Figure 20. Distribution of elevation measurements taken within several bays and channels within the eastern portion of Delta Marsh, Manitoba as determined by Quester Tangent Corporation (QTC) single beam echosounder analysis. Locations for each area may be found in Figure 21.

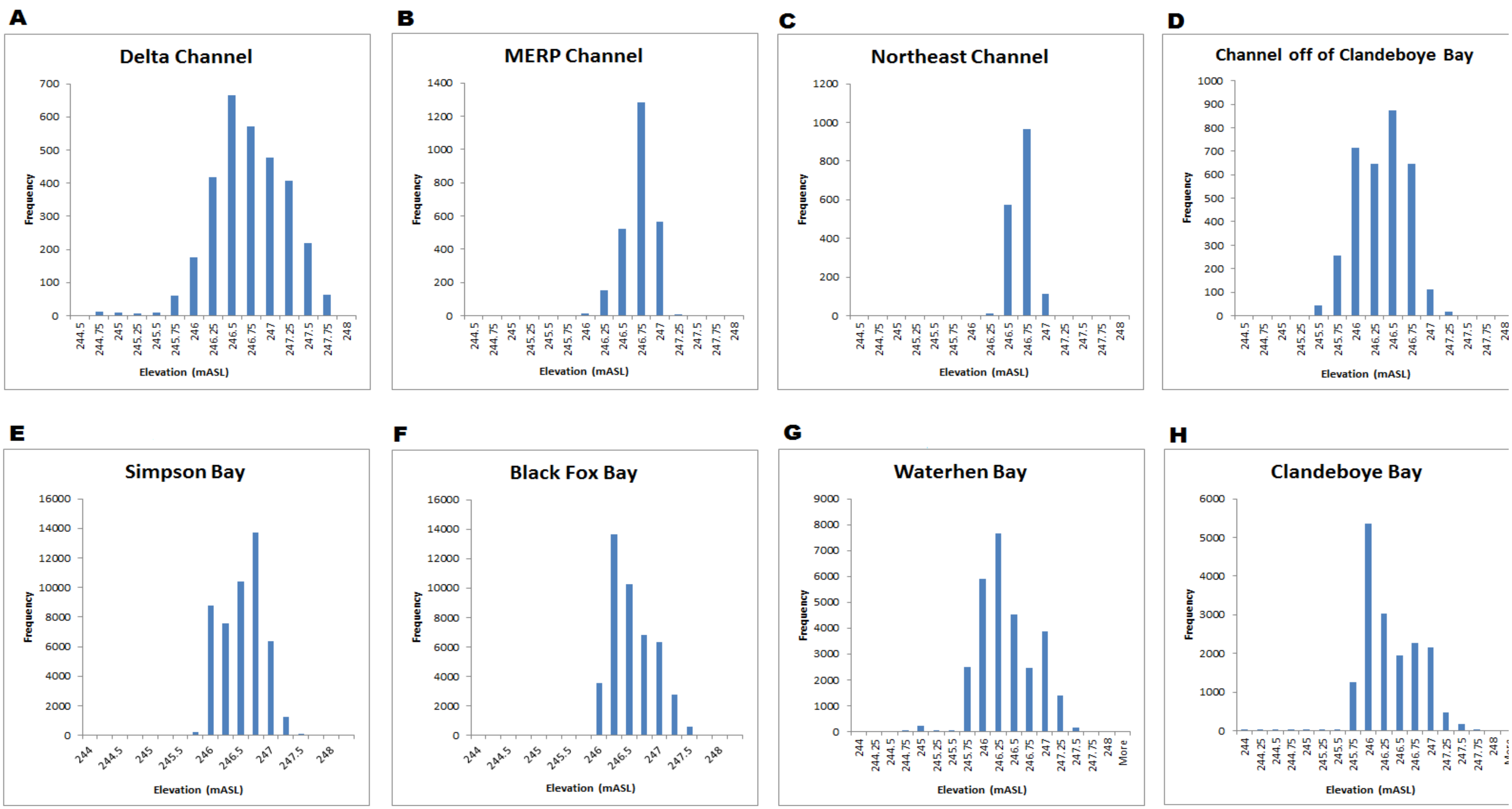
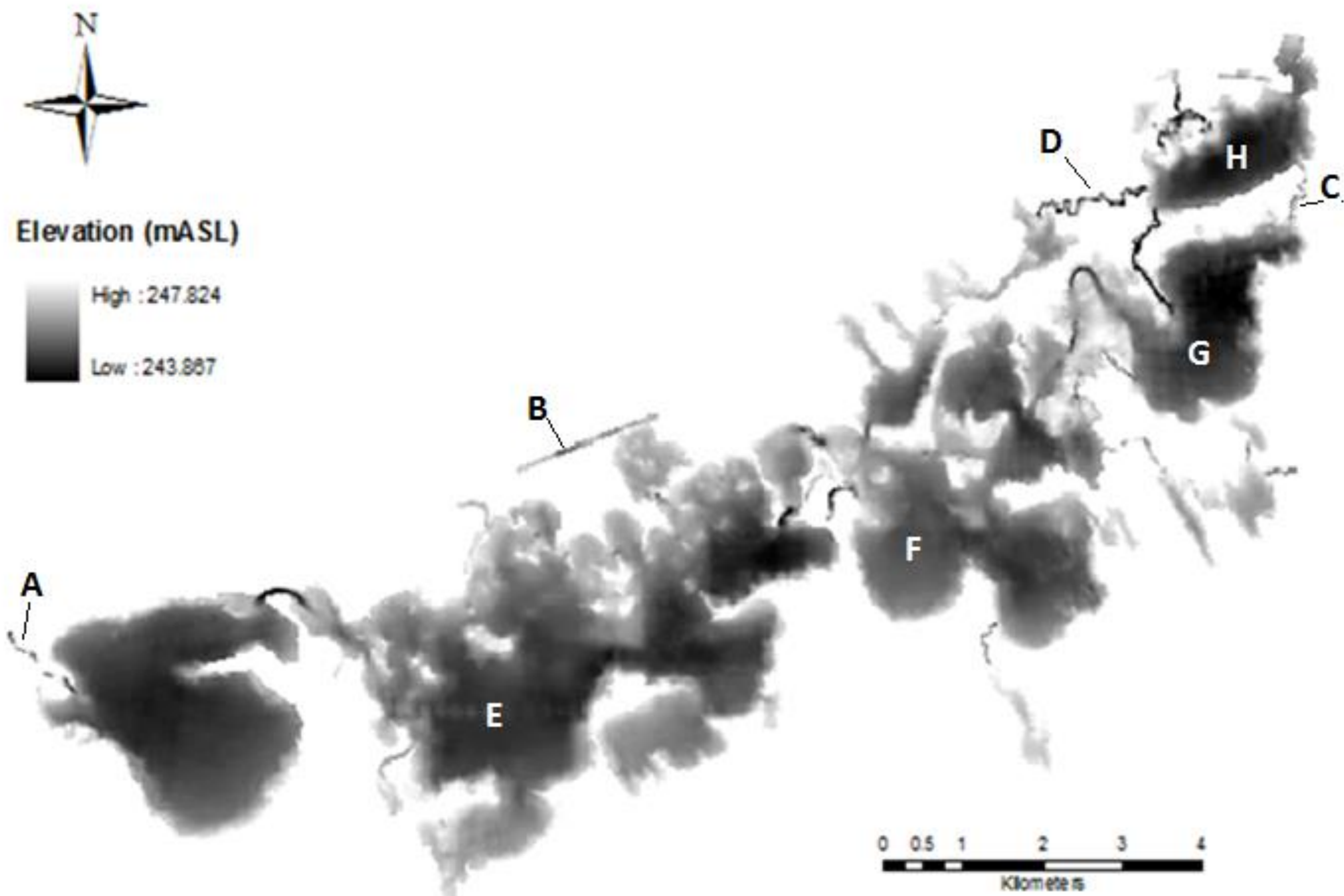


Figure 21. Locations of bays and channels in Figure 20. A)Delta Channel, B) Delta Channel, C) Northeast Channel D) Channel Off of Clandeboye Bay E) Simpson Bay, F) Black Fox Bay, G) Waterhen Bay, H) Clandeboye Bay.



4.0 – Substrata Distribution

4.1 - Introduction

One of the perceived benefits of wetlands is the removal of sediments (Fennessey et al., 1994; Murkin, 1998; Cronk and Fennessey, 2001). Water flowing through these highly vegetated areas slows down, resulting in the deposition of suspended sediments. Many wetlands, including Delta Marsh, receive runoff from surrounding agricultural areas, which includes both nutrient and sediment loads. Additionally, the operation of the Assiniboine River Diversion during flood years results in the deposition of large quantities of sediment in the lake, which may enter the marsh through several connected channels (Kenny, 1985; Berke, 2012). These sediments, combined with the decomposition of organic matter from plant litter as well as the many organisms which use this specialized habitat, create the soils that cover the marsh bottom.

Wetland soils are generally hydric in nature, meaning that they are saturated by water for at least part of the year. These soils are likely to be saturated for a long enough period of time for anaerobic conditions to occur (McKeague, 1965; Ransom and Smeck, 1986; Josselyn et al., 1990; Faulkner and Patrick, 1992). During flood conditions, the spaces between soil particles, which are normally occupied by oxygen, become filled with water. Oxygen depletion within the soil may occur in as little as several days but may take much longer. This process is accelerated when soil temperatures increase as well when ambient temperatures increase due to increased rates of evapotranspiration.

Benthic habitats are important for many wetland organisms for a range of purposes and during different periods in their life history. Substrates provide feeding and spawning habitat and cover for fish and invertebrates (Gurtz and Wallace, 1984) with individual taxa having specific preferences based on sediment particle size (Grossman and Freeman, 1987; Hoeinghaus et al., 2007). Larger particle substrata, such as rock and gravel, tend to be preferred for spawning grounds as they provide cover and protection, whereas fine-particle sediments like clay and silt tend to create flat environments that provide little shelter though they are often used as feeding grounds (Scott and Crossman, 1973; Hall and Werner, 1977; Brazner and Beals, 1997; Bradbury et al., 1999). The common carp (*Cyprinus carpio* L.), a common (and nuisance) fish in many North American wetlands, however, prefers to spawn in shallow, soft bottom areas in thick vegetation (Stewart and Watkinson, 2004). Areas with submerged macrophyte growth are often the most diverse as they provide habitat and cover; as well, they provide a substrate for algae growth which is a food source for many invertebrates (Bruno et al., 1990; Pratt and Smokorowski, 2003). Many wetland fish are known to exhibit habitat preferences; yellow perch (*Perca flavescens* Mitchill) favor covered areas such as vegetation and sunken logs. White sucker (*Catostomus commersonii* Lacepede) are known to feed over sand and mud substrata, whereas fathead minnows (*Pimephales promelas* Raf.) are common over fine substrata, and like carp, they prefer sand and mud for nesting areas. Bullheads (*Ameiurus nebulosus* Lesueur and *A. melas* Raf.) also prefer fine-particle substrata whereas brook stickleback (*Culaea inconstans* Kirtland) prefer weedy habitat for both cover and nesting (Stewart and Watkinson, 2004).

Similarly, invertebrates often exhibit habitat preferences. Oligochaete worms prefer soft substrata such as mud but tend to be found over a wide range of water depths (Sublette, 1957).

Gastropod snails are common over a wide range of substrata and depths but tend to be associated with submerged and emergent vegetation. Water mites are found on larger-particle sediments such as gravel and sand whereas mayflies may be found throughout coarse or fine-particle substrata dependent on the particular species (Sublette, 1957).

Several factors can influence the deposition and distributions of different sediments within a waterbody. The organic content of sediments in large water bodies tends to increase with water depth, while particle size tends to decrease (Sly, 1978). Large particle sediments tend to reach a certain water depth; as they reach deeper areas, the likelihood of being resuspended (due to lessened disturbance as well as their greater weight) decreases and they tend to settle out. Smaller particle sediments, however, may be resuspended with lesser disturbance and tend to remain suspended for longer periods of time allowing them to drift further and into deeper areas (Sly, 1978). Smaller water bodies, however seem to show different distribution patterns; fine particle sediments tend to be found nearer to shore and organic content tends to be closely related to soil water content, which tends to be highest in sediment close to shore as well as in deeper, settled areas (Cyr, 1998).

My study site, Delta Marsh, is underlain with solid bedrock with sediments that have been described as ranging from clay/silt to sand/loam (Walker, 1965). In many areas, these sediments are covered by a layer of decomposed organic matter, especially near vegetated areas (Zbigniewicz, 1981) which results from the decomposition of plants and other biological material (Mausbach and Richardson, 1994). The substrata in vegetated areas are also likely to be covered by a layer of partially or completely undecomposed litter.

By mapping the substrata distributions within Delta Marsh, we may be better able to understand the distributions of aquatic organisms within the environment. It is likely that, due to the shallow nature of the marsh, resuspension of sediments occurs on a regular basis due to wind and wave action. I have determined if any spatial patterns in sedimentation exist by analyzing the substratum composition around the marsh using single beam sonar, supplemented by visual inspection of substratum samples collected in the field. I expected that a high proportion of the marsh would be covered by organic substratum and that due to the shallow nature or the marsh and high occurrences of wind and wave action that the distribution of substrata, if many different types exist, would be homogenous.

4.2 – Materials and Methods

During the period between June and November 2011, bathymetric and categorical substrata data were obtained from the portion of Delta Marsh east of highway 240, an area of approximately 153 km^2. These data were obtained through the use of a Quester Tangent Corporation (QTC) single-beam sonar system consisting of an echo sounder, depth finder, transducer, Trimble GPS receiver, and a ruggedized laptop computer installed with QTC software for data processing. Data were collected from a 14-foot aluminum fishing boat moving approximately 9-10 km/hour, with the transducer generating approximately seven 50 kHz pulses per second. The survey was conducted by the creation of both parallel and perpendicular transects separated by 100 – 200m. To acquire accurate depth and waveform data the transducer must be fairly stable. Any vertical movement of the transducer during data collection resulted in inaccurate or unreadable data. Due to the shallow nature and large surface area of Delta Marsh, waves were created with relatively low wind action. Consequently, surveying was not undertaken during winds exceeding 10 km/hour. This resulted in a large data collection time frame. The amount of data collected was also limited by the formation of ice in sheltered bays near the end of the survey period.

After field work was complete, sonar data were uploaded to the QTC IMPACT software program and manually assessed for accuracy; outliers and waveforms appearing misshapen were removed manually. The remaining data were condensed by averaging groups of five pulses into a single waveform stack. The final data set consisted of over 400,000 data points. In order to identify unique substratum categories the waveforms were evaluated in QTC IMPACT using a Principal Components Analysis (PCA). This analysis used 166 separate features of each waveform, including measures of amplitude, duration and ratio measurements. The PCA reduced the number of significant features from 166 to three, which explained the largest amount of variation with the dataset. These three features were each plotted as an axis, resulting in a three-dimensional representation of this variability. Each datum was placed within the 3D space based on its score on each axis, known as Q-values. The data from the PCA were then run through another analysis known as ACE (Automatic Clustering Engine) which used a K-means clustering algorithm developed by QTC. Each data point was separated statistically into a substratum category into which it fell most closely in the 3D PCA space. The IMPACT program ran through a series of models, which contained increasing numbers of substratum categories, and measured the Bayesian Information Content (BIC) of each model, which was displayed graphically. The BIC is a measure of the likelihood of which, in a series of models, is most likely to be correct. In the cluster analysis, the model with the lowest BIC score was the most likely. The number of iterations that this process repeats was selected manually; generally the more iterations, the more accurate the result. The model with the lowest BIC was chosen and the cluster analysis was run based on the selected number of substratum classes. For the Delta Marsh dataset, a model with six unique substratum classes was chosen. The final product of this analysis was a spreadsheet containing the geographic coordinates, Q-values, depth, substratum class, class confidence, and class probability for each individual data point. The QTC spreadsheet was uploaded into ArcMAP and transformed into a point data set using the geographic coordinates (Figure 22). The points were then subjected to an interpolation method called Create Theissen Polygons in ArcMap. This analysis created a polygon for each individual point in the file. The area within the polygons consisted of locations that were closer to that particular point than any other point in the dataset (Kang, 2008). For a 400,000 point dataset, a total of 400,000 polygons were created. In order to decrease the number of polygons and get a better idea of the continuity of the six classes, the borders of the polygons were reduced through the use of the "Dissolve" function in ArcToolbox. The dissolve was based solely on the class of each polygon; polygons of the same class, which shared a border, were joined. A polygon of the survey area (produced during the creation of the Digital Elevation Model) was then used to clip the Thiessen polygons to create a substrata distribution map of the survey area (Figure 23). The classification provided by the IMPACT program was, however, unsupervised, meaning that ground truthing was needed to identify the composition of each class. Benthic habitat mapping was generally carried out in a "top-down" manner where sonar identification was carried out on a large scale, followed by in-field ground truthing on a smaller scale (Eastwood et al., 2006).

By examining the point data created in ArcMap, I was able to determine which areas, if any, had particularly large quantities of each of the six identified substrata. Although it is best to employ randomized sampling whenever possible several substratum categories were relatively rare, sample locations were chosen from areas throughout the marsh where each substratum was concentrated. Twelve samples from each identified substratum group were taken, 72 samples in total (Figure 24). To remain as unbiased in sampling and processing as possible, sample sites, once chosen, were assigned a random ID number which was not identified until processing was complete. The majority of the samples were collected during February 2012, though several sites were inaccessible where the water column had frozen to the sediment surface or where there was open water. Sample locations were reached by snowmobile and samples were taken by drilling through the ice with a 10" auger and retrieving a substratum sample using an Eckman dredge measuring 15 cm x 15 cm x 15 cm. Sites that were inaccessible in February were visited in June, and samples were collected from a boat using the same dredging technique. Samples were bagged and labeled with the assigned ID number, then refrigerated for 8 to 10 months prior to analysis.

Samples were to be analyzed for particle size and organic content. Particle size analysis was to be done using a sieve technique (Gee and On, 2002) which required that the substratum sample be dried. Samples were laid out to air dry; however, upon drying, samples with fine silt and clay sediments formed large, inseparable mudrocks, a solid made up of a silt and clay mixture. Breakdown of these samples became impossible as separation after conglomeration could result in the creation of completely different particle sizes than were present originally. Consequently, the proposed analysis could not be completed. A visual and tactile identification method was determined to be the best alternative. Samples were analyzed by several criteria: the presence of undecomposed vegetation, the presence of organic materials, and the formation of a mudrock. After analysis was complete, the randomly assigned ID numbers were used to identify the class in which the QTC software had categorized each sample. After comparison of the QTC identified classes and the ground-truthing data, it was determined that the six categories could be subdivided into three subcategories (Figure 25). QTC classes 1, 2 and 6 fell within a clay/silt category, classes 3 and 4 fell within an organic category, and class 5 was classified as having a high proportion of plant matter. This new categorization was then transferred into the ArcMAP point file for the purpose of creating a substrata interpolation of the entire survey area (Figure 26). The same process used to create the continuous map of the QTC identified substratum categories was used to create a map of the classified substrata (Figures 27 and 28).

4.3 - Results

The most abundant substratum category was class three, which is clear in the distribution map (Table 1, Figure 28). Class three covered 33.77 km² or 75.54% of the survey area, making up 79.5% of the sample points. Class two was the second most prominent with 52,237 sample points (13.00% of the total sampled points), covering 7.81 km² or 17.47% of the survey area. The remaining substratum classes were rare in comparison, each making up less than 3% of the total coverage area. As previously mentioned, the categories determined by the QTC IMPACT software program are based solely on analysis of echo waveforms obtained by the QTC VIEW sonar system. Of the 72 substratum samples collected in the winter and spring of 2012, three distinct classes were identified: a clay/silt substratum, an organic substratum, and a substratum with high proportions of undecomposed plant matter. All 72 samples were identified as belonging to one of these three classes with the exception of a single sample dominated by large gravel (Table 1). After comparing the composition-based classifications to the six QTC-identified classes, it could be seen that the QTC classes were separated effectively into the ground-truthed classes. QTC identified classes one, two and six fell into the clay/silt category, whereas QTC classes three and four fell into the organic substratum category. QTC class five was the only class identified to contain a high proportion of undecomposed plant matter.

The agreement between QTC and ground-truthed classes was relatively high, but several QTC-identified samples did not agree with the ground-truthed data (Table 1). This is likely attributable to two unavoidable sources of error: positional error occurring during the recording and locating of GPS positions in the field, and misidentification error during the subsequent QTC analysis. Based on the combination of QTC and ground-truthed data, I found that 33 of 36 sample points predicted to be clay/silt were identified as such during analysis. The remaining three samples were organic in nature. In the organic class 16 of 24 predicted samples were identified as such after examination of ground-truth samples; the remaining samples were identified as clay/silt. Eight out of the twelve areas predicted to have undecomposed vegetation were identified as such, with equal numbers of the remaining samples being identified as clay/silt or organic.

One ground-truthed sample, composed of large gravel, could not be placed into any of the identified classes and was found to be unique amongst ground-truthed samples. It may be that this particular substratum was so rare that the QTC IMPACT software could not create a unique class and therefore it was clustered into the most likely existing class. This sample was collected from the east side of Waterhen Bay, in the eastern portion of the study area (N50.21726, W98.10017). Oddly, both the confidence and probability of this point falling within the assigned class (as calculated by the QTC clustering analysis) are high; 93% and 50%, respectively. It is possible that the QTC data point and the point from which the sample were taken did not coincide exactly due to measurement error by the GPS receiver. If this substratum was actually rare, the sonar survey may have missed it completely. The point from which the sample was taken may have been directly next to the survey transect and yet it would not have been recorded during the survey. With such a large area to cover and limited time in which to do it, the possibility existed of losing smaller scale data such as pockets of rare substratum. A more detailed survey of this particular area may reveal smaller scale changes in substratum type that were not identified during this survey.

I used the error matrix created using the QTC classified and ground-truthed data to examine the accuracy of the produced substrata map. This involved the calculation of producer and user accuracy statistics. The producer's accuracy is the probability that a point in the real world is classified correctly on the map whereas the user's accuracy measures the probability that a classified point on the map matches the conditions in the real world. Looking at the silt/clay class, one can see that the producer accuracy was only 79%, while the user accuracy was relatively high at 92% This means that while 92% of the areas marked as silt/clay on the map were indeed silt/clay substrata in the real world, versus only 79% of the silt/clay areas in the real world being identified as such on the map. Approximately 21% of silt/clay substrata were misidentified as organic substrata. The organic substratum class had relatively similar producer and user accuracies showing that the chances of either type of error were roughly equal and that the organic substratum was most likely to be misidentified as silt/clay substrata. The vegetation class had the highest producer accuracy, indicating that all substrates containing undecomposed vegetation in the real world were represented accurately on the map. The user accuracy was lower, however, suggesting that only 67% of the areas identified as vegetation on the map would be found to be such in the real world. The gravel sample collected in Waterhen Bay suggests that a more detailed survey of the area may result in a fourth substratum category, which cannot be included at this time due to lack of data.

4.4 - Discussion

The PCA and K-means clustering analysis by QTC IMPACT resulted in the separation of sonar data from Delta Marsh into six distinct substratum classes. QTC substrate classification has been shown to be relatively accurate (Freitas et al., 2006; Freitas et al., 2008); Ellingsen et al. (2002) found that substratum particle size was a large contributor to substrate class separation, as was the softness of the substratum, but that other characteristics were likely contributing factors. The roughness of the substratum may also influence the signal picked up at the sonar receiver. An area with a smooth surface and one with a rippled surface may result in the creation of two separate substratum categories, even though the particle sizes in these two areas may be equal (Biffard et al., 2007). In a test of the QTC system and the RoxAnn system (a similar single-beam sonar system), the classes produced by the QTC system were found to be more accurate in distinguishing between particle sizes amongst the substrata. The QTC system was also found to produce more accurate substratum boundaries (Hamilton et al., 1999).

The three identified substrata seemed to be distinctly separated (Figure 28); the Clay/Silt substratum being concentrated near bay centers and the Plant Matter substratum being concentrated near vegetation edges, while the Organic substratum seemed to be found throughout the study area. This appeared to be an elevational separation which will be explored further in Chapter 7.

My data seemed to agree, for the most part, with observations by Sly (1978) which stated that small particle sediments tend to settle in the deeper areas of large water bodies. The main bays of the marsh are relatively large in size and we do see that small particle sediments (the clay substratum) are common in the centers of these bays.

Substratum characteristics such as particle size and organic content can be influential in the distributions of aquatic organisms such as fish, invertebrates, and submergent and emergent plants. Although particle size was not examined thoroughly during this study, it is clear the majority of sediments within the study area could be described as fine-particle. It is not surprising, therefore, that many of the fish common to the marsh, such as common carp, white sucker, minnow, and bullhead (Parks, 2006), are typically associated with soft-bottom substrata. Although larger-grained sediments were found during the study, they could not be attributed to a unique substratum category based on the QTC IMPACT analysis. Further exploration and more detailed surveys may uncover further distributions of this class.

Fine sediments (silt and clay) on the marsh bottom may be resuspended by wave action up to depths of four meters (Cyr 1998). Since the majority of the marsh would not exceed this depth during normal water years, it is likely that resuspension of sediments is common throughout the open water season. The majority of samples were collected during the winter months so it may be interesting to collect similar samples during the summer months to determine if increased disturbance from wind and wave action results in the redistribution of the observed classes.

Figure 22. Distribution of six unclassified substratum categories as identified by Quester Tangent Corporation (QTC) single beam sonar and QTC IMPACT substrate analysis in the eastern portion of Delta Marsh, Manitoba in 2011.

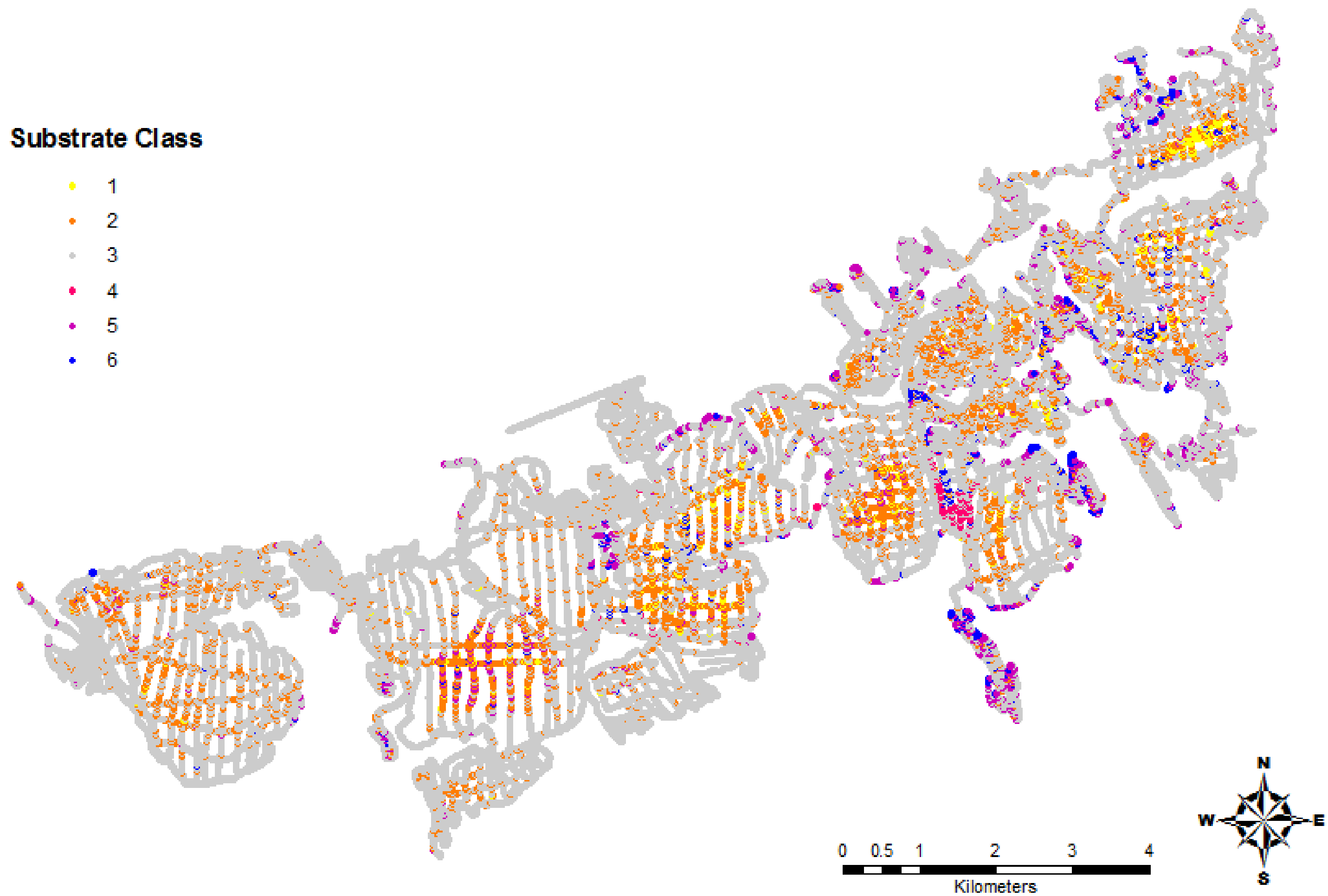


Figure 23. Substrata distribution map of the eastern portion of Delta Marsh, Manitoba in 2011 as determined by Quester Tangent Corporation (QTC) IMPACT substrate analysis. This program identifies potentially unique substrata but further examination of ground-truthed samples is required for classification.

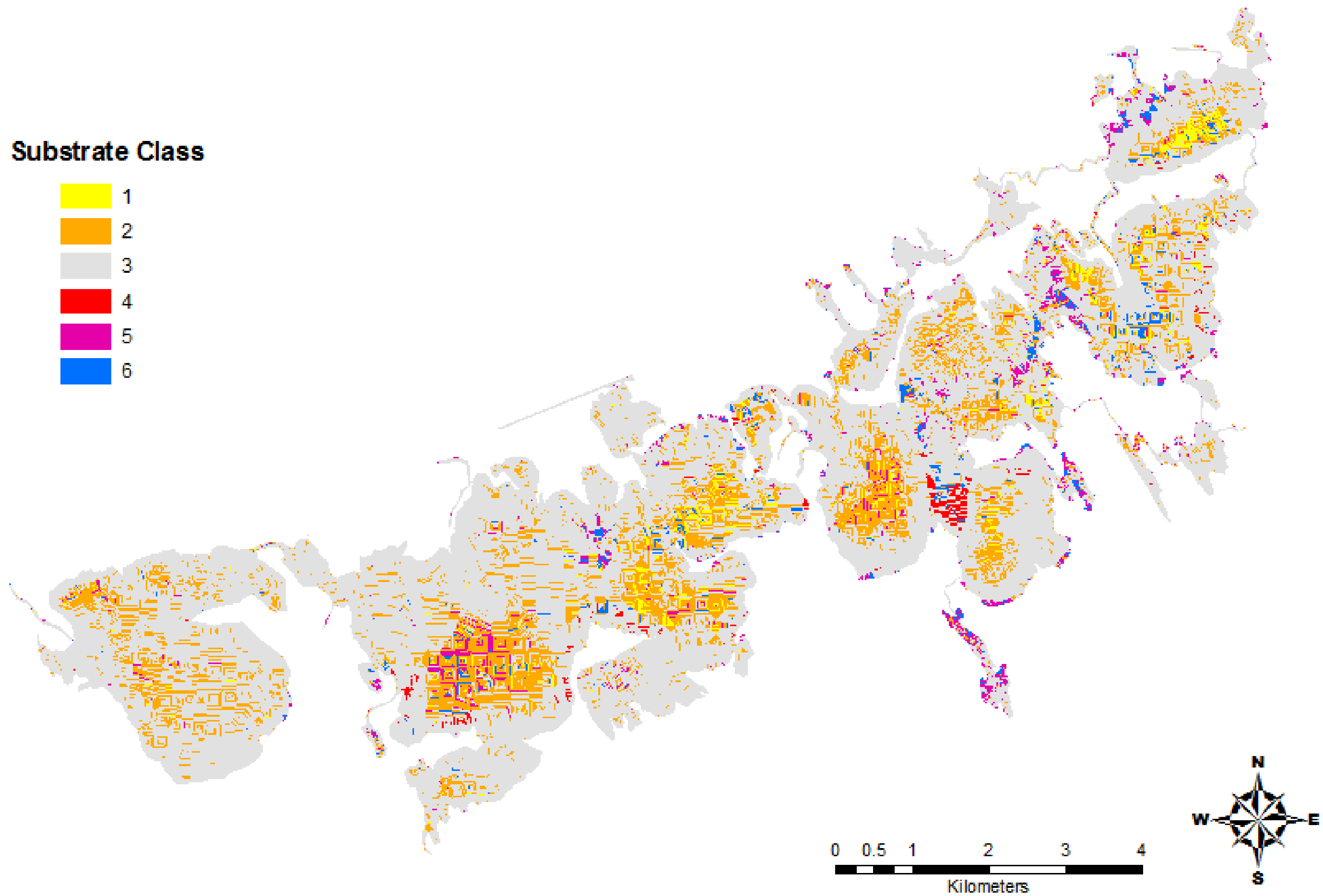


Figure 24. Locations of 72 substratum samples taken in 2011 within the eastern portion of Delta Marsh, Manitoba in order to ground-truth substratum categories identified by Quester Tangent Corporation (QTC) single beam sonar analysis and QTC IMPACT substrate analysis.

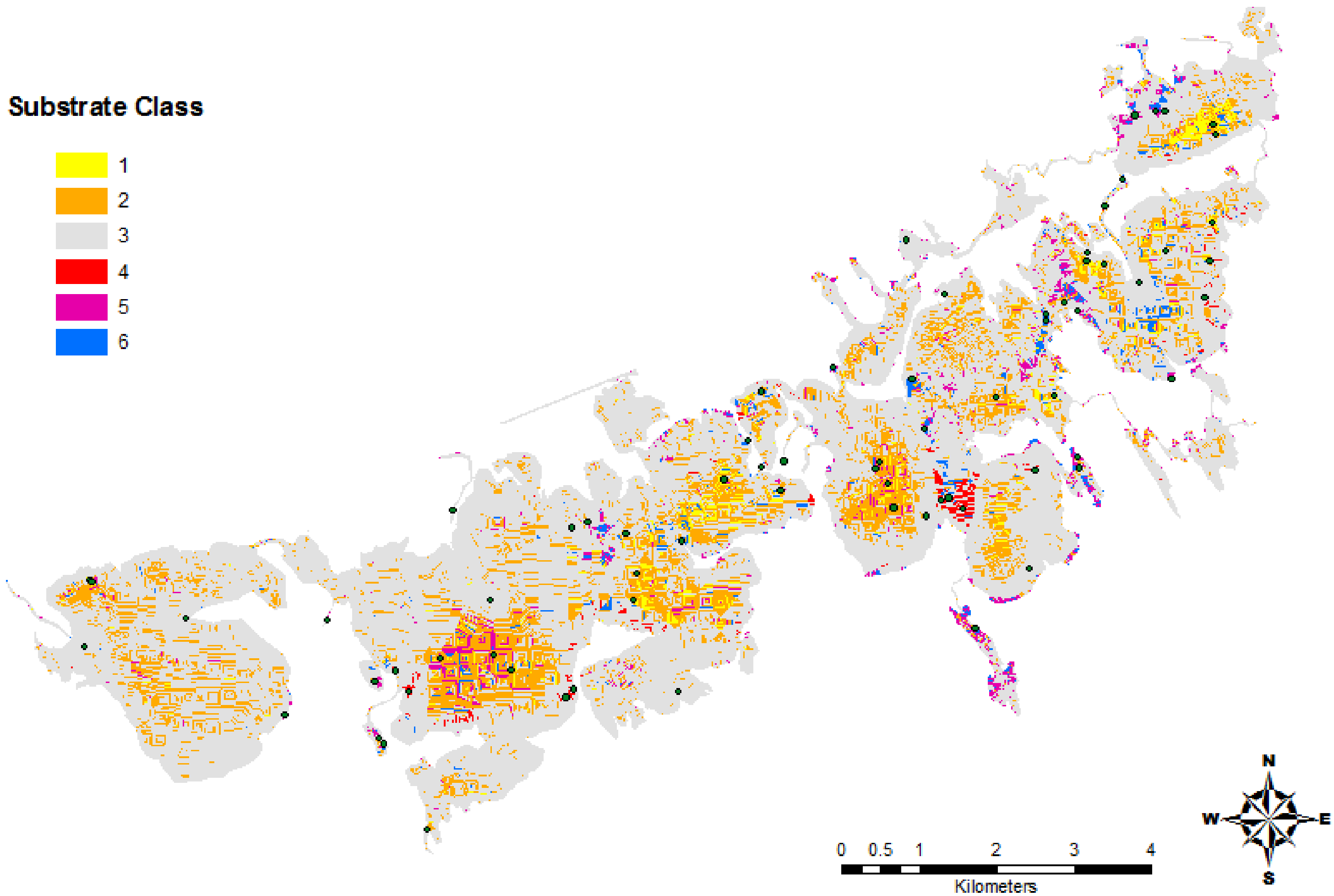


Figure 25. Three substratum categories found within the eastern portion of Delta Marsh, Manitoba as determined by examination of ground-truthed samples from the study area. A) Plant Matter B) Clay/Silt C) Organic Matter.

A B C

Figure 26. Distribution of three classified substratum categories as identified by Quester tangent Corporation (QTC) IMPACT substrate analysis and examination of ground-truthed samples in the eastern portion of Delta Marsh, Manitoba in 2011.

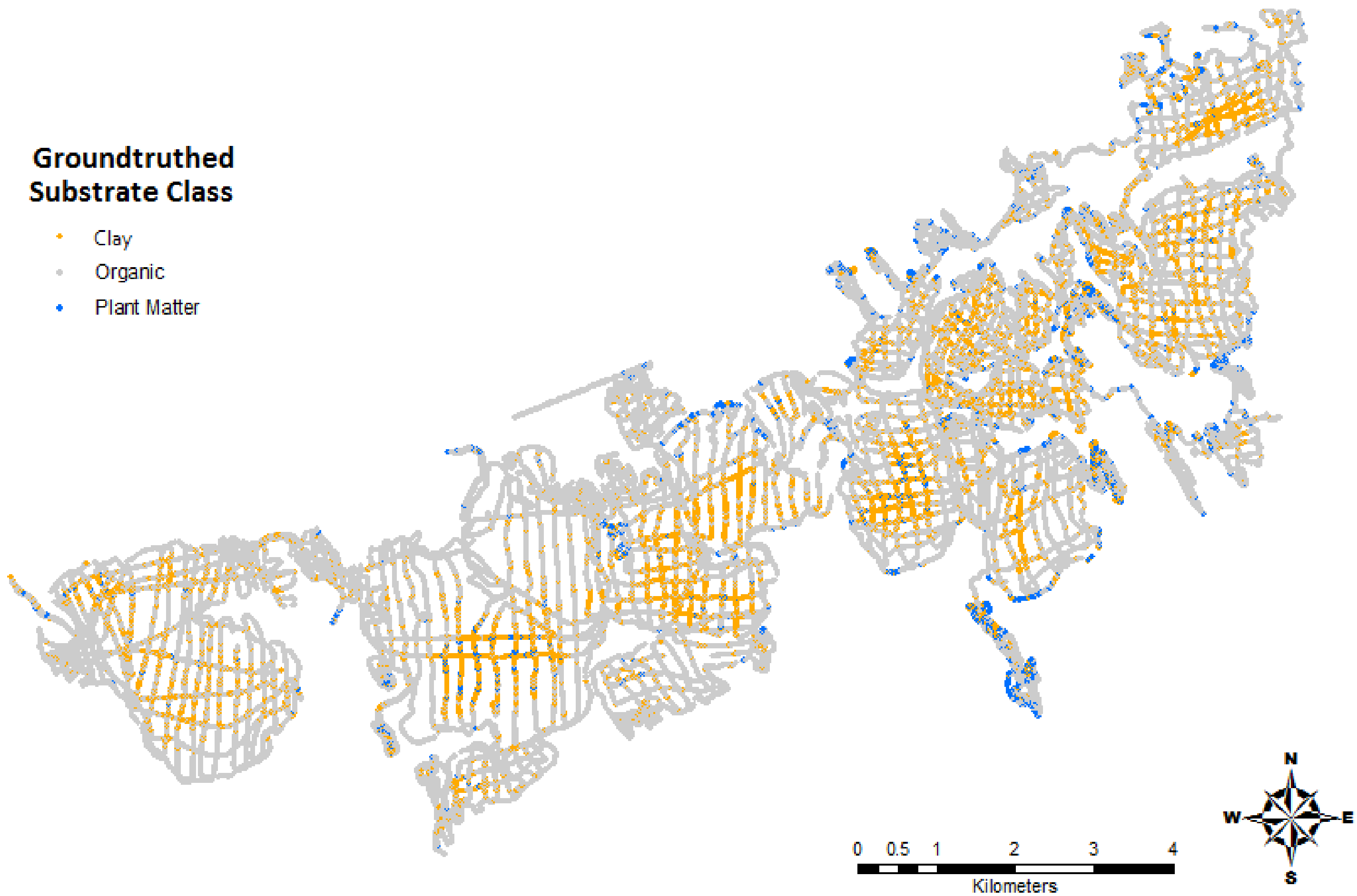


Figure 27. Transition from point data collected by Quester Tangent Corporation (QTC) single beam sonar analysis and QTC IMPACT substrate analysis (A) to an interpolated substrata map as determined by interpolation of QTC data (B) and ground-truthed samples (C) in Cadham Bay, located in the eastern portion of Delta Marsh, Manitoba in 2011.

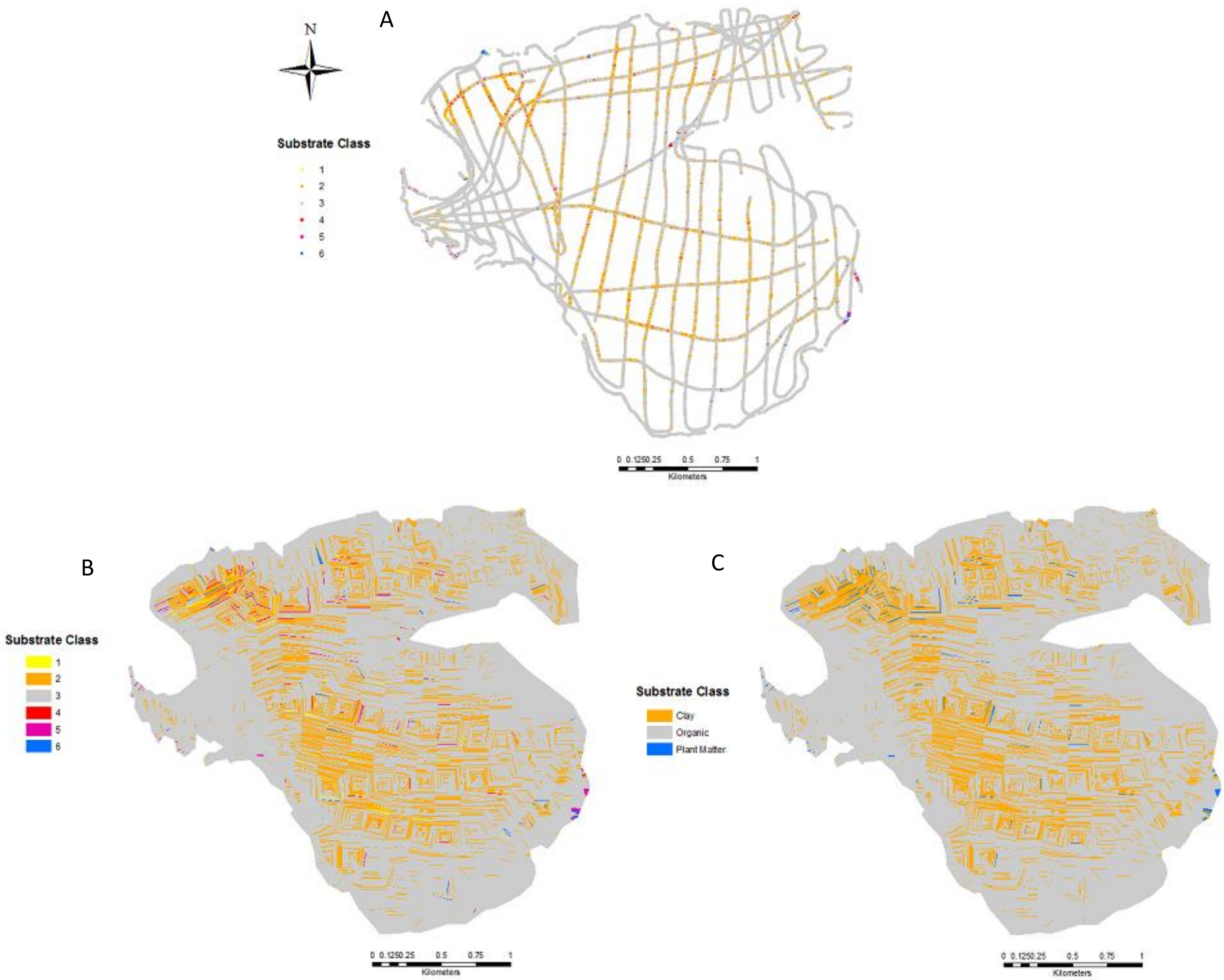


Figure 28. Interpolated distribution of three predominant substratum classes in the eastern portion of Delta Marsh, Manitoba in 2011 as determined by Quester Tangent Corporation (QTC) Impact substrate analysis and examination of ground-truthed samples.

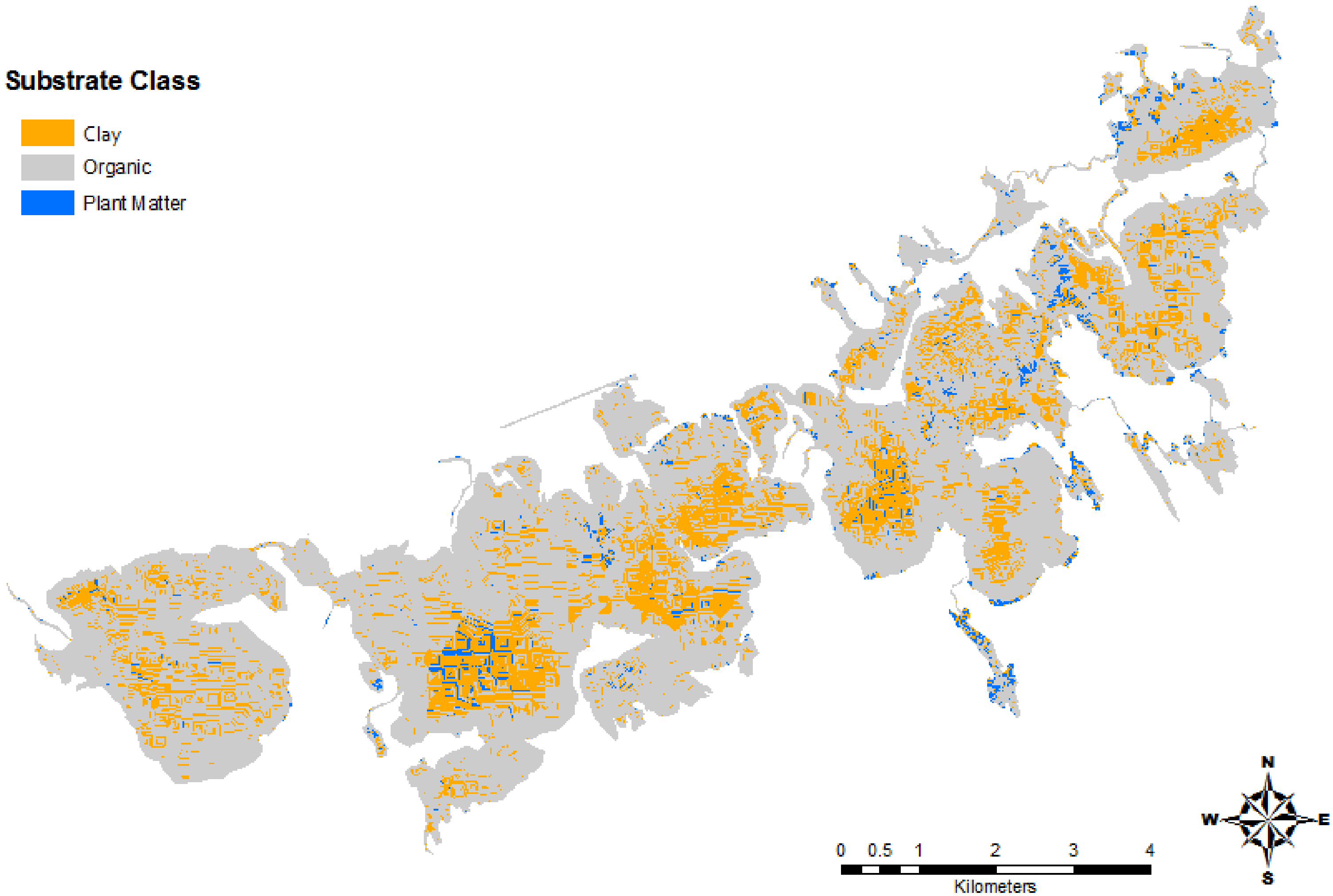


Table 1. Error Matrix calculated for the classified substrata map of the eastern portion of Delta Marsh, Manitoba. Totals on the far right column represent the number of samples that were predicted in each class based on the Quester Tangent Corporation (QTC) IMPACTS substrate analysis, while totals in the bottom row represent the number of samples that were classified within each category after examination of ground-truthed data.

		Ground-Truthed Data				
	Class	**Clay**	**Organic**	**Plant**	**Gravel**	**Total No. of Samples Classified**
Classified Data	**Clay**	**33**	3	0	0	**36**
	Organic	*7*	**16**	0	1	**24**
	Plant	*2*	2	**8**	0	**12**
	Gravel	0	0	0	**0**	**0**
	Total No. of Samples Ground Truthed	**42**	**21**	**8**	**1**	**72**

5.0 – Vegetation Distribution

5.1 – Introduction

Wetland environments can be quite dynamic, changing often with changes in water level. Wetland plants are greatly affected by water level fluctuations as many species have narrow ranges of tolerance to flooding, often distributing themselves in patterns along a depth gradient (Pearsall, 1920; Gleason, 1926; Spence, 1967; Keddy, 1983; Keddy and Ellis, 1985). In Canadian prairie wetlands, changes in water level often occur in the spring after the thaw and during open water months due to fluctuations in precipitation. Monitoring these changes can often be difficult due to large coverage areas and lack of accessibility. Ground surveys can be time-consuming and cover very little of the total area. Aerial photography is an effective alternative; major vegetation zones are identified by eye and grouped together. Although less time-consuming, extensive ground-truthing is still required for verification (Cowardin and Meyers, 1974; Shuman and Ambrose, 2003). Recently, remote sensing methods have become available as a monitoring solution that is accurate and relatively quick (Carter, 1982) and these methods have been used to classify wetland plant communities (Dechka et al., 2002; Everitt et al., 2004; Belluco et al., 2006; Everitt et al., 2008; Sriharan et al., 2008). Processing of remotely sensed imagery involves the separation of vegetation classes based on their spectral signatures over a range of wavelength bands. Each pixel in the image is processed separately. This process may be unsupervised, relying on statistical analyses of the spectral signatures alone, or may be supervised either by visual inspection of the imagery alone or combined with ground-truthing of known vegetation classes (Lillesand et al., 2008). Unsupervised classification is moderately simple, with little work on the user's part, and is relatively common; however, different plant species with similar spectral signatures may be grouped together unintentionally (Everitt et al., 2004). Supervised classification can provide a more accurate result, but it can be much more time-consuming due to the additional step of ground truthing; this is done by identifying plants, usually along a transect, in the real world. As with unsupervised classification, if not all classes are represented accurately, species with similar spectral signatures may be combined. Due to the fact that each pixel in the image is classified separately, areas may be heterogeneous, making a classification map messy and difficult to interpret visually (Thomas et al., 2003; Kelly et al., 2004). Object-based classification can be used in tandem with remote sensing for a more homogenous result. This process groups pixels based on their similarities, such as reflectance values, creating homogenous zones or polygons prior to class analysis. Each polygon is then analyzed by spectral signature and/or ground-truthed data and assigned a single class, which results in a much less convoluted class distribution (Rhyerd and Woodcock, 1996).

The objective of this chapter was to describe the vegetation in the eastern portion of Delta Marsh during 2011, following an extreme flood event, using object-based classification methods based on QuickBird satellite imagery and General Logistics Modeling. These data were then compared to similar data from 2009, a normal water year, to explore the effects of this flood event on macrophyte cover. I expected to observe significant increases in open-water area throughout the marsh and decreases in emergent vegetation due to senescence and decreased growth caused by flooding. Due to its tolerance of flooding and ability to form floating mats I expect that *Typha* would remain the dominant emergent during flooded conditions in the marsh.

5.1.1 - Study Area

The study area consisted of approximately 153 km² of the Delta Marsh, located at the southern end of Lake Manitoba, Manitoba, Canada (Figure 29). Prior to 1961, Delta Marsh experienced a natural wet-dry cycle, which is integral to wetland health and diversity. The development of nearby cropland, recreational space, and summer and year-round homes, has resulted in the need for water-level management. The Fairford River Control Structure (FRCS) began operation in 1961 and has successfully, for the most part, limited the fluctuations within the lake, and the marsh. This stabilization has resulted in the spread of *Typha x glauca* and reduced the diversity of emergent plant species within the marsh (Bossenmeier et al., 1968; de Geus, 1987; Batt, 2000).

Early descriptions of Delta Marsh, prior to water level management, focus on the dominance of common reed, *Phragmites australis* (Hochbaum, 1944; Love and Love, 1954). A comparison of aerial photographs from 1948 until 1980 clearly showed the increasing dominance of *Typha* throughout the marsh (de Geus, 1987). Aerial photographs from 1948, during a low-water period, show dominance by *Phragmites*, with the exception of Clandeboye Bay which was dominated by *Typha*. This low-water period was followed by increasing water levels until a maximum was reached in 1955, after which the coverage of *Typha* within the marsh grew steadily. These high water levels remained until 1960, when overall abundance of emergent vegetation decreased, though the spread of *Typha* continued. Following the construction of the FRCS, water levels began to lower, exposing mudflats that were colonized quickly by *Typha*. Dominance of *Phragmites* continued into the late 1960s, though increased coverage of *Typha* was noted (Bossenmeier et al., 1968). Aerial photography in 1972 showed dominance of *Typha* in all areas of the marsh, with the exception of Centre Marsh, where *Typha* and *Phragmites* were co-dominant; increased cover of *Typha* continued through 1980 where it was considered dominant in all areas of the marsh (de Geus, 1987). Today, Delta Marsh is dominated by monodominant stands of *Typha* which fill in shallow bays and shores. It is likely that, without the reintroduction of a natural wet-dry cycle, marsh diversity will continue to decrease (Batt, 2000). Monitoring these conditions is vital in maintaining the health of the wetland and in developing management strategies for continued health into the future.

5.2 – Materials and Methods

Quickbird satellite imagery, collected on August 29th at 0 – 20° off nadir, was obtained from DigitalGlobe Inc. Imagery consisted of four spectral bands: blue (450 – 520 nm), green (520 – 600 nm), red (630 – 690 nm) and near-infrared (760 – 900 nm) and had a resolution of 0.6 m (Figure 29). Image orthorectification was completed by Ducks Unlimited Canada, as was processing for Object Based Classification (OBC), which was done through the use of Definiens Developer 7®. This process converted the image layer into a series of polygons containing pixels of similar characteristics (Figure 30). Each polygon contained the spectral data of the underlying portion of the satellite imagery. These data were used to calculate values for the Normalized Difference Vegetation Index (NDVI) and the Green Normalized Difference Vegetation Index (GNDVI) values. The NDVI and GNDVI values are a way to determine if live, green vegetation is present; living or photosynthetically active plants absorb a large amount of light in the visible light spectrum or the Photosynthetic Active Radiation (PAR) spectrum. At the same time, these plants reflect a large amount of light in the near-infrared (NIR) spectrum. NDVI and GNDVI values are calculated as follows:

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})} \qquad \text{GNDVI} = \frac{(\text{NIR} - \text{GREEN})}{(\text{NIR} + \text{GREEN})}$$

Values can be either positive or negative, where a negative value indicates low levels of PAR and NIR absorption; this may suggest the presence of dead, vegetation or a general lack of vegetation. Some surfaces, such as water, road and sand substrata result in low positive or even negative values. Different plants may produce statistically different NDVI values based on leaf size, structure and coloration. Forest cover areas will exhibit a high, positive NDVI value due to a dense canopy which absorbs a high proportion of the PAR and reflects a large proportion of the NIR. An area covered by bulrush on the other hand might have a relatively small, though still positive value as the stems are tall and thin, with vertically situated leaves.

Ground-truthing data regarding vegetation distributions was collected concurrently with bathymetric data throughout the summer and fall of 2011. Areas with large monodominant stands of *Typha* and *Phragmites* were recorded as were occurrences of thinned stands in conjunction with flooded conditions. Unfortunately detailed data could not be collected due to time restraints; only regions of *Typha*, *Phragmites*, Common Rush (*Juncus effusus*), Forest and areas with Mixed Vegetation were observed during the bathymetric survey. The locations of these monodominant stands were compared to the satellite imagery to determine the visually identifiable characteristics of each species. Other areas dominated by these species were determined by extrapolating based on the determined visual characteristics on the satellite imagery and polygons in these regions were appropriately labeled to be used a training areas during statistical analysis. Unfortunately I was unable to classify areas containing common rush; due to the thin vertical nature or the stem, lack of leaves and relatively large amounts of water between individual plants they were visually and spectrally indistinguishable from open water areas. Several categories such as roads, buildings, beach and croplands, which are known to be difficult to identify through statistical comparison of spectral signatures, were removed from the layer and identified manually.

Collection of bathymetric data included the creation of an outline of the boundary between open water and vegetated areas; these boundaries were typically located where water depths were measured to be one meter or less. This outline was used to determine the extent of open water for cover class identification purposes

Statistical Analysis Software (SAS) was used to determine the accuracy of the visually distinguished training areas. Several cover classes were removed during this step as they were known, due to the occurrence of similar problems in the vegetation classification of the marsh in previous years, to be difficult to differentiate statistically. These classes included roads, buildings, beach/sand substrata, forest and farm lands including pasture and crop lands. This left me with seven visually identified categories: *Typha*, *Phragmites*, Mixed Vegetation (where the species could not be separated based on ground truthing and visual classification), Flooded *Typha*, Flooded *Phragmites*, Dead Vegetation and Water. General Logistic Models (GLMs) were created for these seven classes through the use of PROC LOGISTIC in SAS software in order to determine the accuracy of the classes. This analysis was based on spectral characteristics within the satellite imagery and included: mean reflectance values in each of the blue, green, red and near-infrared bands, the standard deviation of the reflectance in the four bands, the maximum difference between pixel values within each polygon, brightness (the average of the mean reflectance values in the four bands), NDVI and GNDVI. Each characteristic was evaluated for correlations and highly correlated characteristics (> 90%) were removed in order to reduce redundancies within the statistical analyses which could result in artificially high accuracies. Several iterations of the analysis were carried out including full (all characteristics included), reduced (only uncorrelated characteristics included), forward stepwise and backward stepwise. All models utilized an $\alpha = 0.001$ retention in order to reduce error due to the large size of the data set (>50,000 polygons). The features used during the reduced analysis were mean reflectance in the red and near-infrared bands, maximum difference between pixel values, standard deviation and NDVI. A forward stepwise analysis of the reduced characteristics was chosen, as it provided the greatest accuracy without the possibility of an artificial inflation due to redundancy within the features. The analysis determined the probability of each polygon belonging to its assigned class as well as the probability of belonging to each of the other classes; the class with the highest probability in each polygon was recorded. The accuracy of each class as a whole was calculated through the use of a confusion matrix which compares the number of polygons classified to the number of polygons predicted by the GLM.

Based on the SAS analysis those polygons that were identified as belonging to a different class than initially labelled were reassigned to the appropriate category and polygons that had not been identified based on visual analysis and ground-truthing were assigned their predicted class. These data (along with the manually identified cover classes) were then used in ArcMap to create a classification map of the study area. In order to simplify the map adjacent polygons belonging to the same cover class were combined using the Dissolve tool in ArcMap. The map was then compared to data from 2009 (provided by Ducks Unlimited Canada) to explore the effects of the flood experienced in 2011. As the data collected by the satellite imagery was slightly different for each year, the distribution maps were trimmed so that only overlapping, classified areas were used for comparison.

5.3 – Results

Object-based classification of the satellite imagery resulted in the creation of approximately 73,700 individual polygons. During classification (both manual and statistical) each polygon was assigned to one of the following classes: Water, *Typha*, *Phragmites*, Mixed Vegetation, Flooded *Typha*, Flooded Vegetation, Grass/Pasture, Crop Land, Dead Vegetation, Forest, Beach or Road/Other (including buildings and other structures).

The accuracies of the ground-truthed/visually identified cover classes were relatively high with the exception of the Mixed Vegetation class (Table 2). The Mixed Vegetation class was defined as a vegetated area comprised of a variety of species (in most cases a combination of Cattail, Common Reed and/or Common Rush). It is likely that the distribution of various emergent plant species within the polygons was dissimilar enough to make classification an issue. The pixels within each separate polygon may have been similar enough in characteristic to be grouped together during object-based classification, but polygons within the class as a whole may not be similar enough to be grouped as a single separate class. Unfortunately the relatively low amount of ground-truthing and existence of areas with variable and diverse vegetation were not conducive to more accurate classification. Ground-truthing and analysis of the satellite imagery resulted in the classification of 337 polygons as Mixed Vegetation, however only 161 polygons were predicted to be Mixed Vegetation during statistical analysis. 121 (75.16%) of these polygons had originally been identified as Mixed Vegetation. The remaining polygons had originally been identified as either *Typha* (28), Dead Vegetation (11) or *Phragmites* (1).

The Flooded Vegetation class was defined as a mixed vegetation area with a noticeable amount of thinning due to flood waters. Surprisingly the classification accuracy of this class was relatively high. It is possible that the combination of vegetation and interspersed water resulted in reflectance values intermediate to either open water or fully vegetated areas. Out of the 14,760 polygons originally identified as Flooded Vegetation, statistical analysis indicated that 92% (13,579) had been correctly identified. Those polygons that were statistically identified as other classes included Flooded *Typha* (703), *Typha* (224), Water (251) and *Phragmites* (3). An additional 1,488 polygons were reclassified as belonging to the Flooded Vegetation class during statistical analysis, of which 763 had originally been identified as Flooded *Typha*, 335 as *Typha*, 241 as Water, 144 as *Phragmites* and 5 as Dead Vegetation.

The cover with the highest classification accuracy was Water likely due to the fact that a large portion of open water areas were ground-truthed during collection of bathymetric data. A total of 21,828 polygons were classified as Water due to ground-truthing and examination of satellite imagery. During statistical analysis 98.78% of these polygons were confirmed to represent open water. The remaining polygons were originally identified as Flooded Vegetation (241), Dead Vegetation (12), *Phragmites* (11) and Flooded *Typha* (2). Several polygons that had previously been classified as Flooded Vegetation, *Phragmites* and *Typha* were reclassified to represent open water cover (251, 3 and 2 polygons respectively).

The remainder of the classes had relatively high classification accuracies ranging from 82.56 % (*Phragmites*) to 95.48% (Dead Vegetation). Statistical analysis showed that during ground-truthing dead vegetation was most often misclassified as *Typha* or *Phragmites*, while *Typha* and *Phragmites* were most often misclassified as flooded vegetation, as was the Flooded *Typha* class.

The final classifications as determined by SAS were used to create a vegetation/cover distribution map of the study area (Figure 31). The data provided by the statistical analysis could also be used to determine both the user and producer accuracy of the map. As previously described in Chapter 4, the user's accuracy measures the probability that a classified point on the map matches the conditions in the real world while the producer's accuracy is the probability that a point in the real world is classified correctly on the map. The cover classes with the highest user accuracy were the Water and Dead Vegetation categories at 98.78 and 95.48% respectively. This accuracy represents the percentage of polygons on the map that can be expected to be accurately represented in the real world. Again the high accuracy of the Water class is likely due to large number of polygons in the class as well as the high proportion of ground-truthed points. The lowest user accuracies belonged to the Mixed Vegetation and *Phragmites* categories (35.91 and 82.56% respectively). The likelihood of a Mixed Vegetation polygon on the map being inaccurate in the real world was relatively high; when misclassified these areas were most likely to be found to be either *Phragmites*, *Typha* or Dead Vegetation. *Phragmites*, when misidentified, was most likely to be found to be Flooded Vegetation or Dead Vegetation. The classes with the highest producer accuracy were again Water and Dead Vegetation at 98.83% and 93.50% respectively. This accuracy represents the probability that an area in the real world will be properly represented on the distribution map. The classes with the lowest accuracy were Mixed Vegetation and Flooded *Typha*. An area of Mixed Vegetation in the real world was most likely to be misclassified as either *Typha* or Dead Vegetation on the map, while an area of Flooded *Typha* was most likely to be misidentified as Flooded Vegetation.

Quartile box plots, representing the range of values for each characteristic used in the GLM (mean reflectance in the red and near-infrared bands, maximum difference, standard deviation in the red band and NDVI) visually display the variations within each class (Figure 32).As you can see the range of values displayed by each cover class varies between the measured characteristics. For instance, mean reflectance values between the 1st and 3rd quartile for Water and Flooded *Typha* were relatively similar (Figure 32A) yet values for these same classes in the NDVI were drastically different (Figure 32C). The standard deviation values in the red spectral band between the 1st and 3rd quartiles for *Typha* and Flooded *Typha* were relatively comparable (Figure 32E), yet they were quite disparate when compared based on the maximum difference between pixel values within polygons (Figure 32D). The two flooded classes on the other hand exhibited a large amount of overlap throughout all five measured characteristics, which accounted for the fact that these two classes had relatively low prediction accuracies. If we compare the individual boxplots we can see that the relationships between classes changed when looking at different characteristics. For example, looking at the values falling between the 1st and 3rd quartiles in A we see that the values in the Water class were similar to those in the Flooded *Typha* class while the values in the *Typha* class roughly align with those in the Flooded Veg class. The ranges in the *Phragmites* and Mixed Vegetation classes were close together while the values in Dead Vegetation class were by far the highest. Comparing this to the values in B we see that Water had by far the lowest values while the values in the *Typha* class had shifted closer to those seen in the Mixed Vegetation and *Phragmites* classes. The Dead Vegetation class continued to have the highest values while the range of values within the Flooded *Typha* class sat within the range for the Flooded Vegetation class. The variations between classes seen in each of the box plots contributed to correctly identifying the polygon classes within the cover distribution map.

The completed map from 2011 was then compared to a similar study from 2009 (Figure 33). It is clear from a quick view of the two distribution maps that the coverage of open water increased drastically from 2009 (63.83 km²) to 2011 (99.55 km²) (Table 3). Due to reduced vegetation cover caused by decreased growth and senescence as well as a reduced ability to ground-truth in 2011, not all coverage classes described in the 2009 study could be found in 2011, most noticeably the *Carex* and Whitetop vegetation classes. Similarly, due to normal water conditions, no classes for flooded vegetation or dead vegetation were described in 2009. In order to more directly compare distributions between the two years a condensed list of classes was created by amalgamating several classes into more ambiguous categories (Table 4). All live vegetation classes (with the exception of Forest) decreased in 2011. Emergent vegetation cover (including *Carex*, Whitetop, *Typha* and *Phragmites*) decreased significantly from 52.09 km² in

2009 to 7.82 km² in 2011. Even when the Flooded and Emergent Vegetation categories are combined they only accounted for 67.46% of the emergent vegetation described in 2009. Grass and Pasture Land decreased by 53.32% from 22.6 km² in 2009 to 10.55 km² in 2011. Similarly Crop Land decreased from 9.27 km² to 0.64 km², a reduction of 93.10%. As shown in Chapter 3. Much of the crop and pasture land located south of the marsh possessed a shallow slope which resulted in a large portion of the area becoming flooded as waters in the lake and marsh rose. Beach cover, mainly located along the northern southern edge of Lake Manitoba along the northern edge of the beach ridge, decreased by 62.50% (from 0.16 km² to 0.06 km²). Road cover (which also included buildings and other structures) was also reduced from 0.21 km² to 0.11 km² (a decrease of 47.62%).

The rise in water levels also resulted in the senescence of large areas of vegetation. This can be seen with the inclusion of a Dead Vegetation class in the 2011 data. As seen in Figure 32 A and B, reflectance in these areas was quite high, making classification straightforward, which was corroborated with the results of the class's user and producer accuracy.

The only cover class represented in both 2009 and 2011 which experienced an increase in coverage was the Forest category. Forested regions included the beach ridge along the southern edge of the lake and areas within the crop lands in the eastern and central southern portions of the study area. The tree coverage within the eastern portion of the study area was much more extensive in 2011 than in 2009. Though some growth of these forested areas is possible, it is likely that some of the variation is due to the fact that this area was classified visually (this class was removed from statistical analysis).

5.4 – Discussion

The most inaccurate coverage class was, not surprisingly, the Mixed Vegetation class. Due to the fact that polygons classified as such contained multiple species of emergent vegetation, the low accuracy of this class is predictable. Unfortunately, time constraints did not allow for thorough ground-truthing of the study area and data collected during QTC analysis relied heavily upon for identification of the main coverage classes. Any future studies would benefit from a more rigorous ground-truthing process based on the examination of multiple transect through varied vegetation within the marsh. This would likely result in a much more accurate map. The 2009 study also found that the accuracy of classes was drastically decreased when multiple species were found within a polygon (Baschuk 2011). I was unable to identify any areas containing sedges (*Carex)* or Whitetop, which were found in the 2009 study. However, the majority of areas in which these plants were found in 2009 became flooded in 2011 (Figure 33), which may have prevented them from growing. Additionally, C*arex spp.* covered a very small area (approximately 2 m² - much less than 1% of the total study area) and would therefore not greatly affect the study had it been missed. The 2009 study showed that Whitetop was misidentified more than 50% of the time (as either Grass/Pasture or *Phragmites*) and likely would have been classified into another category had they been found present in the 2011 survey.

Although the Mixed Vegetation class exhibits a relatively low accuracy, the flooded vegetation class was found to be much more precise. Areas with flooded vegetation consisted of sparse vegetation combined with open water so the spectral signature was likely quite unique. The mean reflectance of Flooded *Typha* and Flooded Vegetation in the NIR band (B) was much different than for the other classes (Figure 32). The two flooded classes do, however, have quite a bit of overlap, which explains why Flooded Vegetation was often misidentified as Flooded *Typha* and vice versa (Table 2). Although it appears that *Typha* has remained the dominant emergent, despite its decline, this is difficult to verify due to the ambiguity Mixed and Flooded Vegetation classes. Many areas around the edges of bays were observed, both during ground truthing and in the satellite imagery, to have dense stands of *Typha,* backed by flooded areas or thinned and dead vegetation. Based on the topography of the area we can postulate that these edge areas are likely deeper than the flooded zones behind them; it is possible that these *Typha* stands survived as floating mats.

The Water class, being heavily surveyed during the bathymetric analysis of the study area, was quite accurate both in user and producer accuracy. The unique spectral signature of the class also contributed to accurate classification. The water class was separated from the other classes in mean reflectance in the NIR band, the NDVI and the standard deviation of reflectance in the red band (Figure 32). Similar results were found in the 2009 study, Water having an accuracy of over 99% (Baschuk, 2011).

Based on the data obtained from the bathymetric analysis of the study area, I expected that the amount of open water would increase drastically. The area south of the marsh consisted of gradually sloping crop and pasture lands which would be greatly affected by increasing water levels. This expectation was corroborated by the satellite imagery, which showed considerably increased open water coverage as compared to data from 2009, as well as by the statistical analysis of the satellite imagery which shows an increase in open water by approximately 56% during 2011. I expected that cover of emergent vegetation would decrease and senesce due to the increased water levels. This was demonstrated by the large area covered by the Dead Vegetation class as well as the decreased coverage areas for Crop Land, Grasses and Emergent Vegetation. This data agreed with previous studies which found that increased water levels resulted in the decline of emergent species and increases in open water areas (Grace and Wetzel, 1982; Bukata et al., 1988; Wallsten and Forsgren, 1989; Squires and van der Valk, 1992; van der Valk, 1994)

Typha spp. have spread throughout the marsh over the past several decades, and but decreased significantly in coverage area between 2009 and 2011 (33.37 km^2 versus 6.56 km^2, respectively). This shows that, in accordance with previous studies, water level manipulation is a successful management strategy for the invasive cattail although dramatic increases in water depth, as seen in the study site in 2011, or prolonged periods of less intense flooding would be required for efficacy (Mallik, 1986; Ball, 1990). It may be that a more controlled flooding regime on Lake Manitoba could prevent the spread of invasive cattail and the subsequent decline in species diversity that has been seen in the marsh since the construction of the Fairford River Control Structure and the ensuing stabilization of water levels in the marsh.

Figure 29. Quickbird satellite imagery of the vegetation study area in the eastern portion of Delta Marsh, Manitoba obtained from DigitalGlobe Inc. on August 29th, 2011.

Figure 30. Vegetation study area in the eastern portion of Delta Marsh, Manitoba. Object-based classification – grouping of similar pixels within satellite imagery – was used to create polygons of homogenous cover zones.

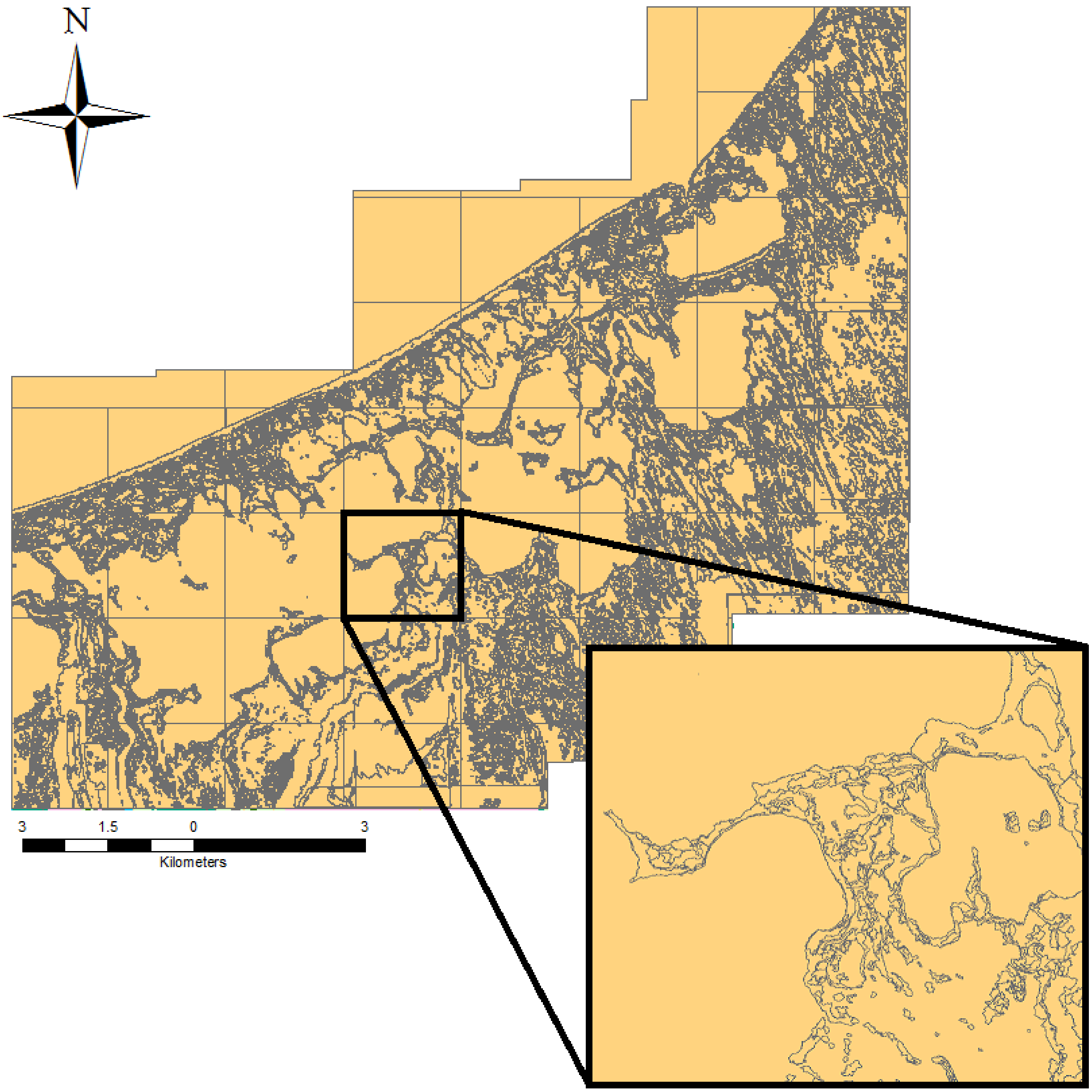


Table 2. Error Matrix calculated for the classified vegetation map of the eastern portion of Delta Marsh, Manitoba. Totals on the far right column represent the number of samples that were classified within each category after examination of ground-truthed data and satellite imagery, while totals in the bottom row represent the number of polygons that were predicted in each class based on analysis of spectral signatures.

		Predicted Cover Type							Total No. of Polygons Observed	User Accuracy (%)
		Dead	**Flooded *Typha***	**Flooded Veg**	**Mixed Veg**	***Phragmites***	***Typha***	**Water**		
Observed Cover Type	**Dead**	**3383**	0	5	11	55	87	2	**3543**	**95.48**
	Flooded *Typha*	0	**4615**	763	0	0	93	0	**5471**	**84.35**
	Flooded Veg	0	703	**13579**	0	3	224	251	**14760**	**92.00**
	Mixed Veg	64	0	0	**121**	60	92	0	**337**	**35.91**
	Phragmites	98	0	144	1	**1188**	5	3	**1439**	**82.56**
	Typha	61	0	335	28	18	**4650**	0	**5092**	**91.32**
	Water	12	2	241	0	11	0	**21562**	**21828**	**98.78**
Total No. of Polygons Predicted		**3618**	**5320**	**15067**	**161**	**1335**	**5151**	**21818**	**52470**	
Producer Accuracy (%)		**93.50**	**86.75**	**90.12**	**75.16**	**88.99**	**90.27**	**98.83**		

Figure 31. Distribution of cover classes in the eastern portion of Delta Marsh, Manitoba as determined by statistical analysis of ground-truthed and visually extrapolated cover areas within Quickbird satellite imagery obtained from DigitalGlobe Inc. on August 29, 2011.

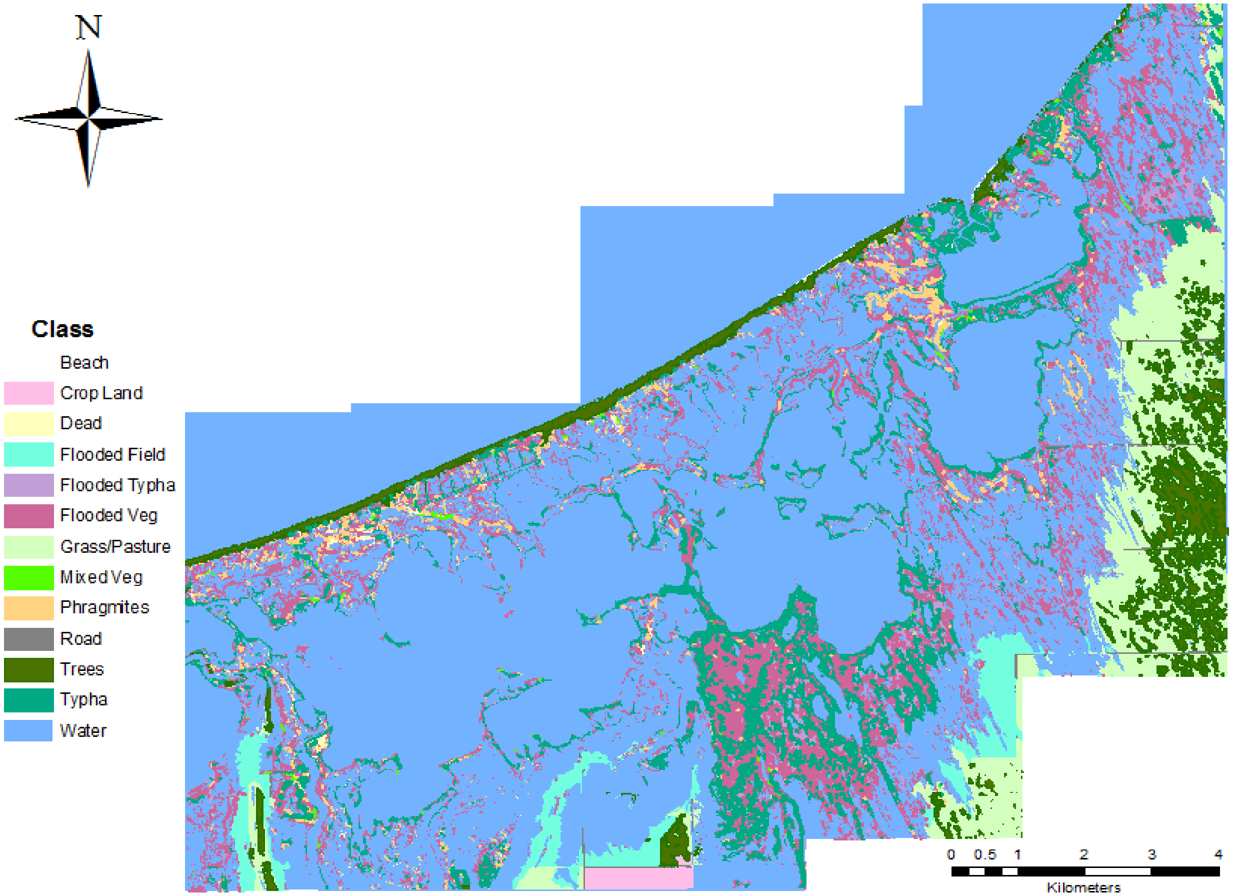


Figure 32. Box plots displaying the range of values displayed by dominant cover classes in the eastern portion of Delta Marsh, Manitoba based on **A.** Mean reflectance in the red spectral band (630 – 690 nm) **B.** Mean reflectance in the near-infrared (NIR) spectral band (760 – 900 nm) **C.** Normalized Difference Vegetation Index (NDVI) **D.** Maximum difference between two pixels of a classified polygon and **E.** Standard deviation in the red spectral band (630 – 690 nm).

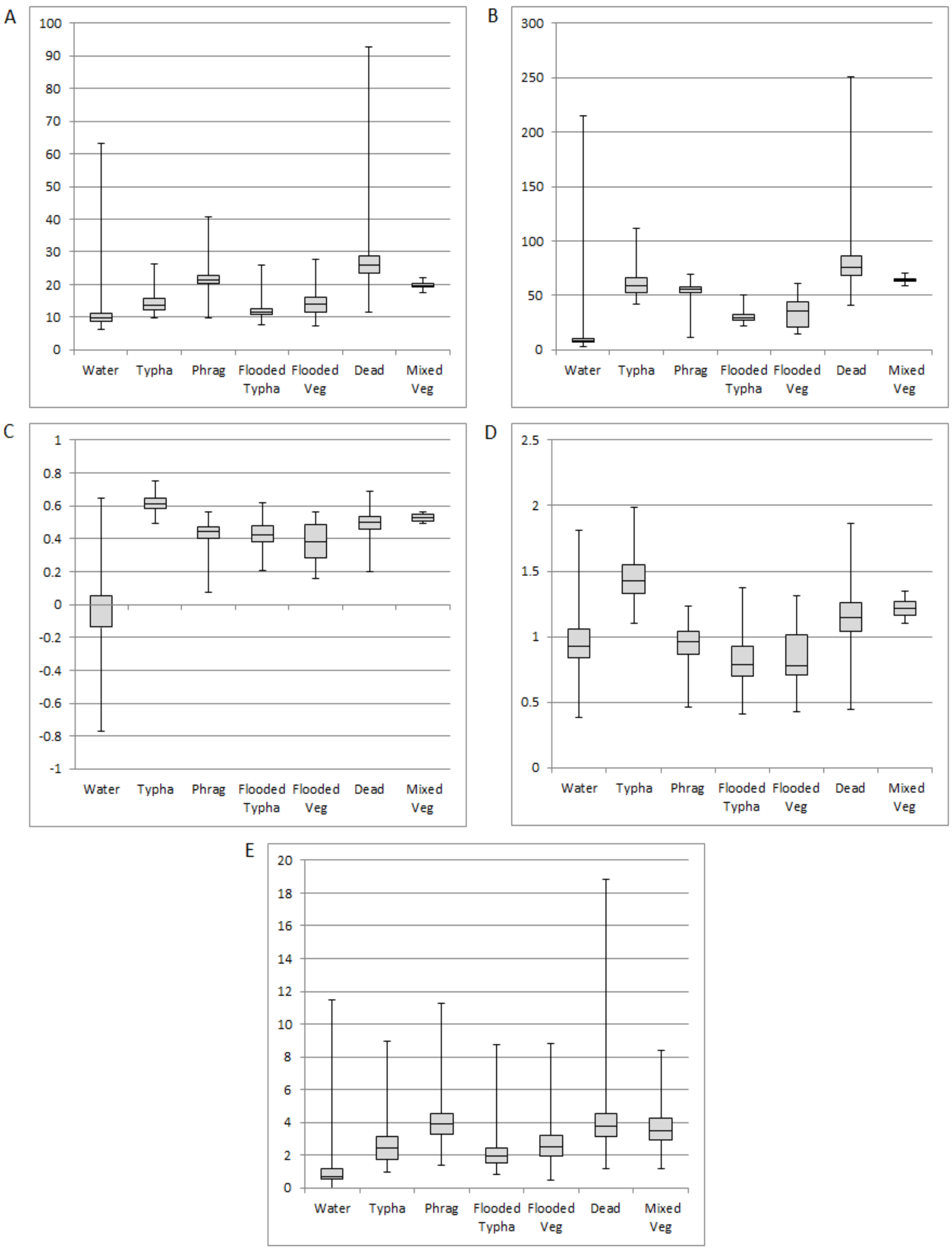


Figure 33. Comparison of cover distributions in the eastern portion of Delta Marsh, Manitoba in 2009 and 2011 as determined by statistical analysis of ground-truthing and visually extrapolated data from Quickbird satellite imagery.

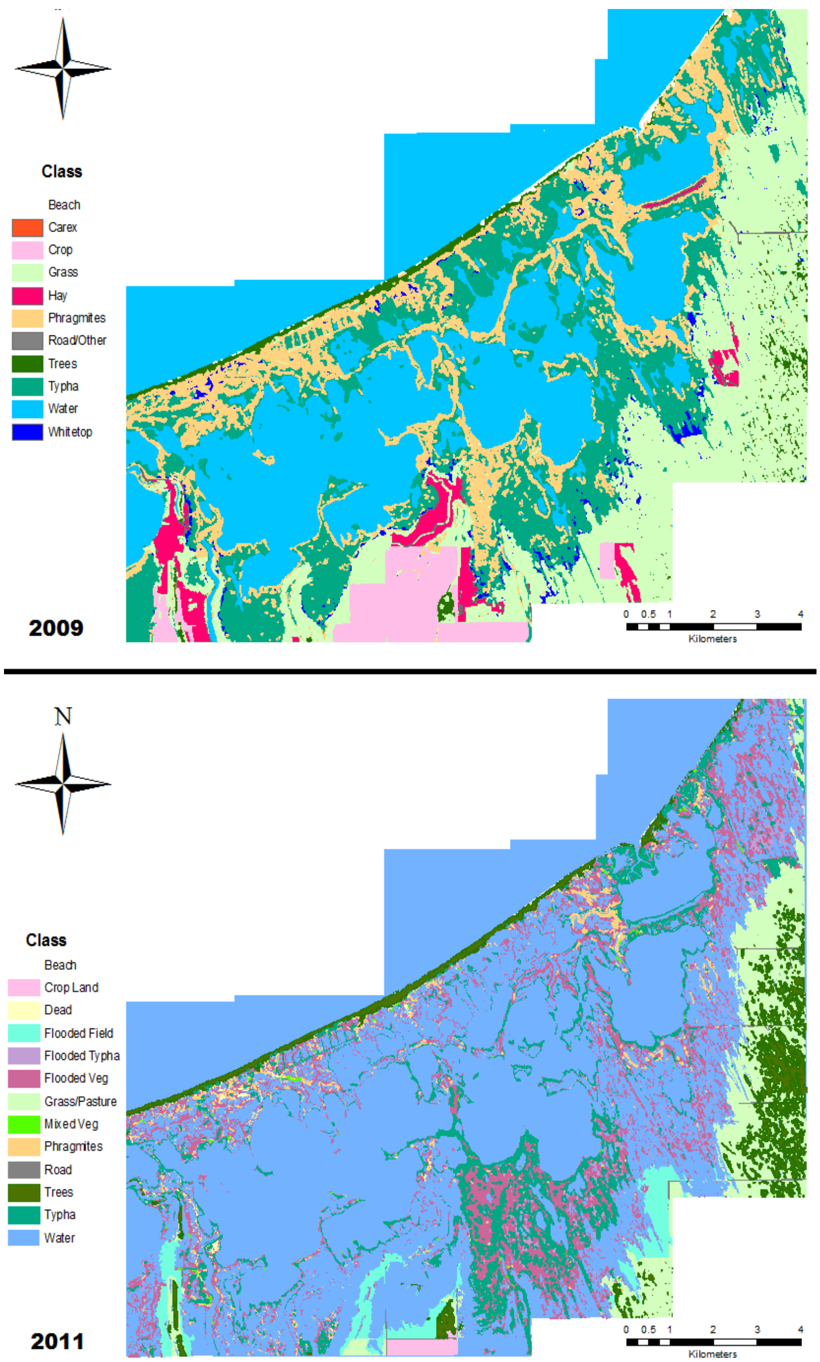


Table 3. Coverage areas of cover classes within the eastern portion of Delta Marsh, Manitoba in 2009 and 2011 as determined by Quickbird satellite imagery.

Class	**Area (km2)**	
	2009	**2011**
Beach	0.16	0.06
Carex	0.00	-
Crop	5.24	0.64
Dead Vegetation	-	2.10
Flooded Field	-	3.63
Flooded *Typha*	-	6.61
Flooded Vegetation	-	17.08
Grass	22.60	10.55
Hay	4.03	-
Mixed Vegetation	-	0.17
Phragmites	11.79	1.09
Road/Other	0.21	0.11
Forest	4.68	5.02
Typha	33.37	6.56
Water	63.83	99.55
Whitetop	6.92	-
Total	152.85	153.16

Table 4. Coverage areas of condensed cover classes in the eastern portion of Delta Marsh, Manitoba in 2009 and 2011 as determined by Quickbird satellite imagery

Class	**Area (km2)**	
	2009	**2011**
Beach	0.16	0.06
Crop	9.27	0.64
Dead Vegetation	0.00	2.10
Grasses	22.60	10.55
Flooded Vegetation	0.00	27.32
Emergent Vegetation	52.09	7.82
Road/Other	0.21	0.11
Forest	4.68	5.02
Water	63.83	99.55
Total	152.85	153.16

6.0 - Seed Bank Analysis

6.1 - Introduction

The composition and distribution of emergent species in the vegetation communities within wetlands rely on many factors including available resources, seed dispersal, and environmental conditions. Plants are often distributed along a water depth or soil saturation gradient, each species having a distinct range of tolerances to flooding and changes in water level may result in the redistribution of species based on this factor (Pearsall, 1920; Gleason, 1926; Spence, 1967; Keddy, 1983; Keddy and Ellis, 1985; Welling et al., 1988). Flood conditions may result in the senescence of many species while drought conditions may result in the exposure of mud flats and the germination of seeds within the soil, or seed bank. The composition of a wetland's seed bank, then, is largely responsible for the diversity of plants germinating following a decrease in water level and can often predict the vegetation that will develop during these conditions (van der Valk and Davis, 1978; Pederson, 1981).

A seed bank can be described as a reserve of seeds from a variety of plants, which remain dormant, but viable, in the soil until the proper conditions for germination arise (Roberts, 1981). Seeds may have a limited amount of time during which they remain viable. Two common methods of seed bank composition analysis include seedling emergence and seed extraction. Seed emergence involves the collection of soil samples, which are spread out, either alone or over sterilized soil. Germinating seeds are allowed to grow to maturity and identified (Keddy and Reznicek, 1982; Leck and Simpson, 1987; McGraw, 1987; Ungar and Woodell, 1993; Gurnell et al., 2007). Seed extraction involves the separation of seeds from the soil. Separation may be carried out by rinsing or sieving of the samples or by flotation (seeds in a salt solution will float, while sediments will sink) (Malone, 1967; Roberts, 1981; Gross, 1990; Bernhardt et al., 2008). The seed emergence method tends to underestimate the density of seeds within the seed bank and may underestimate the number of species depending on the germination requirements of each unique species and the range of environmental conditions explored (Brown, 1992,; Casanova and Brock, 2000; Bernhardt et al., 2008). The seed extraction technique is much more accurate in estimations of density and species number, but does not provide data on the viability of seeds (Brown, 1992).

Although the composition of the seed bank can be indicative of the current plant community (Leck and Graveline, 1979; Parker and Leck, 1985; Leck and Simpson, 1987), it may also represent plants which are no longer, or never were, found in the area (Wilson et al., 1993; Leck and Simpson, 1995; Brown, 1998). This may be the case where particularly competitive species displace others, such as when an invasive species creates a monodominant stand. *Typha x glauca* is widespread in Delta Marsh and has decreased species diversity in the area (de Geus, 1987; Batt, 2000). In instances of stable environmental conditions, especially stable water levels, species diversity tends to decrease (van der Valk and Davis, 1978). It is known that *T. x glauca* spreads relatively quickly and outcompetes many other emergent wetland species in stable conditions (Wilcox et al., 1985; Shay et al., 1999; Wilcox et al., 2007), such as those seen in Delta Marsh. In situations such as this, when disturbance is uncommon, drawdown and germination through the seed bank may result in renewed diversity through reintroduction of native species (van der Valk and Davis, 1978).

In 1981 (Pederson), a study of the seed bank in the Delta Marsh found that the seed bank was dominated by Softstem Bulrush (*Scirpus validus* Vahl.), Cattail (*Typha* spp.), Red Goosefoot (*Chenopodium rubrum*), and Sago Pondweed (*Potamogeton pectinatus* Linnaeus). Soil samples exposed to drawdown conditions were dominated by Bulrush, Cattail, and Goosefoot whereas samples exposed to flooded conditions were dominated by Bulrush, Pondweed, and Cattail. A total of 34 species germinated in the drawdown treatments whereas only 18 species germinated in the flooded treatment (2-3 cm of water above the soil surface). With the exception of Sago Pondweed and Common Bladderwort (*Utricularia vulgaris* Linnaeus), both submergent species, the numbers of germinating seedlings was much lower in flooding treatments than in drawdown treatments. Samples taken from large bays within the marsh contained far less germinating seeds than those from open water areas in the Marsh Ecology Research Program (MERP) cells (93/m^2 compared to 850/m^2) (Pederson, 1981). The germination requirements of different species can be specific and often a mere two or three cm of water can make a large difference in germination success (van der Valk and Davis, 1978; Pederson, 1981).

My objective was to determine what species were present in the seed bank of shallow water and exposed soils in the eastern portion of Delta Marsh. With the high water levels experienced in 2011, I expected that retreating waters would expose large open soil areas in the future, which would result in the germination of seeds from the seed bank. Many areas now dominated by monodominant stands of *Typha spp.* and *Phragmites australis* may become more diverse during these drawdown conditions. Based on the current and historic dominance of *Typha* within the marsh (de Geus, 1987; Shay et al., 1999; Batt, 2000) I expected that the seed bank would also be dominated by *Typha* spp. but that a wider variety of plants would be present. Based on the relatively unique ability of *Typha* to germinate in flooded conditions I expected the flooded treatments, to have relatively low species richness.

6.2 – Materials and Methods

During July of 2011, ten soil samples were collected from the eastern portion of Delta Marsh (Figure 44). Samples were collected in 1.2 to 2.6 meters of water. The sample site was reached by boat and samples were collected using a sediment corer attached to a meter long pole with handles for leverage and rotation. The corer measured approximately 8” in diameter and 15” deep with a mouth equipped with sawing teeth to cut through vegetation within the soil. The corer was inserted to the soil/vegetation surface, where it was rotated back and forth to ensure all vegetation within the sample was cut until the top of the corer was level with the soil surface. The sample was extruded and passed into the boat where it was bagged and labeled. Samples were brought back to the lab and refrigerated for approximately one month until greenhouse space became available.

Samples were rinsed through a 500 µm sieve to remove plant material and other debris in the soil. Large pieces of vegetation were removed manually and rinsed thoroughly to retain any soil materials. Samples were air dried and stirred thoroughly, then separated into three equal portions, each to undergo a unique emergence treatment: moist soil, saturated soil, and flooded soil conditions. One of the ten samples was discarded during processing as it was contaminated by another sample. Each sample was spread out over approximately 2 cm of sterilized potting soil.

Treatments were carried out in a greenhouse on a flooding table with a water depth of 5 cm. Moist and saturated soil treatments were carried out in 25 x 50 cm potting trays. Trays were filled with 375 ml of sterilized potting soil and samples were spread evenly on top. Holes were punched near the bottom of the trays on all sides to allow for water movement. Saturated trays were placed directly on the bottom of the flooding table, while moist trays were elevated by 2 cm (Figure 35). The flooding table was refilled daily to maintain the desired water level. Flooded treatments were placed in plastic containers measuring 34 cm x 43 cm and 13 cm deep to accommodate a higher water level than the flooding table could support (Figure 35). Containers were filled on an as-needed basis to maintain water levels at approximately 5 cm above the soil. One control sample was created for each treatment containing only sterilized soil.

Treatments were observed daily at the beginning of the experiment to watch for germinating seeds. Seedlings were allowed to grow until they flowered, when they were removed to create space for further germination. Flowering plants were photographed and dried in a plant press prior to identification. Plants were identified to genus, or species when possible, using Scoggan (1957). The majority of plants grew to a mature state and flowered, though no flowering occurred in *Typha*. In an attempt to encourage further growth, *Typha* plants were transplanted into pots measuring 7 inches in diameter with a depth of 8 inches. No more than five individuals were placed in one pot. The pots were then placed in deep plastic containers on the floor of the greenhouse and filled with water to 3 inches above the soil surface. Containers were filled on an as-needed basis to maintain this water level. *Typha* individuals did grow much larger but would not flower and the experiment was discontinued.

6.3 – Results

Typha was the dominant plant throughout all moisture treatments, being found in 25 out of 30 samples: 70% of flooded treatments, 90% of saturated treatments, and 90% of moist treatments (Table 5). The remainder of saturated and moist treatments lacking *Typha* were control samples not expected to contain this species. The saturated control sample did, however, contain dock (*Rumex* sp.) (Figure 36) Longstyle Rush (*Juncus longistylis* Torr.) (Figure 37) and an unidentified grass (Figure 38), while the moist control samples contained Wild Mustard (*Sinapsis arvensis* Linnaeus) (Figure 39) and a second species of grass (Figure 40). Flooded samples without *Typha* did not contain any other species and the flooded control sample exhibited no growth at all.

Commonly found species within the moist treatments included Red Goosefoot (*Chenopodium rubrum*) (Figure 41), Dock, and Celery-leaved Buttercup (*Ranunculus scleratus* L.) (Figure 42), appearing in 50% of samples. Wild mustard was less common, in 20% of samples, while Rough Bugleweed (*Lycopus asper* Greene) (Figure 43), Wild Mint (*Mentha canadensis* L.) (Figure 44), Dwarf Raspberry (*Rubus pubescens* Raf.), Salt Marsh Bulrush (*Scirpus paludosus*) (Figure 45) and Common Reed (*Phragmites australis*) were least common, occurring in 10% of samples. Two unidentified species of grass (Figures 38 and 40) also appeared in 10% of moist treatment samples. A total of 12 species were identified within this treatment with an average of 3.3 species per sample.

Commonly found species in the saturated treatments included Dock (60% of samples), Red Goosefoot and Common Reed (30% of samples). Longstyle Rush was also relatively common, appearing in 30% of samples. This treatment also produced Rough Bugleweed (20% of samples), Wild Mint, Canada Thistle (*Cirsium arvense* L.), Northern Willowherb (*Epilobium ciliatum* Raf.) (Figure 46), Rayless Annual Aster (*Symphotrichium ciliatum* Ledeb.) (Figure 47) as well as an unidentified grass (10% of samples). A total of 12 species were also identified within this treatment with an average of 3.8 species per samples. Compared to the moist soil treatment, the saturated soil treatment lacked one of the three species of rush as well as Wild Mustard and produced two species (Canada Thistle and Northern Willowherb*)* which the moist soil treatment did not.

Species richness within the flooded treatments was lower than in either the moist or saturated soil treatments, producing only four unique species with an average of 0.9 species per sample. Two floating leaves species, Common Duckweed (*Lemna minor* L.) (Figure 48) and Star Duckweed (*Lemna trisulca* L.) (Figure 49) were found, as well as one submergent species, Common Bladderwort (*Utricularia vulgaris* L.) (Figure 50). Common Duckweed was the most frequently found of these three species, appearing in 20% of samples, while Star Duckweed and Common Bladderwort appeared in only 10%.

Although at the time of sampling all sites were located in flooded areas all samples were separated into either onshore or offshore locations based on normal water level conditions. The majority of plant species observed in the emergence study were isolated to onshore sites (dry in a normal water year, but found in up to 1.4 m of water at the time of sampling). These species included the submergent macrophyte Bladderwort, the floating leaved species Star and Common Duckweed, the emergent species Salt Marsh Bulrush, Longstyle Rush, Common Reed and cattail and other common wetland species including Rough Bugleweed, Wild Mint, Wild Mustard, Dwarf Raspberry, Rayless Annual Aster, Canada Thistle and Northern Willowherb. All species found within the offshore sites (flooded in a normal water year and in 2.0 to 2.7 m of water at the time of sampling) were also found at the onshore sites. These species included Red Goosefoot, Celery-leaved Buttercup, Common Reed and dock. There did not seem to be any patterns in the distribution of species based on location, either from east to west or from north to south, within the marsh.

6.4 – Discussion

The majority of species observed in this emergence study were either emergent species (*Typha*, Common Reed, Longstyle Rush and Salt Marsh Bulrush) or more terrestrial species that are commonly found in wetlands (Wild Mint, Canada Thistle, Rough Bugleweed etc.). As expected *Typha* was the most dominant species, being found in 93% of the samples throughout all three of the emergence experiments. I was surprised, however that *Phragmites*, being a relatively prominent emergent species throughout the marsh, was not found more often. Most of the species observed in the experiments were known to grow in the Delta area. Although *Juncus spp.* and *Scirpus spp.* are very common, Longstyle Rush and Salt Marsh Bulrush have not generally been found in the area (Shay, 1999). Although I did not expect to find any plants in the control samples I did in fact observe the growth of three species in the saturated control and two species in the moist control. I observed dock, Longstyle Rush and an unidentified grass in the saturated control sample. Both dock and rush were found in field samples; dock being relatively common throughout both saturated and moist experiments, while Longstyle Rush was only found in one other saturated sample. The unidentified grass however was not found in any of the other samples. I observed a second unknown grass as well as Wild Mustard in the moist control sample, both of which were found in one other sample; the grass being found in a saturated treatment and the mustard being found in another moist treatment. It is possible that the sterilized soil that was used in these experiments was not completely sterilized, resulting in the growth of these particular species in both the control and field samples or that the control samples somehow became contaminated by the field samples.

A similar study, using moist and flooded emergence treatments (Ger Boedeltje, 2002), found that Celery-Leaved Buttercup exhibited greater germination success in moist soils than in soils flooded by only 2 – 3 cm of water while *Phragmites* and Dock exhibited no germination in flooded conditions and *Typha spp.* germinated equally well in moist and flooded treatments. We found quite similar results in our study with Celery-Leaved Buttercup, Dock and *Phragmites* germinating in moist and saturated conditions and *Typha* germinating in moist, saturated and flooded treatments.

Although a wide variety of species, including submergent, floating leaved, emergent and terrestrial species, were found in my study, historically a much greater diversity has been found in the Delta Marsh area. A study of the Delta Marsh in 1959/60 (Walker, 1965) found a wide variety of species present following a drawdown, including several species found in this study (Table 6). Whitetop was common in shallow water (5 cm deep), while Goosefoot was common on waterlogged soils and in newly dried areas. *Typha* was also associated with waterlogged soils while Dock was common in drier areas.

A 1981 (Pederson) laboratory study found the seed bank of Delta Marsh to be dominated by bulrush, cattail and goosefoot with a large variety of other plants, 34 other species in total, being much less common. The number of species observed within this study was found to be much lower though many of the species found in my study coincided with those found in 1981 (Table 6). This is likely due to the fact that the 1981 study looked at a large number of samples (250 in total) which increased the probability of acquiring a large variety of species (Pederson 1981).

A 1986 field study in Delta Marsh found that on newly exposed mudflats the dominant annual species were Spear Saltbush (*Atriplex patula* L.), Red Goosefoot and Rayless Annual Aster (Galitano and van der Valk, 1986). Both Red Goosefoot and Rayless Annual Aster were found in the current study although Spear Saltbush was not. This may simply be due to the small number of samples taken. A 1988 (Welling et al.) study at Delta Marsh found that the dominant emergent species, both in the seedbank and germinating on exposed mudflats, were Great Bulrush (*Scirpus lacustris* Linnaeus), Cattail, Common Reed, Common Rivergrass (*Scolochloa festucea* Willdenow) and Wheat Sedge (*Carex atherodes*). Cattail and common reed were both found in the current study and it is likely that one of the unidentified grasses (Figure 40) was Common Rivergrass. This species is known to be common throughout the Delta Marsh area (van der Valk, 1986; Shay, 1999). Although *Scirpus lacustris* was not found, a closely related species, *Scirpus paludosus*, was. Pederson found both of these species in his 1981 study (Table 6). It should be noted however, that both the 1986 and 1988 study were focused on a few dominant plants and did not look into the seed bank as a whole.

As described in the aforementioned studies, drawdowns, and the resultant exposure of mudflat areas, often result in the emergence of a wide variety of species. Areas such as Delta Marsh, which are dominated by a few aggressive emergent species, benefit from fluctuating water conditions that result in the exposure of mudflats. Since the construction of the Fairford River Control Structure on Lake Manitoba in 1961, water levels in Delta Marsh have been relatively stable, which is not conducive to these types of disturbance. Reintroduction of water level fluctuations in the marsh may result in the reestablishment of once-common species. This study suggests that, given the opportunity (uncovered, newly exposed soil in a variety of saturation levels), plants that are now uncommon in the marsh may re-emerge. A larger study, covering a wider variety of sites and saturation treatments may produce more species than seen in the current study, which would be helpful in the creation of management strategies should a varying water regime be introduced to the marsh. A study similar to that carried out in 1981 would be very interesting. Seeds are only viable in the seed bank for a limited amount of time and viability changes from species to species (Conn and Werdin-Pfisterer, 2010). Delta Marsh has been dominated by a select few species in recent years so it may be that diversity of viable seeds within the seed bank has decreased since the last extensive survey in 1981. Although this study did observe fewer species than found in 1981, as previously mentioned this may simply due to the discrepancies between sample sizes.

Figure 34. Locations of ten seed bank samples taken from the eastern portion of Delta Marsh Manitoba in July 2011. Basemap obtained from the Manitoba Land Initiative (MLI) website http://mli2.gov.mb.ca/

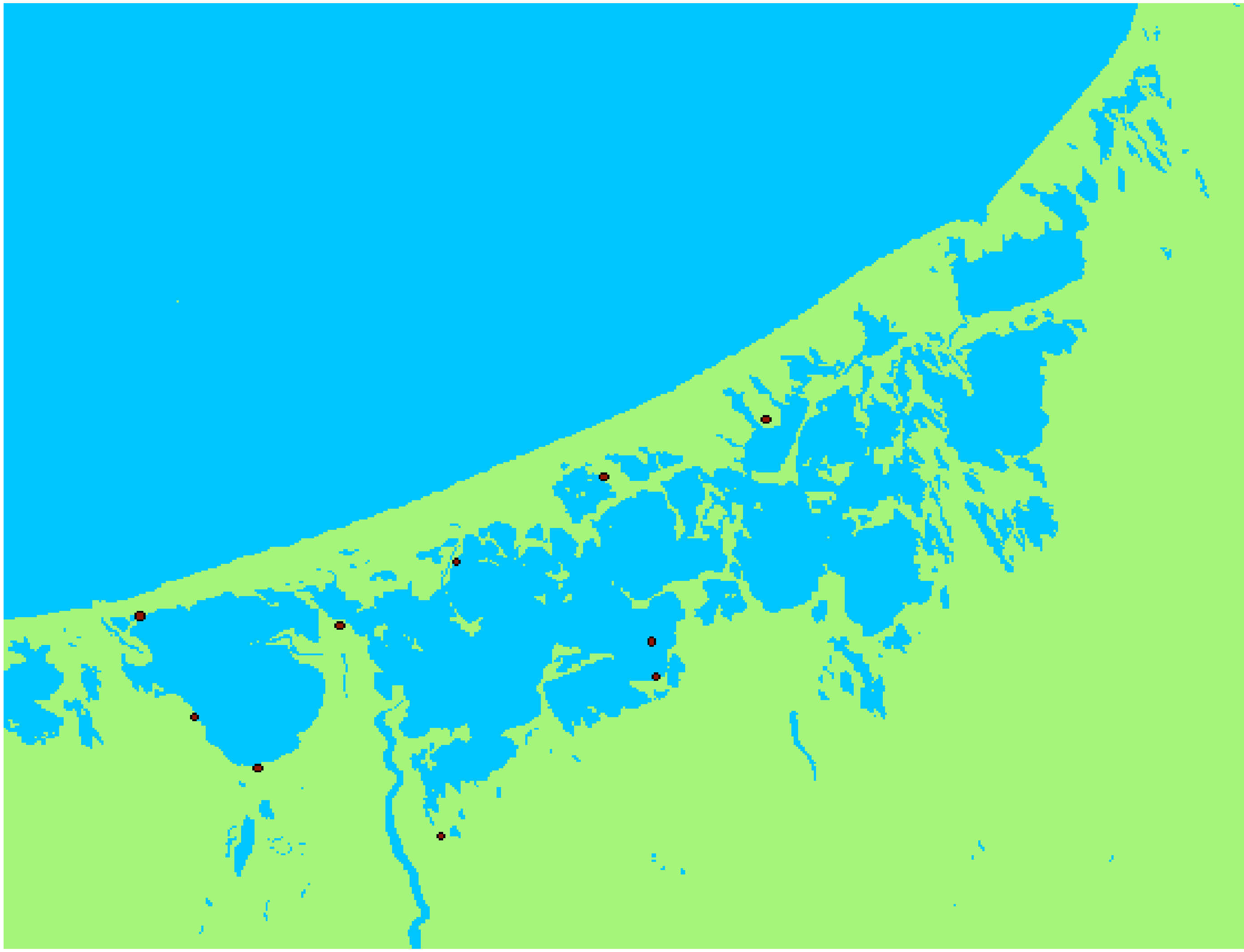


Figure 35. Handling of seedbank samples from the eastern portion of Delta Marsh, Manitoba included three unique treatments A) Moist soil – trays were elevated 2 cm from the bottom of the flooding table resulting in minimal water reaching the soil B) Saturated soil – trays were placed directly on the bottom of the flooding table allowing water to saturate the soil sample C) Flooded soil – samples were placed within Rubbermaid containers and flooded to a level 2” above the soil surface.

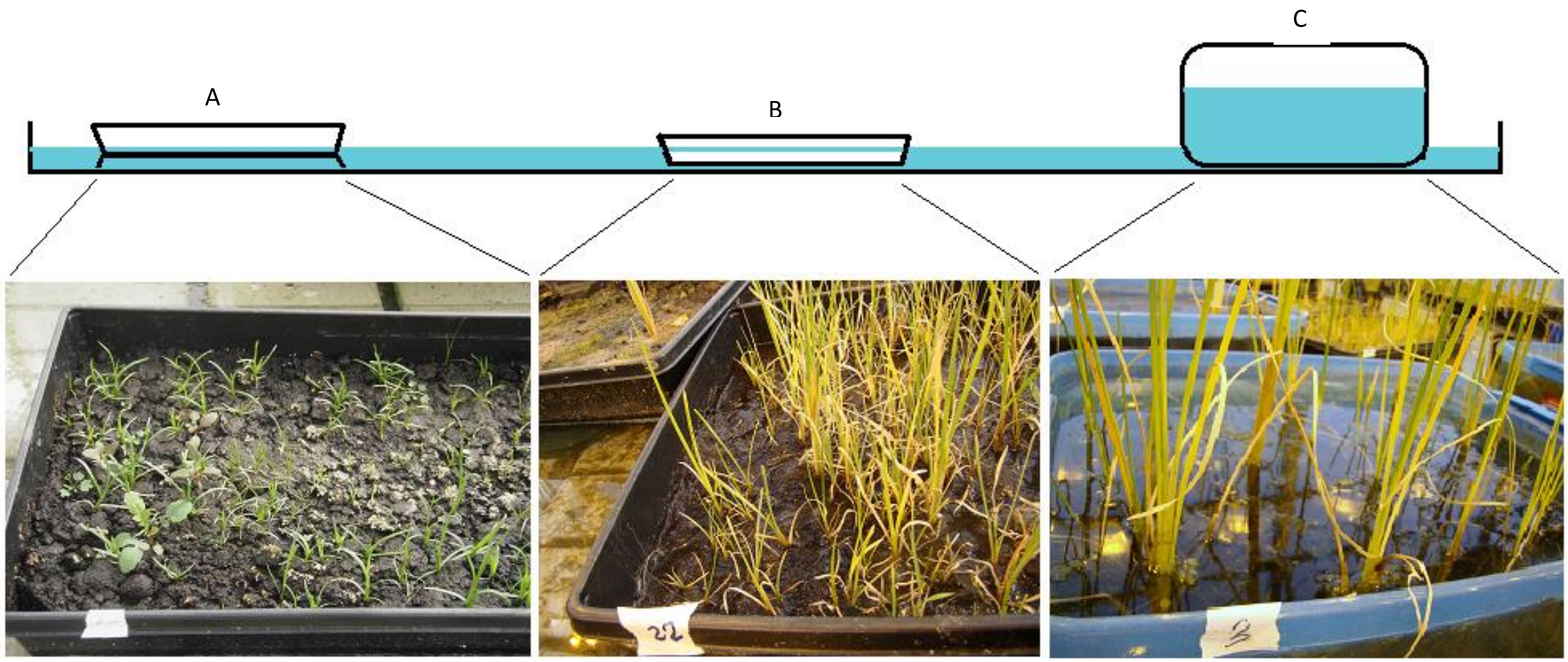


Table 5. Distribution of wetland plant species as germinated from seedbank samples from the eastern portion of Delta Marsh, Manitoba in three saturation treatments. Values are presented as the percent of samples each species was found in. Values are displayed as the percent of samples in which each species was present.

Species	Common Name	Treatment		
		Moist	Saturated	Flooded
Chenopodium rubrum	Red Goosefoot	50	30	-
Cirsium arvense	Canada Thistle	-	10	-
Epilobium ciliatum	Northern Willowherb	-	10	-
Juncus longistylis	Longstyle Rush	-	20	-
Lemna minor	Common Duckweed	-	-	10
Lemna trisulca	Star Duckweed	-	-	10
Lycopus qsper	Rough Bugleweed	10	20	-
Mentha Canadensis	Wild Mint	10	10	-
Phragmites australis	Common Reed	10	30	-
Ranunculus scleratus	Celery-Leaved Buttercup	50	50	-
Rubus pubescens	Dwarf Raspberry	10	-	-
Rumex sp.	Dock	50	60	-
Scirpus paludosus	Salt Marsh Bulrush	10	-	-
Sinapsis arvensis	Wild Mustard	20	-	-
Symphotrichium ciliatum	Rayless Annual Aster	-	10	-
Typha spp.	Cattail	90	90	70
Unknown Grass #1	-	10	-	-
Unknown Grass #2	-	10	10	-
Utricularia vulgaris	Common Bladderwort	-	-	10

Figure 36. Sample of dock (*Rumex sp.*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

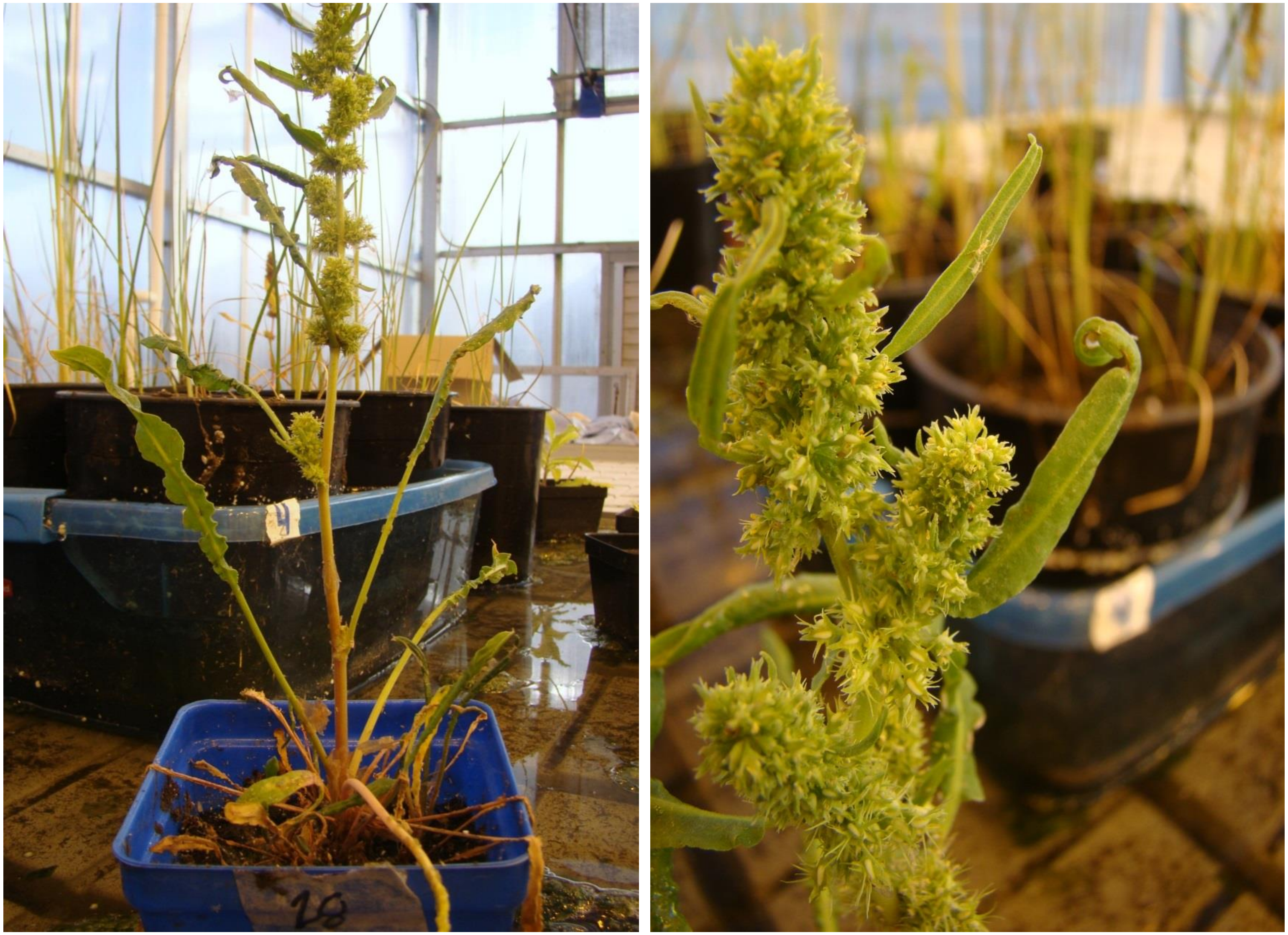


Figure 37. Sample of Longstyle Rush (*Juncus longistylis*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

Figure 38. Sample of unknown grass #1 grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

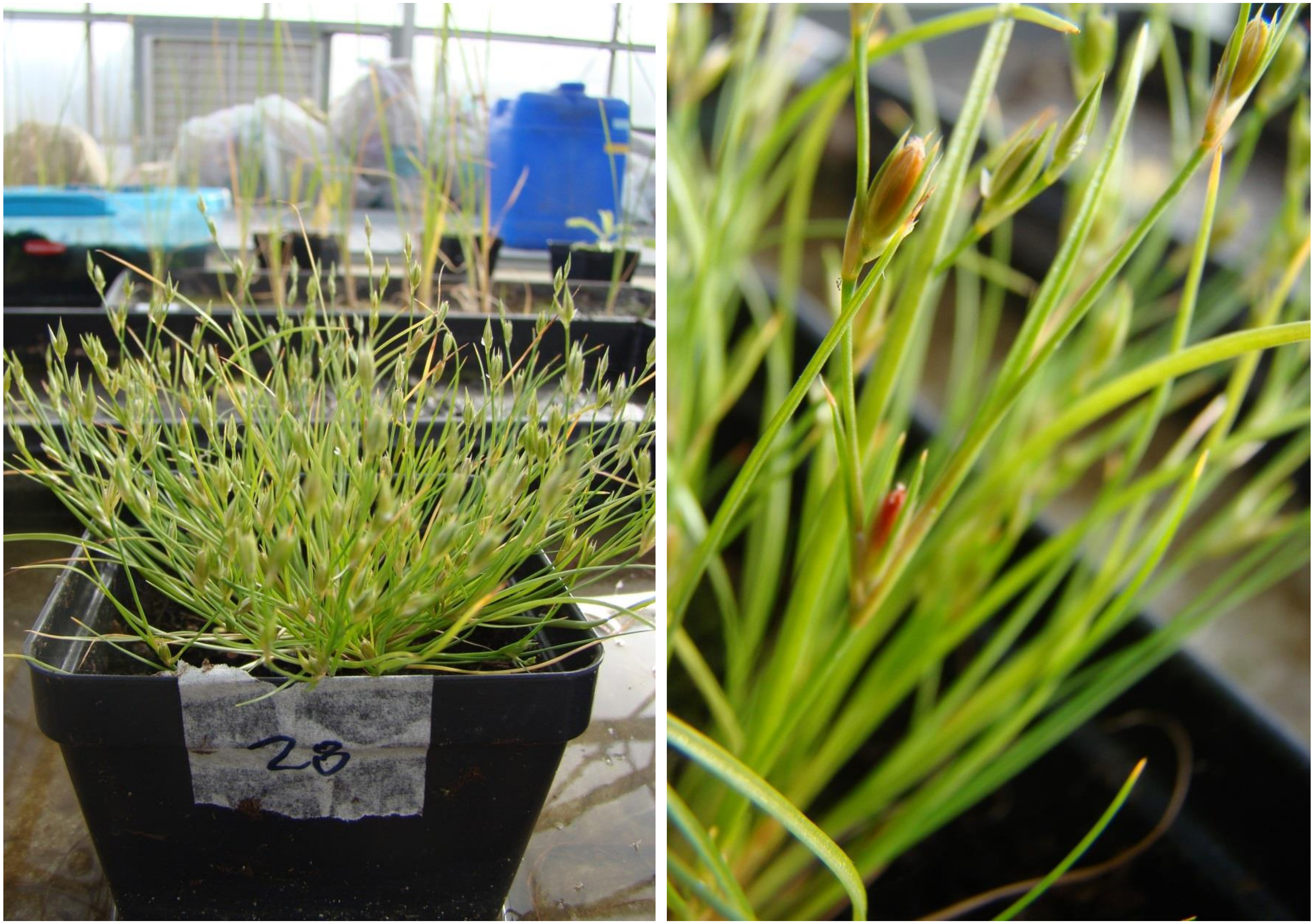


Figure 39. Sample of Wild Mustard (*Sinapsis arvensis*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

Figure 40. Sample of unknown grass #2 grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

Figure 41. Sample of Red Goosefoot (*Chenopodium rubrum*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

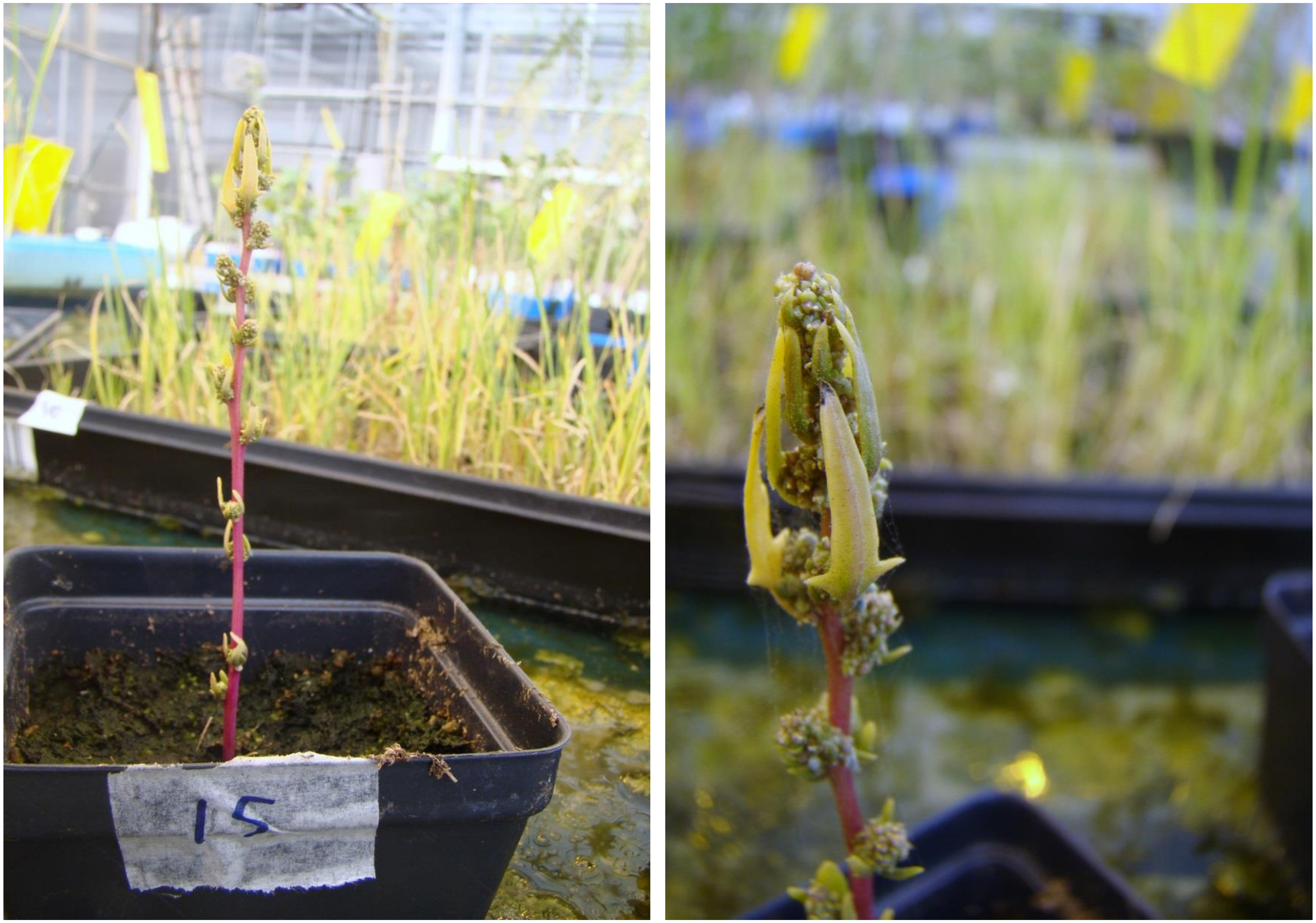


Figure 42. Sample of Celery-leaved Buttercup (*Ranunculus scleratus*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

Figure 43. Sample of Rough Bugleweed (*Lycopus asper*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

Figure 44. Sample of Wild Mint (*Mentha canadensis*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

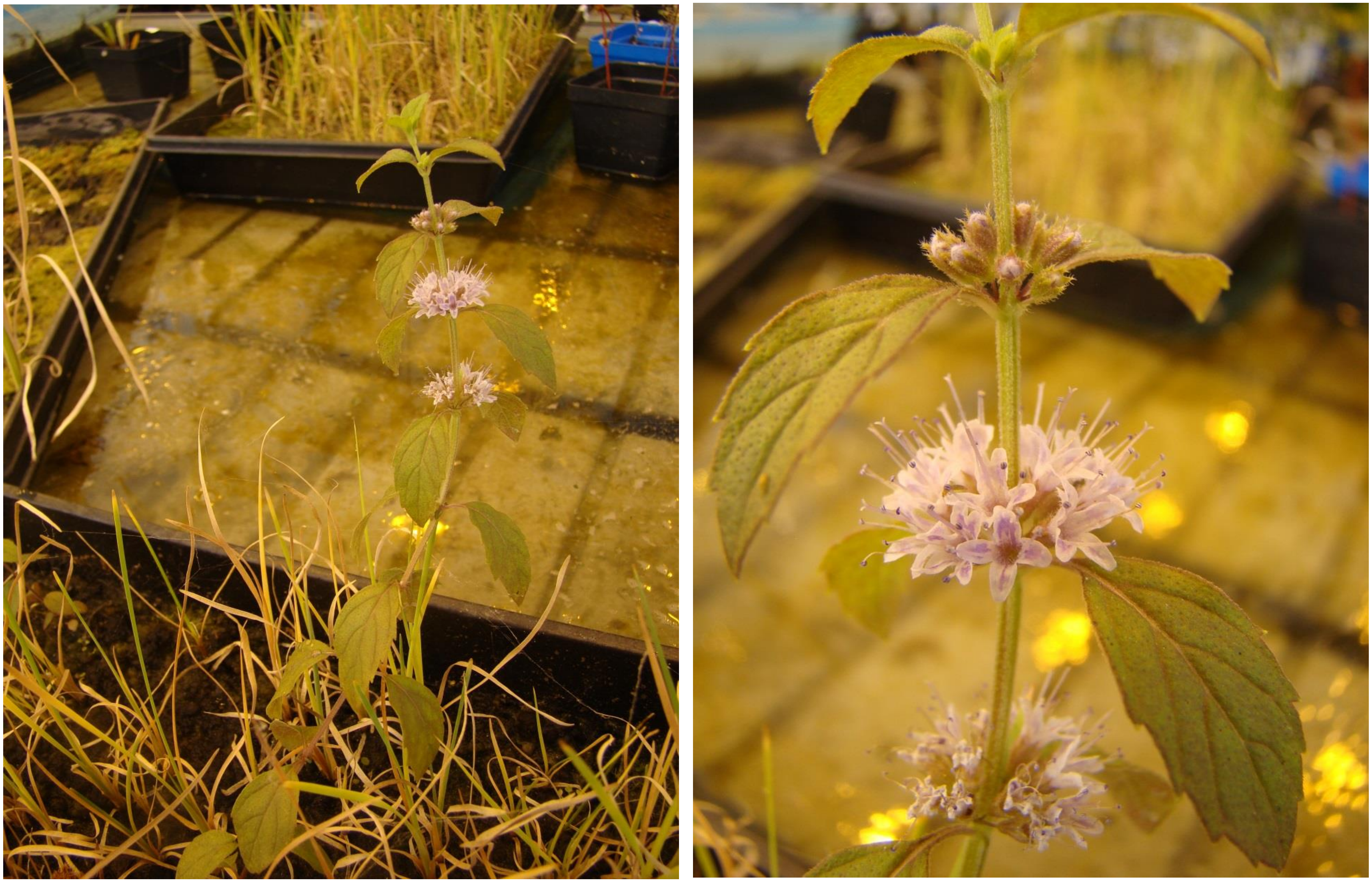


Figure 45. Sample of Salt Marsh Bulrush (*Scirpus paludosus*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

Figure 46. Sample of Northern Willowherb (*Epilobium ciliatum*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

Figure 47. Sample of Rayless Annual Aster (*Symphotrichium ciliatum*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

Figure 48. Sample of Common Duckweed (*Lemna minor*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

Figure 49. Sample of Star Duckweed (*Lemna trisulca*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

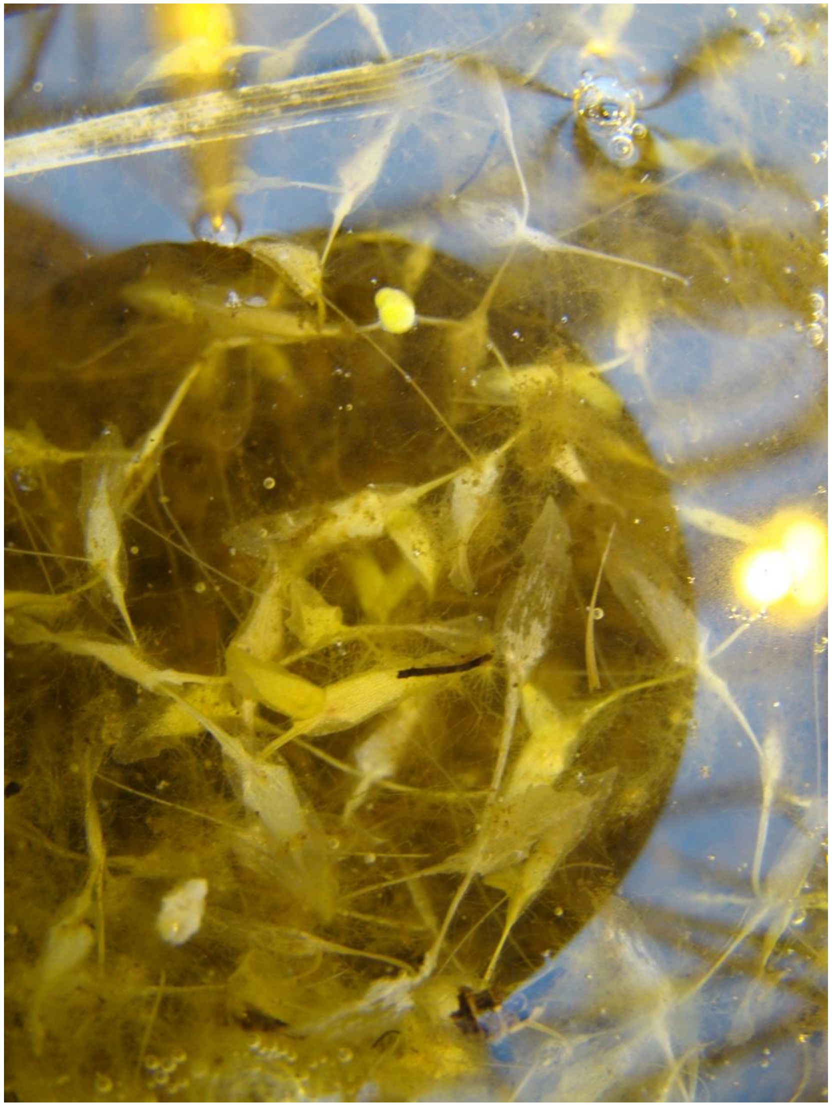


Figure 50. Sample of Common Bladderwort (*Utricularia vulgaris*) grown from seedbank samples taken in the eastern portion of Delta Marsh, Manitoba.

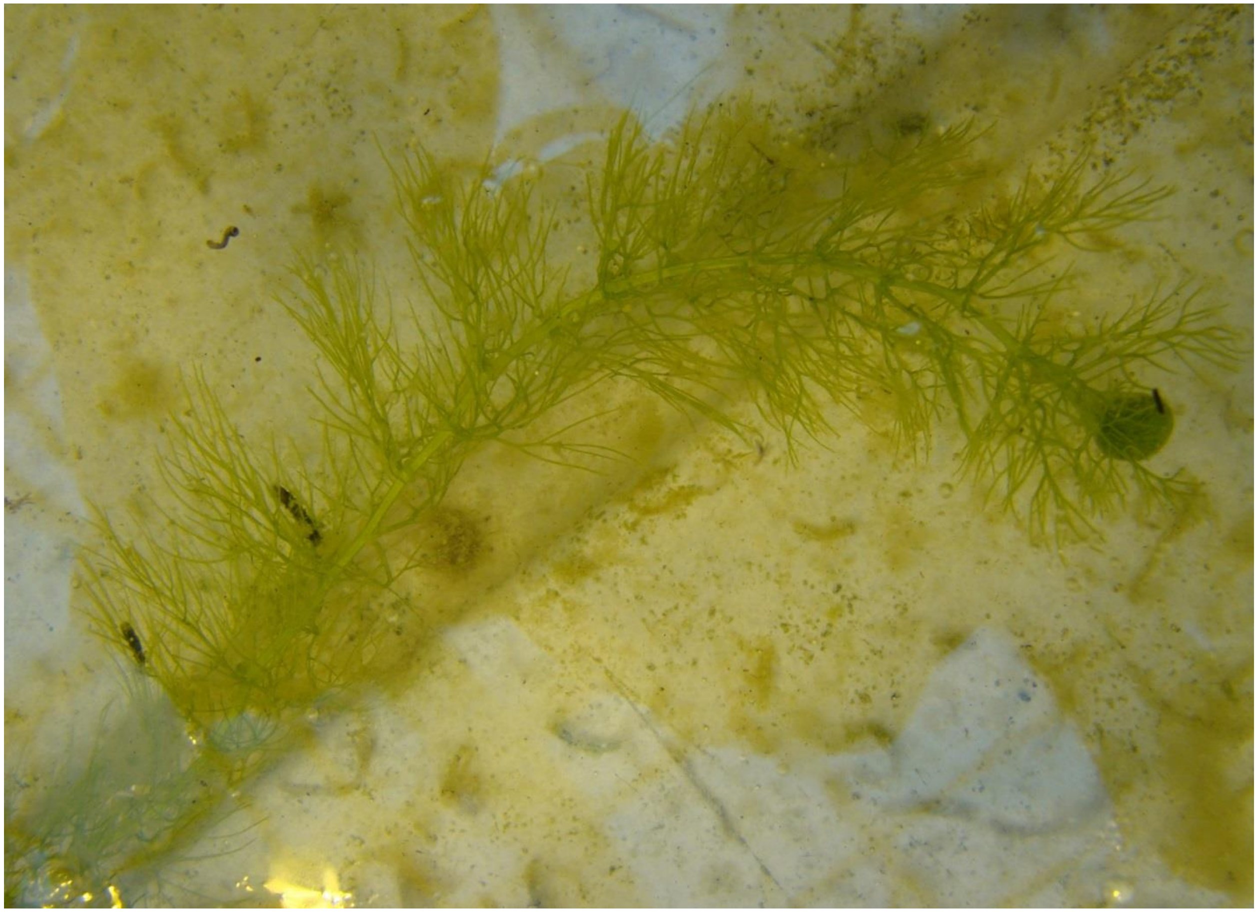


Table 6. Common plant species found in the Delta Marsh area seed bank.

Species	Common Name	Walker, 1965	Pederson, 1981	Galitano and van der Valk, 1986	Welling et al., 1988	Geard, 2015
Atriplex patula (L.)	Spear Saltbush	X	X	X		
Carex atherodes (Spreng.)	Wheat Sedge	X	X		X	
Chenopodium glaucum (L.)	Oak-leaved Goosefoot		X			
Chenopodium rubrum	Red Goosefoot	X	X	X		X
Cicuta maculata (L.)	Water Hemlock	X	X			
Cirsium arvense	Canada Thistle	X	X			X
Eleocharis palustris (L.)	Common Soike Rush		X			
Epilobium ciliatum	Northern Willowherb	X	X			X
Galium trifidum (L.)	Threepetal Bedstraw	X	X			
Hordeum jubatum (L.)	Foxtail Barley		X	X		
Impatiens capensis (Meerb.)	Orange Jewelweed		X			
Juncus longistylis	Longstyle Rush					X
Lemna minor	Common Duckweed	X				X
Lemna trisulca	Star Duckweed					X
Lycopus qsper	Rough Bugleweed		X			X
Lycopus americanus	American Bugleweed	X				
Mentha canadensis	Wild Mint	X	X			X
Phragmites australis	Common Reed	X	X	X	X	X
Populus deltoides (Marsh.)	Eastern Cottonwood		X			
Potamogeton pectinatus (L.)	Sago Pondweed		X			
Ranunculus scleratus	Celery-Leaved Buttercup	X	X			X
Rorippa paulstris (Borbas)	Bog Yellow Cress	X	X			
Rubus pubescens	Dwarf Raspberry					X
Rumex maritimus (L.)	Golden Dock	X	X			
Rumex sp.	Dock					X
Schoenoplectus acutus (Muhl.)	Hardstem Bulrush		X			
Schoenoplectus tabernaemontani (Vahl.)	Softstem Bulrush		X		X	
Scirpus paludosus	Salt Marsh Bulrush	X	X			X
Scolochloa festucacea (Link.)	Whitetop	X	X	X	X	
Scutellaria galericulata (L.)	Marsh Skullcap	X	X			
Senecio congestus (R. Br.)	Marsh Fleabane	X	X			
Sinapsis arvensis	Wild Mustard					X
Solidago canadensis (L.)	Canada Goldenrod	X	X			
Sonchus arvensis (L.)	Corn Sow Thistle	X	X			
Sonchus palustris (L.)	Marsh Sow Thistle		X			
Stackys palustris (L.)	Marsh Hedgenettle	X	X			
Suaeda calceolifotmis (Wats.)	Pursh Seepweed		X			
Symphotrichium ciliatum	Rayless Annual Aster		X	X		X
Teucrium canadense (L.)	Canada Germander		X			
Typha spp.	Cattail	X	X	X	X	X
Urtica dioica (L.)	Stinging Nettle	X	X			
Utricularia vulgaris	Common Bladderwort		X			X

7.0 – Synthesis

7.1 – Introduction

The physical, chemical, and biological characteristics of wetlands are greatly affected by their elevations. Most importantly, the elevational distribution of a wetland directly influences the distribution of water throughout the environment as well as the spatial and temporal variation of water depth and flow. Both the distribution and fluctuation of water depth affects the distribution of vegetation in wetlands (Robel, 1961; Anderson, 1978; van der Valk, 1994; Seabloom et al., 1998; Murkin et al., 2000). *Potamogeton pectinatus*, a common submergent species, will preferentially grow in relatively deep waters (maximal growth in 40 to 65 cm of water) (Robel, 1961; Anderson, 1978) while *Phragmites australis*, a common emergent species will preferentially grow in dryer areas (maximal growth at 10 to 60 cm above flooded areas) (Yamasaki and Tange, 1981) though it will grow in flooded conditions (Squires and van der Valk., 1992). Wetland plant species may be influenced by water depth at multiple life stages including during germination (Leck, 1989; Seabloom et al., 1998; Casanova & Brock, 2000; Kellogg et al., 2003), during plant growth (Coops and van der Velde, 1995; Conner et al., 1997) and during reproduction (Warwick and Brock, 2003). Species that are found at higher elevations in the mature life stages tend to have decreasing germination success as water levels increase, while those found at lower elevations will tend to display increased success with increasing water depth (Seabloom et al., 1998). For example, *Typha spp.* which are often found at lower elevations (Welling et al., 1988; Waters, 1989; Squires and van der Valk 1992), show increased germination in submerged conditions (Harris and Marshall, 1963; Coops and van der Velde, 1995; Seabloom et al., 1998) while *P. australis*, which is found at higher elevations (Yamasaki and Tange 1981) germinated well in dry conditions but not in saturated soils (Coops and van der Velde, 1995). Once established, growth of *Phragmites* tends to decrease under flooded conditions, while growth of *Typha* increases (Coops and van der Velde, 1995). When growth is delayed, either due to exposure to flooded conditions (as seen in *Phragmites*) or a lack of the proper saturation levels (as would be seen in submergent species) reproductive organs may not have the chance to form or mature, resulting in loss of reproductive ability (Warwick and Brock, 2003).

Distribution of wetland plants often occurs along a water depth gradient (Pearsall, 1920; Gleason, 1926; Spence, 1967; Keddy, 1983; Keddy and Ellis, 1985; Seabloom et al., 2001). Increasing water depth generally results in decreased oxygen and light availability; plant zonation will occur based on tolerances to these conditions and also on competitive ability of each species. Grace and Wetzel (1981, 1982) examined the zonation of *Typha latifolia* and *Typha angustifolia* and found that although both species had optimal water depth of approximately 50 cm, *T. angustifolia* is often displaced to deeper water due to the higher competitive ability of *T. latifolia*. *Typha x glauca*, a hybrid of the previously mentioned *Typha* species, can grow in a wider range of water depths than either parent and due to its aggressive nature is capable of outcompeting both at their preferred depths (Smith, 1967; Waters and Shay, 1992; Kuehn and White, 1999). Emergent plant diversity tends to decrease with increasing water depth, especially when flooding occurs over a long period of time (Casanova and Brock, 2000; Raulings et al., 2010) though several common emergent species, such as *Phragmites australis* and *Typha* spp. are capable of tolerating relatively high water levels (Raulings et al., 2010). Submergent vegetation abundance, however, tends to increase with extended periods of flooding

(Raulings et al., 2010). The distribution of this vegetation is also influential in the distribution of wetland organisms as it provides sources of food, habitat and cover (Robel, 1961; Mittlebach, 1988; Campeau et al., 1994; Murkin et al., 1997).

Previous experiments with water level manipulation in Delta Marsh reported a decline in species richness, diversity and shoot density in response to prolonged flooding (van der Valk et al., 1994). Flooded treatment areas exhibited increased percent cover of open water within three years as emergent vegetation senesced and retreated, while areas exposed to normal water level conditions experienced a decrease in the percent cover of open water as emergent vegetation spread.

Water depth also influences other communities of wetland organisms, including insects (Voigts, 1976) which provide an important food source for many bird (Krull, 1970; Longcore et al., 2006) and fish species (Zimmer et al., 2000; Hornung and Foote, 2006). The distribution of invertebrates is often influential in the distribution of other organisms (Kaminski and Prince, 1981; Murkin et al., 1982; Murkin and Kadlec, 1986; Cooper and Anderson, 1996). Additionally the distribution and diversity of fish is positively correlated with diversity of habitat and water depths (Maltchik et al., 2010).

Wetlands are important habitat for many waterbirds and the distribution of these animals is heavily dependent on water depths as well as the ratio of open water to cover. Diversity of waterbirds is often greatest in shallow water areas as both wading birds and shore birds are limited to feeding in these zones due to their physical characteristics (Robertson and

Massenbauer, 2005). Baschuk et al. (2012) found that diving ducks showed a tendency towards deeper waters, while dabbling ducks exhibited an opposite relationship, being attracted to shallow water areas. Dabbling species abundance also displayed a positive relationship with the presence of shallow water emergent species such as sedges and horsetail, which support a wide variety of invertebrates and therefore provide an important food source. Dabbling ducks also display increased diversity where emergent vegetation and open water are present in equal parts (Kaminski and Prince, 1981).

The relationship between substrata distribution and elevation is more complex, being influenced by the distribution of vegetation, patterns of water flow and disturbance by wind and wave action. Small-particle sediments tend to be found in shallower waters, especially in highly vegetated zones which slow the flow of water allowing for sedimentation and protecting these sediments from disturbance (Cyr, 1998). Wetland soils tend to be highly organic due to the large amount of plant matter and slow rates of decomposition (Mausbach and Richardson, 1994). Underlying sediments may be silt or clay in nature, overlain by organic material (Zbigniewicz, 1982). The distribution of substratum types is also influential in the distribution of wetland organisms such as invertebrates and fish (Sublette, 1957; Scott and Crossman, 1973; Grossman and Freeman, 1987). For example the Common Carp, Brook Stickleback and Yellow Perch are commonly found in areas with muddy substrata and high levels of vegetation, while White Sucker and Fathead Minnow are common over a wider variety of substrata including sand, silt and mud and darters are more likely to be found over sand or gravel substrata (Stewart and Watkinson, 2004).

The objectives of this study were to determine what relationships, if any, could be observed between elevations and the emergent vegetation community of Delta Marsh, as well as the substrata distributions within the study area. I expected based on other studies at Delta Marsh (Welling et al., 1988; Waters, 1989; Squires and van der Valk 1992) that *Typha* would be most closely associated with lower elevations while *Phragmites* would be situated in relatively high elevations. I also expected that the large surface area and shallow nature of the marsh, wind and wave action, and the resulting disturbance of sediments, would result in a homogenous distribution of substratum classes.

7.2 – Materials and Methods

QTC data processing provides both water depth and substrata identification so it is relatively simple to explore the relationship between the two characteristics. The elevations for each data point, which had been adjusted to account for water depth changes, were used for this process. Both the six substratum classes identified by the QTC program and the final three classes used in Chapter 4 (Clay, Organic and Plant Material) were examined. Box plots representing the range of measured depths displayed as quartiles were created for each substratum class; frequency distribution graphs were also produced for comparison. Two of the three final substratum classes were comprised of multiple QTC classes; these were broken down to determine if the separation of QTC classes could be explained by water depth. This was also explored through the use of Komogorov-Smirnov statistical analysis to determine if the range of elevations in which each substratum class was found could be statistically separated. This test determines whether two separate samples are likely to be from the same distribution.

Exploring the relationship between vegetation distribution and water depth was a more complicated matter because the data for these two characteristics existed in separate data sets, one a polygon layer and the other a raster. The elevation measurements in the raster layer were created as float data so I was unable to directly join the elevation data to the vegetation polygons. The raster data had to be converted into a point file. Before this was done, the raster was resampled to increase the size of the pixels from 0.5 to 2 meters to reduce the number of points created. This was done using the Resample tool in the ArcGIS Data Management toolset, which averaged the values of the original pixels that fell within each resampled pixel. The raster was then converted to a point file using the Raster to Point tool in the Conversion toolbox, which created a point at the center of each pixel, containing the elevation data. This point file was then joined, using a spatial join, to add the elevation data to the vegetation polygons. In the case that multiple points fell within a polygon, an average of all points falling within that polygon was calculated. Just as with the substrata data, the elevation ranges of vegetation classes were compared through the use of box plots and frequency distribution graphs.

7.3. – Results

7.3.1 – Elevation vs Vegetation Distribution

I examined the relationship between elevation and vegetation distribution, determined through the analysis of satellite imagery, by using the elevation data extrapolated from the QTC survey and the MLI data for the region surrounding the study area. The largest vegetation class, Flooded Vegetation, had a relatively low mean elevation (247.38 mASL) and was found over the large elevational range of 7.03 m (245.84 – 252.83) (Table 7). Due to the inability to differentiate between vegetation species in flooded conditions within the satellite imagery, it is likely that this class represented several of the dominant emergent plants found within the marsh and could therefore be considered vague. The nature of this category contributes to the wide range of elevations in which it was found. At the time the satellite imagery was taken water levels in the marsh were approximately 248.81 mASL (based on measurements taken at the elevational benchmark at the boat launch); the Flooded Vegetation class therefore ranged from approximately 2.15 m above the water line to flooded areas up to 2.97 m deep.

The Mixed Vegetation class had similar characteristics to the Flooded Vegetation class, having an average elevation of 247.26, only 0.12 m lower than that of the Flooded Vegetation class. It ranged from 246.03 to 250.39 mASL, a total of 4.36 m which fitted within the total elevational range of the Flooded Vegetation class. This translates to a range of approximately 1.58 m above the water line to flooded areas up to 2.78 m deep.

The dominant emergent plant taxa found in the study area were *Typha* and *Phragmites*, representing 12.26% and 2.04% of the total vegetation cover, respectively. *Typha* exhibited the lowest mean elevation at 247.23 mASL, which was expected as *Typha* is known to be tolerant of deep water conditions. Distribution of *Typha* ranged from 245.85 to 250.99 mASL a total of 5.14 m (approximately 2.18 m above the water line to areas up to 2.96 m deep); however, the elevations within the second and third quartile were more concentrated, ranging from 246.84 to 247.43 (translating to a range from approximately 1.38 m to 1.97 m above the water line), a total of 0.59 m, (Figure 51). *Phragmites'* mean elevation was only slightly higher at 247.40 and had a smaller elevation range of 4.17 m (246.16 – 250.33 mASL or 1.52 m above the water line to flooded areas up to 2.65 m deep). The minimum elevation for *Phragmites* was 0.31 m higher than that of *Typha*, as might be expected by its lower tolerance of flooded conditions. As with *Typha* the elevational range within the second and third quartiles was more concentrated, ranging from 246.95 to 247.68 (an approximate range of 1.13 to 1.86 m above the water line), a total of 0.727 m. The total range of *Phragmites* fell within the total range of *Typha*; *Phragmites* and *Typha* habitat often overlaps, although *Phragmites* is often found at higher elevations due to its lower flooding tolerance (Yamasaki and Tange, 1981; Welling et al., 1988).

We can see from the box plots in Figure 51 that the previously described classes (*Typha*, *Phragmites*, Flooded Vegetation and Mixed Vegetation) are quite similar in extent and mean elevation. The Dead Vegetation class fell within a similar range as well, covering elevations from 245.61 to 250.34 mASL (4.73 m in total – ranging from approximately 1.53 m above the water level to flooded areas up to 3.2 m deep) and exhibiting a mean elevation of 247.30 mASL. The minimum elevation observed in this class, however, was the lowest of any class. The remaining classes, including Flooded Field, Crop Land, Grass/Pasture, Beach and Forest, were located at relatively high elevational ranges (Figure 51). The high elevational ranges for these classes was expected; grasslands are generally found in dry areas, as are pastures and crop lands, beaches, though located near water tend to be dry as well, and forested areas in this region tend to be located in higher elevations. Of these classes, the Flooded Field class exhibited the lowest mean elevation at 248.23 mASL and a relatively small range compared to the lower elevation classes (247.09 to 249.84 mASL, a total of 2.75 m). Based on the approximated water level of 248.81 mASL I would have expected that this class would be limited to those areas below the water level. This class was however concentrated to the area south of the marsh complex, which is characterized by a gradual slope. It was approximated that the Flooded Field class was located as much as 1.03 m above the water level which could be explained by error within the data (as previously mentioned the data used to interpolate this area was of relatively low resolution) or by varying water levels throughout the marsh due to wind seiche effects. Due to its location south of the marsh and the gentle slope of the area even a light northerly wind may result in redistribution of water into higher elevations than in calm conditions. Although the water level was measured at 248.81 mASL at the benchmark location it is possible that water levels throughout the marsh were not constant. Flooded Field occupied a lower elevational range than either the Crop Land or Grass/Pasture classes (247.46 to 250.21 mASL and 247.08 to 252.83 mASL respectively), which was understandable given that low-elevation areas are more likely to flood. The forest class had a relatively large elevation range compared to the other high elevation classes (range of 246.98 to 253.18 mASL for a total of 6.20 m) and exhibited the highest maximum elevation of all the vegetation classes (253.18 mASL).

7.3.2 – Elevation vs Substrata Distribution

I examined the distribution of substratum classes in relation to depth using the depth data obtained from the QTC sonar system and substrata data obtained through the clustering analysis performed by the QTC IMPACT software. The depth distribution itself was relatively normal (Figure 52). The average elevation of the survey areas was 246.437 mASL with an average water depth of 2.36 m. Because the water levels in Delta Marsh were approximately 1.37 m above normal levels at the time of this study, the average water depth in the surveyed area in a normal year would be approximately 0.85 m. As the QTC sonar requires 1.0 m of clearance between the substrate and the water surface, I would not have been able to survey a large portion of the marsh in a normal water year.

All of the classes had low coefficients of variance (CV) (Table 8). The largest CV belonged to class six. The range of depth values for each substratum category was quite large, each covering a similar total range (Figure 53). For the most part, however, 50% of the samples in each class (those falling within the 2^{nd} and 3^{rd} quartiles) fell within a relatively small range, with the exception of class six (Figure 53). Class six possessed the largest CV (0.27%) and the largest range of values within the second and third quartiles. The majority of classes were normally distributed (Figure 54); however, class six seemed to have a bimodal distribution, which may explain the large CV. It is clear that the six QTC-identified substratum categories could not be distinguished by depth distribution alone. Based on ground-truthed samples, the six QTC categories were amalgamated into three substratum classes (Table 9). The largest category, organic, made up 80.08% of all sample points and approximately 76.20% of the total coverage area, with an elevational range of 4.00 m, from 243.95 to 247.96 mASL. The range covered by all three classes was relatively similar, though slight differences were seen when concentrating on the data within the second and third quartiles. The clay class was concentrated in relatively low elevations whereas the plant class was concentrated in higher elevation, with the organic class being intermediate. When compared to the substrata distribution map (Chapter 4, Figure 28), the clay category tended to be found towards the centers of the larger bays where elevations would be at their lowest. Although the plant class was also found centrally within bay areas, it is often found around the edges of bays and channels where elevations would be relatively high.

The organic class appeared to be found throughout the marsh, in the highest concentrations in intermediate zones (Chapter 4, Figure 28).

As mentioned in Chapter 4, there appeared to be a separation of the three substratum classes based on elevational ranges (Figure 55). Additionally the QTC classes within each of the ground-truthed substratum classes also exhibited separation based on elevation (Figure 56). Although the total ranges for each of the QTC categories was similar, the data within the second and third quartiles show a relatively distinct range of elevations. Within the clay substratum, QTC class 1 seemed to be concentrated in lower elevation, class 6 in higher elevations and class 2 in intermediate elevations. Within the organic substratum, QTC class 4 seemed to be concentrated in higher elevations while class 3 was concentrated in lower elevations. It is, however, possible that characteristics other than those explored during this investigation can explain the separation of these classes by the QTC system.

7.4 – Discussion

7.4.1 – Elevation vs Vegetation Distribution

I expected that all of the vegetation cover classes would be found at higher elevations than the Water cover class; however, multiple classes (*Typha*, Dead Vegetation, Flooded *Typha* and Flooded Vegetation) were actually found at lower elevations (Table 7, Figure 51). Many of the polygons at these low elevations were found west or north of Clandeboye Bay in the far eastern portion of the study area. It is unclear why this may have occurred; it may be that these lower elevational areas can simply be attributed to errors in elevation measurements, errors in interpolation due to the coarse resolution of elevation data, or they may exist as isolated depressions that are completely separated from flooded areas of the marsh by higher elevation areas.

The elevational range of many of the classes was large (Figure 51). As noted above, the large range of the Water class was likely due in part to overestimations of elevation in areas outside of the QTC bathymetry. The large ranges of the Mixed Vegetation and Flooded Vegetation classes were likely due to the fact that they were comprised of multiple species, while the large ranges of the *Typha* and Flooded *Typha* classes were likely due to the fact that *Typha* was the dominant species within the marsh and, due to its aggressive and competitive nature, can be found in a wide variety of conditions. In addition, *Typha* is known to form dense root structures that, when disturbed by flooding or heavy wind and wave action, can break away from the substrate and form a floating mat (Krusi and Wein 1988). This allows the species to survive in areas that would have relatively deep water/lower elevations. The Grass/Pasture class also exhibits a large elevational range and this can be attributed to that fact that they take up a relatively large area, stretching along most of the far eastern border of the study area. The elevations of this region increased moving east and or south so a large range was not surprising. This can be said as well for the Forest class which was, in part, located in the same area as the Grass/Pasture class. The beach ridge between the marsh and Lake Manitoba is heavily forested and tended to have a relatively low elevation which likely contributed to the stretched distribution of the second and third quartiles as compared to most of the other classes (Figure 51).

In regards to the water class, many of the smaller polygons found to be located at relatively high elevations were situated towards the eastern and southern edges of the study area (Figure 31) Although these areas tended to exhibit increasing elevation, it is important to note that they were interpolated using few elevational measurements. The less data available for extrapolation, the less accurate the output, especially at the edges of the interpolation where data were not available from all sides. For example, the Water class could be considered to have high accuracy because much of its extent was measured directly during the QTC bathymetric survey. There were, however, many small water bodies and flooded areas that could not be surveyed in this matter. The eastern and southern portions of the study area were especially removed from the QTC study area and so interpolated elevations were influenced mainly by MLI data which was much less detailed. When data points were sparse, variation within the landscape was easily missed and interpolation tended to result in a flattened representation of the surface. Polygons representing water in these areas were likely to be found in depressions in the landscape but unless one of the elevational measurements happened to fall within one of these depressions it was improbable that a depression would appear in the interpolation. It is likely that many of the polygons predicted to contain water in these areas had an overestimated elevation.

Although there are some obvious issues with the elevation interpolation outside of the QTC survey, these data can provide a general sense of the elevational distributions of the dominant vegetation classes within the study area. *Typha* and *Phragmites* occupy similar elevational ranges though *Typha* occupies lower elevations than does *Phragmites*. The fact that the Flooded *Typha* and Flooded Vegetation categories occupied similar ranges to the *Typha* and *Phragmites* categories was unexpected. This may be due to different densities within stands; thinner stands would have exhibited a higher proportion of water at the surface after flooding, therefore being grouped into one of the flooded categories, while dense stands would not have appeared different after flooding unless senescence occurred. It may also be due to the fact that the elevation model created for the vegetated zones of the study area was created using relatively coarse resolution data. A more detailed topography of this area would result in more accurate distributions of the emergent vegetation classes.

7.4.2 – Elevation vs Substratum Distribution

The most distinct substratum class was class six, having a relatively large CV and bimodal distribution (Table 8, Figure 54). Although relatively rare, it was distributed equally in near-shore and bay-central locations. This likely explains both the large CV and the elevational distribution. Class five displayed a similar distribution pattern (Figure 54) but was not as equally distributed between the two areas, being more concentrated within higher elevations, resulting in a more normal distribution and smaller CV. The measurements within the second and third quartile were also much more concentrated than those seen in class six (Figure 53).

Although some distinction could be made between the six QTC classes based on the ground-truthed samples, I could not separate each class based on visual inspection alone and no further analysis was possible. It is conceivable that, given the opportunity to examine the samples in more detail through analysis of particle size and organic content, that the six QTC classes could have been identified separately. With the present dataset, I found three unique substrata: one dominated by silt and clay sediments, one dominated by decomposed organic material, and one composed of large portions of undecomposed organic matter. Based on ground truthed data QTC classes 1, 2, and 6 were amalgamated into the clay substratum class, while QTC classes 3 and 4 were amalgamated into the organic substratum class (Table 9). Further examination of the three substratum classes showed there was a distinct spatial separation based on elevation (Figure 54). The clay/silt substratum was more concentrated in lower elevations/deeper water areas. On the other hand, the substratum with high proportions of plant materials tended to be concentrated in the higher elevation areas, which is understandable given that macrophytes tend to grow in relatively shallow water. The organic substratum was found throughout the study area within and between the two extremes. Within the Clay class, all three QTC classes had similar distributional ranges, but 50% of the data (data within the second and third quartiles) was relatively concentrated. Class 1 was concentrated at a relatively low elevation, though there was overlap between classes 2 and 6. Class 2 was concentrated at slightly higher elevations than class 1, while overlapping largely with class 6. Class 6 tended to be found at relatively high concentrations (Figure 55). A Komogorov-Smirnov test showed that the depth distributions of these classes were statistically different ($p = 0.05$). The two QTC classes within the organic class also exhibited a large amount of overlap in their total distributions. Again, looking at the data within the second and third quartiles class 3 was concentrated at relatively high elevations while class 4 was concentrated at relatively low elevations (Figure 55). Again a Komogorov-Smirnov test showed these distributions to be statistically different. It is possible that the depth at which these substrata were found may have influenced their placement into their assigned class.

It is unknown if the substrata distributions identified within this study change in relation to wind and wave action or water flows through the marsh. Changes in flow and disturbance may result in variations in sedimentation which could produce alterations to the bathymetry. It would be interesting to reexamine these characteristics in the future to determine if this might be true. A study conducted in the future may be helpful in determining how stable the distribution of substrata in the marsh is.

The distribution of sediments is often an important factor in the selection of habitat for many wetland organisms, as is the distribution of water depths. Knowledge of the distributions of different substrata can often be helpful in the development of management strategies for various habitat types or for the organisms that use them. The distribution of substrata within Delta Marsh, however, seems to be rather homogenous yet the lone sample of gravel substratum is intriguing and may be important as a unique and isolated habitat type. Future surveys of the area may uncover more information about the distribution of this particular substratum.

Table 7. Summary of elevation data for SAS-identified vegetation classes in the eastern portion of Delta Marsh, Manitoba as determined by extrapolation of Quester Tangent Corporation (QTC) and Manitoba Land Initiative (MLI) elevation data and analysis of QuickBird satellite imagery.

Class	**Crop Land**	**Dead Vegetation**	**Flooded Field**	**Flooded *Typha***	**Flooded Vegetation**	**Grass / Pasture**	**Mixed Vegetation**	***Phragmites***	**Forest**	***Typha***
# Samples	9	1,918	43	2,933	5,062	162	136	1,101	518	1,802
Coverage Area (km²)	0.64	2.10	3.63	6.61	17.08	10.55	0.17	1.09	5.02	6.56
Coverage Area (%)	1.20	3.92	6.78	12.35	31.92	19.72	0.32	2.04	9.38	12.26
Mean Elevation (mASL)	249.04	247.30	248.23	247.37	247.38	249.97	247.26	247.40	250.21	247.23
Standard Deviation	1.01	0.64	0.88	0.71	0.78	1.51	0.56	0.65	1.72	0.61
Coefficient of Variance	0.41	0.26	0.35	0.29	0.31	0.61	0.23	0.26	0.69	0.25
Minimum Elevation (mASL)	247.46	245.61	247.09	245.76	245.84	247.08	246.03	246.16	246.98	245.85
Maximum Elevation (mASL)	250.21	250.34	249.84	250.89	250.89	252.83	250.39	250.33	253.18	250.99
Range (m)	2.75	4.73	2.75	6.73	7.03	5.75	4.36	4.17	6.20	5.14

Figure 51. Quartile box plots representing the elevational ranges of classified vegetation cover within the eastern portion of Delta Marsh, Manitoba as determined by Quester Tangent Corporation (QTC) and Manitoba Land Initiative (MLI) elevational data and analysis of QuickBird satellite imagery. Boxes represent data within the 2nd and 3rd quartiles while whiskers represent data within the 1st and 4th quartiles.

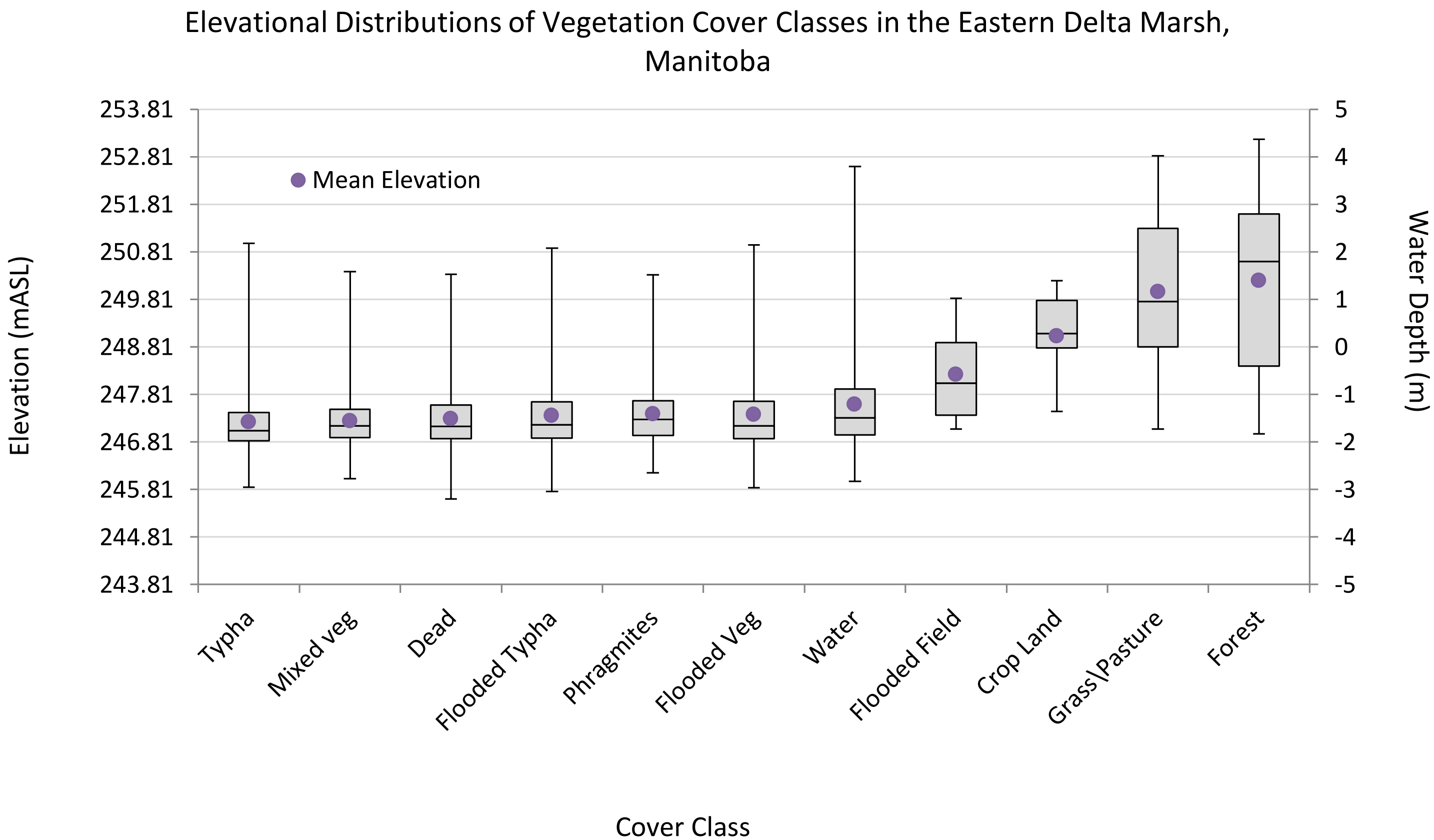


Figure 52. Frequency distribution of elevations measured within the eastern portion of Delta Marsh, Manitoba as determine by Quester Tangent Corporation (QTC) single beam sonar analysis.

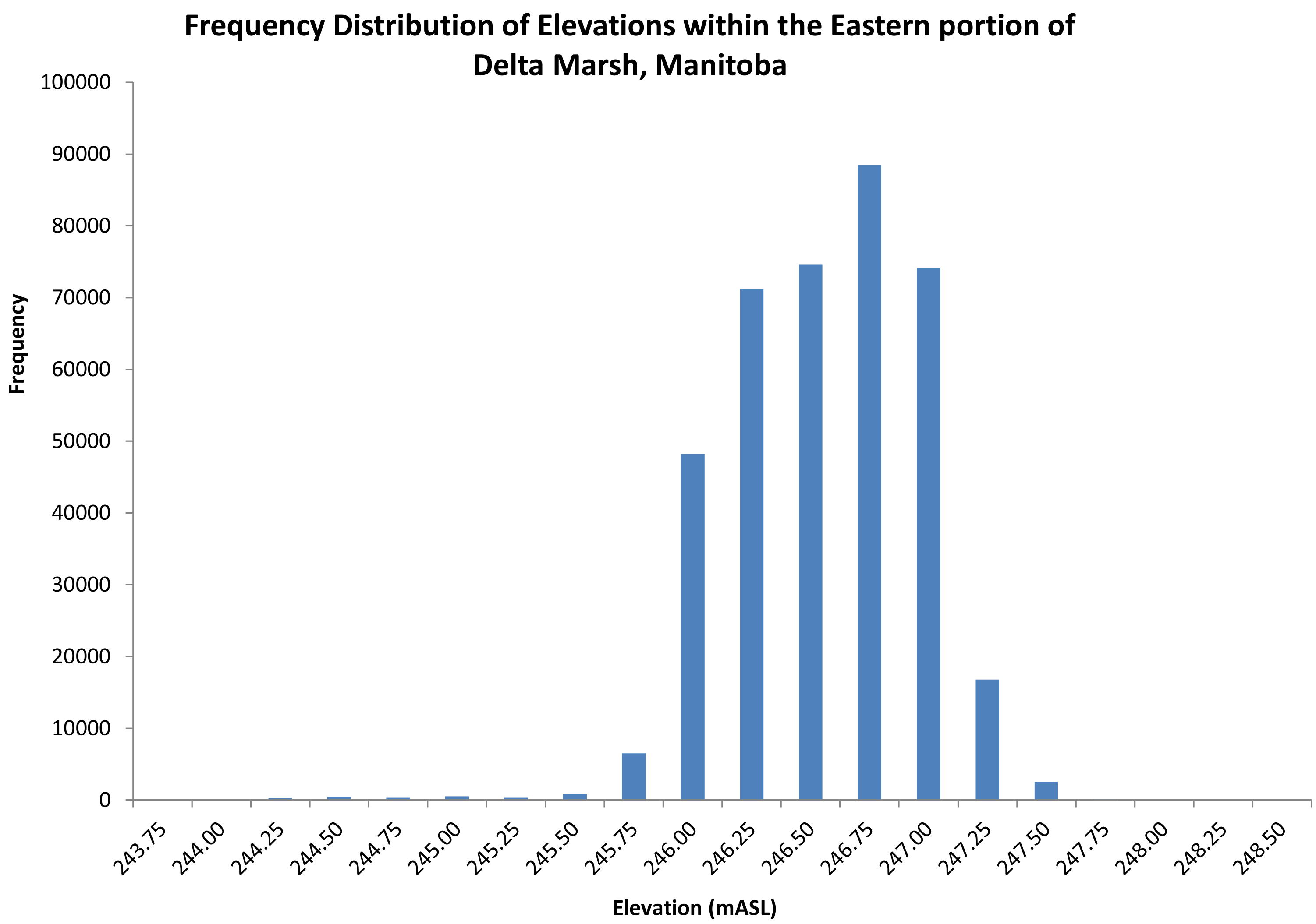


Table 8. Summary of depth data for substratum classes identified by Quester Tangent Corporation (QTC) single beam sonar analysis and QTC IMPACT substrate analysis in the eastern portion of Delta Marsh, Manitoba.

Class	1	2	3	4	5	6	Total
# Samples	**4,865**	**52,289**	**320,570**	**2,341**	**14,196**	**8,070**	**402,331**
% Total	1.21	13.00	79.68	0.58	3.53	2.01	100.00
Mean Elevation	246.05	246.22	246.50	246.10	246.88	246.67	246.40
Standard Deviation	0.36	0.38	0.40	0.38	0.48	0.67	-
Coefficient of Variance	0.15	0.15	0.16	0.15	0.20	0.27	-
Minimum Elevation	244.20	243.95	243.99	243.88	244.13	244.13	243.88
Maximum Elevation	247.93	247.95	247.96	247.89	247.28	247.94	247.96
Range (m)	3.73	4.00	4.01	3.14	3.81	3.96	4.07
Coverage Area (km2)	0.87	7.81	33.77	0.30	1.20	0.76	44.71
Percent Coverage (%)	1.95	17.47	75.54	0.67	2.68	1.70	100.00

Figure 53. Quartile boxplots describing the range of depth distributions among substratum classes identified by Quester Tangent Corporation (QTC) single beam sonar analysis and QTC IMPACT substrate analysis in the eastern portion of Delta Marsh, Manitoba. Boxes represent data within the 2nd and 3rd quartiles while whiskers represent data within the 1st and 4th quartiles. For more details regarding the six substrate classes refer to Table 7.

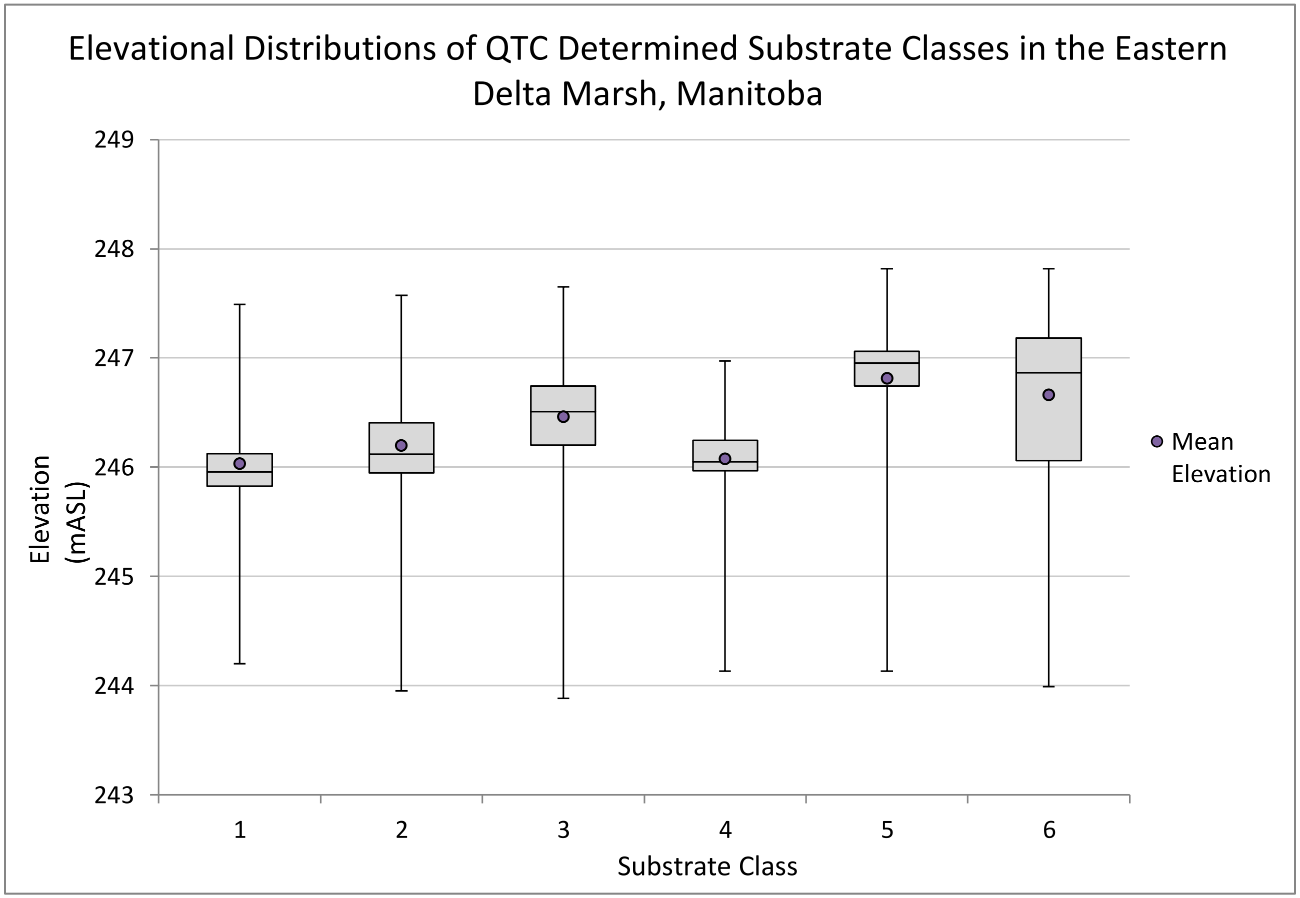


Table 9. A summary of substratum classes identified through Quester Tangent Corporation (QTC) single beam sonar analysis and examination of ground-truth samples in the eastern portion of the Delta Marsh, Manitoba.

Ground-Truthed Class	Clay	Organic	Plant	Total
Amalgamated QTC Classes	1 2 6	3 4	5	
# Samples	66010	321755	14027	401792
% Total	16.43	80.08	3.49	100.00
Mean Elevation	246.26	246.50	246.88	246.43
Standard Deviation	0.45	0.40	0.48	-
Coefficient of Variance	0.18	0.16	0.20	-
Minimum Elevation	243.95	243.88	244.13	243.88
Maximum Elevation	247.96	247.89	247.94	247.96
Elevational Range (m)	4.00	4.01	3.81	4.07
Coverage Area (km2)	9.44	34.07	1.20	44.71
% Coverage	21.12	76.20	2.68	100.00

Figure 54. Quartile boxplots describing the range of depth distributions among substratum classes as determined by Quester Tangent Corporation (QTC) single beam sonar analysis, QTC IMPACT substrate analysis and ground-truthed samples in the eastern portion of Delta Marsh, Manitoba.

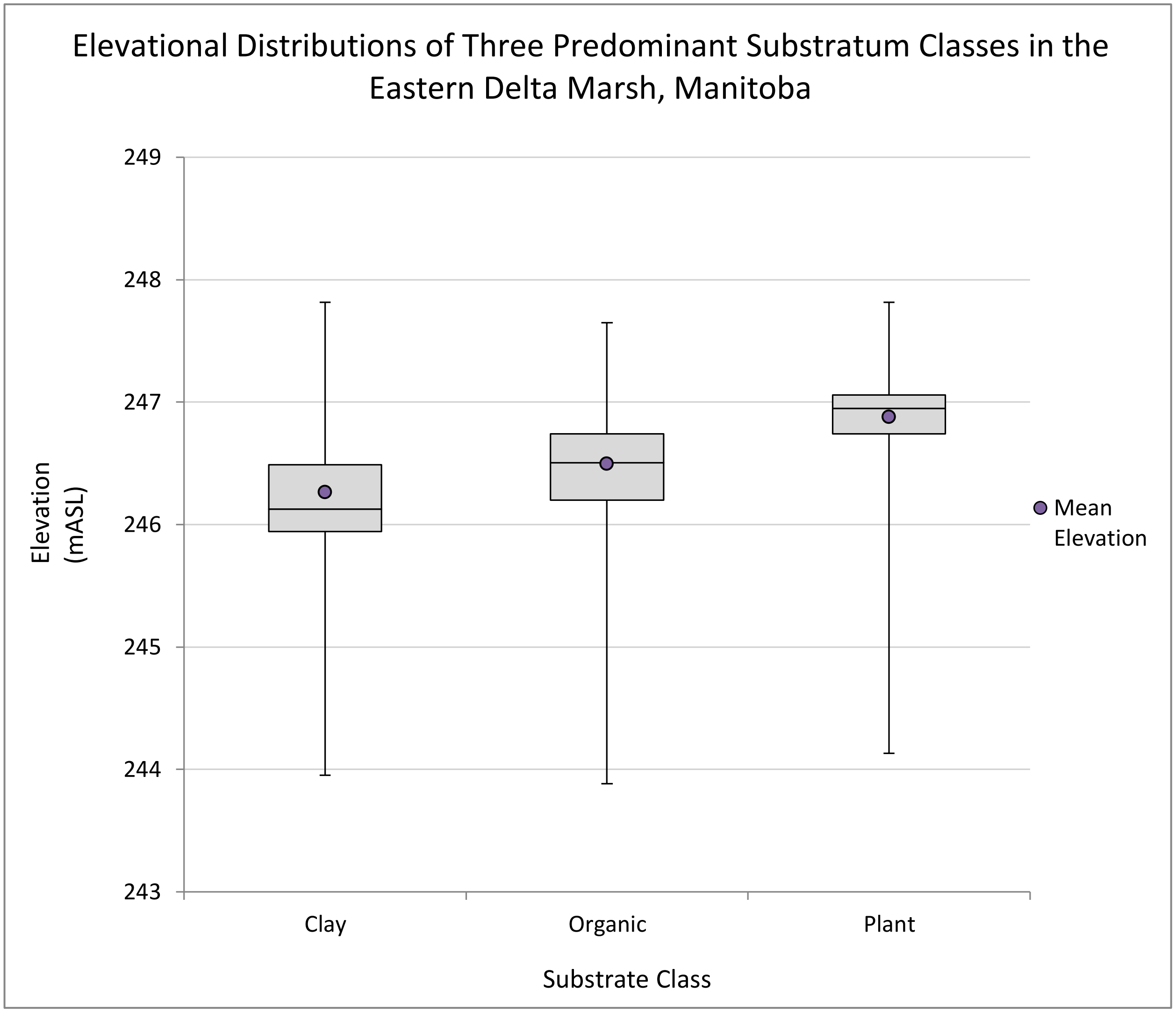
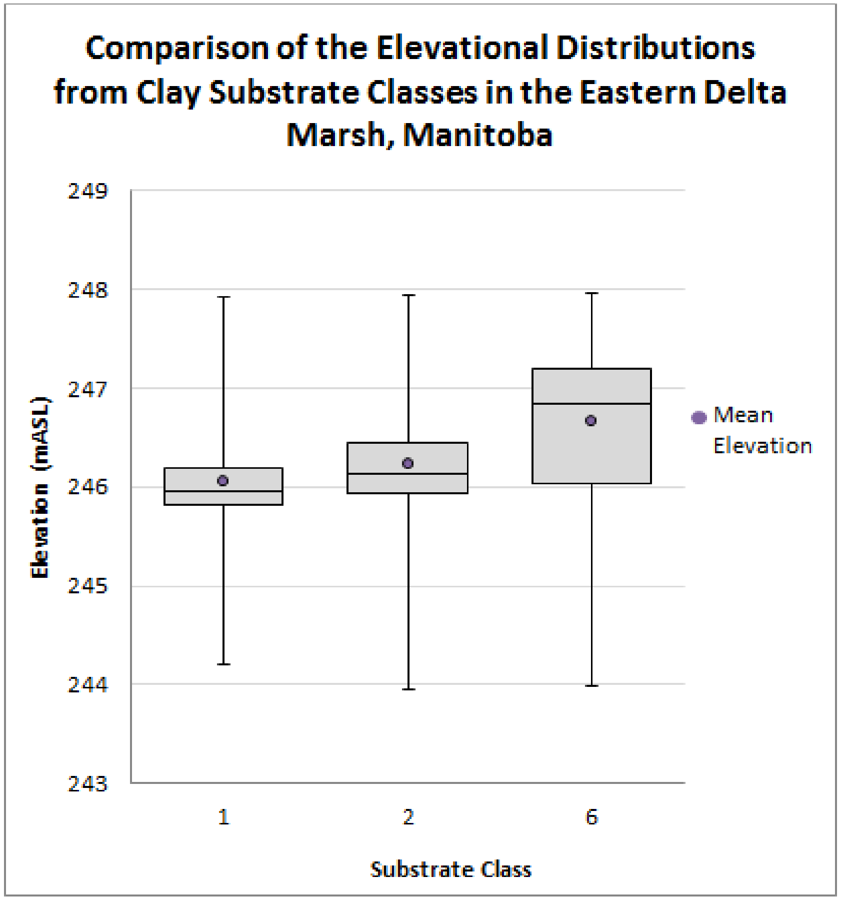
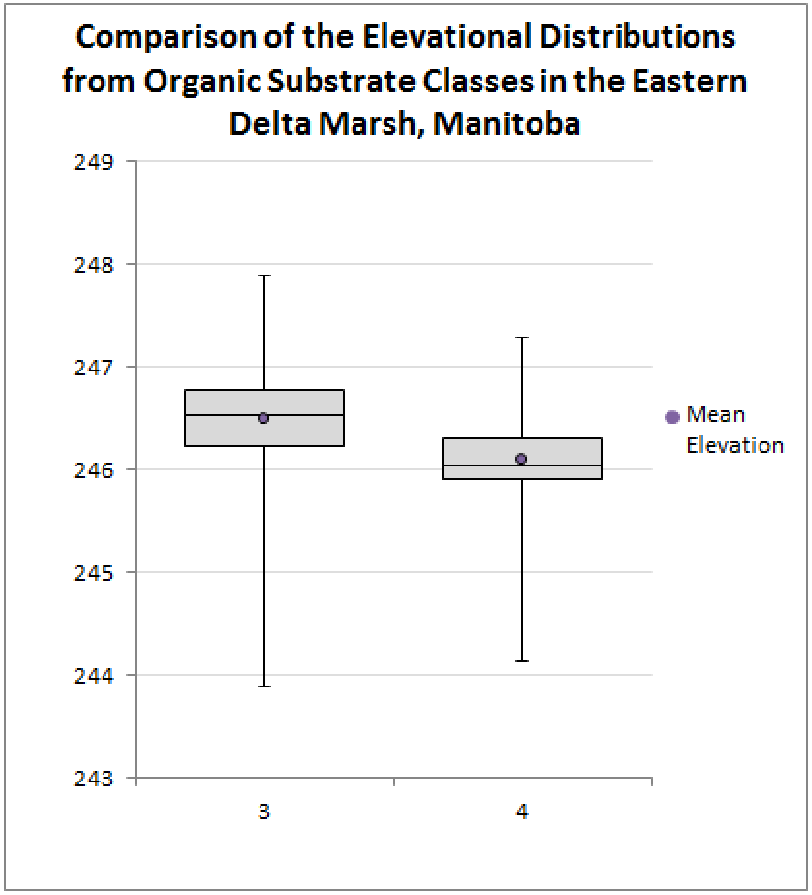


Figure 55. Comparison of substrate categories, identified by Quester Tangent Corporation (QTC) single beam sonar analysis and QTC IMPACT substrate analysis ,within the clay and organic substrate classes identified by ground-truthed samples in the eastern Delta Marsh, Manitoba.





8.0 – Final Discussions and Recommendations

8.1 - Hypotheses

- **Due to the large amount of vegetative material and highly productive nature of the marsh I expected that sediments in the marsh would be dominated by organic substrata.** This hypothesis was well supported. The organic substratum was the most prominent, comprising over 80% of sample points and over 75% of the total coverage in the study area. It was also the substratum class with the largest elevational range (4.01 m).

- **Substrata within the marsh would be distributed in a homogenous manner due to resuspension as a result of the shallow nature of the area and disturbance from wind and wave action.** Substrata within the marsh tended to be elevationally divided rendering this hypothesis invalid. I had originally hypothesized that the shallow nature of the marsh would result in frequent resuspension of sediments and a homogenous distribution of substrata classes but this does not seem to be the case.

- **Due to the shallow slope in the marsh and surrounding areas and the drastic increase in water levels, I expected that coverage of open water throughout the marsh in 2011 would increase in comparison to 2009 while the coverage of emergent vegetation would decrease significantly due to flooding and senescence.** Coverage of open water areas increased by approximately 56% from 63.83 km^2 in 2009 to 99.25 km^2 in 2011. Considering the rise in water levels of approximately 1.5 m and the shallow nature of the marsh this was not unexpected. The extent of flooded zones was much greater than this, but the growth of emergent vegetation conceals much of this area.

- ***Typha* would remain the dominant emergent species due to its preference for flooded conditions and its ability to form floating mats.** This hypothesis was proven valid. *Typha* was indeed the dominant emergent species during flooded conditions but it's difficult to determine to what extent. Because many vegetated areas became flooded and I was unable to distinguish between flooded areas populated by *Typha* or another emergent species I cannot present a concrete figure for percent coverage. Many of the areas that became flooded in 2009 were dominated by both *Typha* and *Phragmites* in 2009 so it is likely that the Flooded Vegetation class is comprised of both. In addition several flooded areas were observed to also contain large mats of floating *Typha*.

- **Due to its historical and present dominance in the marsh I expected that *Typha* would also be the dominant presence in the viable seed bank.** *Typha* was found to be the dominant species throughout all seed bank emergence experiments, being present in 100% of both moist and saturated treatments and 78% of flooded treatments. *Typha* was so prevalent in many of the moist and saturated treatments that seedlings were often removed in order to make room for the germination of other plants. Given its prevalence in the past and present vegetation communities and its ability to germinate over a wide range of conditions this was a likely outcome.

- **As many wetland plants require the presence of moist or saturated soils for germination, yet are not capable of germinating in flooded soils I expected that the diversity of germinating seeds would be lower in flooded emergence experiments than in moist or saturated experiments.** Given that many wetland plant species require exposed mudflat conditions for germination I did not expect that many species to appear in this treatment. Compared to the 12 species in the moist treatment and the 11 species in the saturated treatment only four species germinated in the flooded treatments. Additionally out of the four species that did germinate one was a submergent species and two were floating species. *Typha* was the only emergent species to germinate in the flooded treatment.

- **Due to its preference for flooded conditions *Typha* would be associated with relatively low elevations, while *Phragmites* would be associated with relatively high elevations.** The mean elevation for the *Typha* class was the lowest out of all vegetation classes (247.23 mASL) followed by the Mixed Vegetation and Flooded *Typha* classes (247.26 and 247.37 mASL respectively), though it had a relatively large range (245.85 – 250.99 mASL). *Phragmites,* although having a very similar mean elevation (247.40 mASL) had a minimum elevation over one meter higher than *Typha* ranging from 246.16 – 250.33 mASL. *Typha* is known to grow over a wide range of elevations.

8.2 – Recommendations

8.2.1 – Bathymetry

Although the data obtained from the bathymetry study could be used for many management purposes, including improving our understanding of the hydrology of the area, data for the flooded areas of the marsh and the terrestrial zones surrounding the marsh, are not very detailed. Although this data would be much more difficult and time consuming to obtain (emergent vegetation would make either remote sensing or manual collection of elevational data difficult) it would be very beneficial. This would also allow for a more accurate examination of the relationship between vegetation distributions and elevation/water depth in the marsh. Additionally, because of the difficulties encountered with regards to seiches, I would recommend that any future studies would benefit from multiple baseline depth measurements. This way any uneven distributions of water level during the study can be accounted for.

8.2.2 – Substrata Distribution

My study found that the distribution of substratum classes within the eastern portion of Delta Marsh is relatively distinct with silt/clay being heavily distributed in low elevation areas, plant materials being found in both low elevation areas and those close to vegetated areas, while the organic substratum seems to be distributed throughout most areas. As mentioned in Chapter 4 it is unknown if this separation of substrata would be observed in a normal water year or if the increased water depths experienced due to the flood reduced the suspension of sediments from wind and wave action. A future study conducted during a normal water year may be interesting in further exploring the patterns of sedimentation and resuspension in the marsh. Further study of the marsh substrata themselves, through particle size and organic content analyses, would possibly allow for the distinction of more than three substrata classes, as was suggested by the QTC analysis.

8.2.3 – Vegetation Distribution

Although the observations obtained from the comparison of vegetation distributions from normal water level and flood years were not unexpected they were very informative. Based on the shallow slope of the majority of the marsh a small change in water level can result in a significant redistribution of water. These changes can have a large impact the distributions of emergent vegetation as well. As demonstrated by my study the 2011 flood resulted in the senescence and flooding of large portions of previously vegetated areas. Unfortunately while analyzing the satellite imagery several classes could not accurately be identified, namely the Mixed Vegetation and Flooded Vegetation classes. Additionally two of the classes identified in 2009, *Carex spp*. and Whitetop, were not identified in the 2011 survey. This may have been due, in part, to the lack of ground-truthing during the study. An examination of the vegetation distributions in the marsh in the near future would be beneficial in better understanding the patterns of vegetation growth following a drawdown and would profit from a more thorough ground-truthing survey to more accurately classify satellite images.

8.2.4 – Seed Bank Analysis

Although most of the species identified in my seed bank study were commonly found in Delta Marsh and had been identified in previous studies the number of species that germinated in the emergence experiments was lower than I had expected. This is likely due to the relatively low number of samples which I examined; unfortunately the number of samples examined was limited due to greenhouse space. Pederson's 1981 study of 250 soil samples from Delta Marsh resulted in the germination of 34 unique species. A larger study would likely provide a better understanding of the viable seeds that remain available in the marsh's seed bank. Due to the variety of species found in each of the three treatments I would recommend that at least two treatments (moist and saturated) be implemented. Data from this and other future studies will be beneficial in predicting the diversity of post drawdown areas in the marsh.

8.2.5 - Management

Since the installation of the FRCS fluctuations in water level on Lake Manitoba and Delta Marsh have decreased drastically (Lake Manitoba Regulation Review Advisory Committee, 2003; Water Office of Canada, 2014). Prior to the installation of this control structure, water levels were much more unstable. It is widely known that fluctuating water levels are integral in the maintenance of healthy wetlands as they create a pattern of cyclical environmental conditions. This cyclical nature prevents the dominance of aggressive species through flooding conditions as well as allowing for the resurgence of less aggressive species during drawdown conditions (van der Valk and Davis, 1978; Spence, 1982; Keddy and Ellis, 1985; Squires and van der Valk, 1992; van der Valk et al., 1994). The stabilized water conditions in Delta Marsh have resulted in the spread and domination of *Typha x glauca*. Due to the 2011 flood the coverage area of *Typha* in the marsh was decreased considerably. Since the flood water levels have returned to normal (Figure 1) and it is likely that many of the areas in which vegetation senescence occurred were exposed as mudflats when these waters receded. Based on the results of my seed bank experiments I would expect that the diversity of plant species in these areas would have been much more diverse than those previously existing. It would be very beneficial to conduct a study in the near future to determine if this is in fact the case. Based on the results of the satellite imagery classification I would recommend that ground truthing be an integral part of any future study in order to more accurately interpret the imagery. Future considerations into the management of the marsh should explore the possibility of reintroducing some fluctuation into the water level regulation of the Lake, though clearly not to the extent seen in this study. This was actually recommended in 2003 by the Lake Manitoba Regulation Review Advisory Committee and in 2013 by the Lake Manitoba Lake St. Martin Regulation Review Committee. Recommendations included reduction of the maximum water level to 247.5 mASL, which is lower than the current average water level, as well as decreasing the minimum water level and allowing water levels to drop to at least 0.3 m below the maximum following a flood event in order to allow regeneration through the seed bank. It is likely that this would assist in managing the dominance of *Typha* in the area.

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