IMPACTS OF ANTRHOPOGENIC DISTURBANCE AFFECTING COASTAL WETLAND VEGETATION

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I want to dedicate this to my family for all the

support they provided me throughout this process.

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ABSTRACT

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by W. Cody Webster

Great Lakes coastal wetlands are a vital component in maintaining the environmental quality of the Laurentian Great Lakes. They provide many environmental services such as ground water recharge, filtration, nutrient storage and cycling, flood control, erosion control, and habitat for aquatic, terrestrial, and avian species. The value of coastal wetlands is of increasing awareness to the general public and managers. With approximately 70% of the states coastal wetlands lost due to anthropogenic stress, it is important that we understand the detrimental impacts we may be having on these systems in order to better protect them.

Agriculture and fragmentation are two major types of disturbance that has contributed to the reduction in coastal wetland habitat and quality. The Great Lakes have been experiencing prolonged low water levels, which have been accelerating the rate of fragmentation. This results from waterfront property owners cutting boat channels within the vegetation or deepening existing ones to maintain access to the open water.

The primary objective of this study was to determine if disturbance from boat channels was having an effect on coastal wetland vegetation adjacent to disturbances. Furthermore, over half of the sites sampled were part of channelized drainage systems emptying agricultural runoff from the adjacent land. This led to the second objective which was to examine the effects of drainage ditches on coastal wetland vegetation. The study was conducted by comparing areas adjacent to disturbance with intact coastal wetlands along Michigan’s shoreline in Lakes Huron and Michigan. Study sites were located in Saginaw Bay of Lake Huron, Northern Lake Huron, and Northern Lake Michigan, and were sampled in the years of 2009, 2010, and 2011. An

inventory of plant taxa and accompanying physical/chemical data were analyzed to relate coastal wetland vegetation to disturbance.

Boat channels and drainage ditches were found to influence both the plant community and the abiotic conditions. However, the ordinations revealed that large scale factors, such as region sampled, effective fetch, and land use, had the greatest influence over plant communities as opposed to the local disturbance caused from boat channels. Invasive species richness had a tendency to be higher at boat channels and had differences in the abiotic conditions. Additionally, drainage ditches increased nutrient levels in the near shore areas of where they emptied and seemed to facilitate the spread of the invasive species, *Typha angustifolia*.

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CHAPTER I

INTRODUCTION

The Laurentian Great Lakes are subject to major water level fluctuations which are an important component in maintaining the integrity of fringing Great Lakes coastal wetlands. Fluctuating water levels provide the natural disturbance necessary to help maintain the structure and function of wetland plant communities which are vital to the health of the system (Gathman *et al.* 2005, Keddy and Reznicek 1986). Along with promoting the integrity of Great Lakes coastal wetlands, water level fluctuations also provoke accelerated rates of anthropogenic disturbance adding to disturbance they have been experiencing from urbanization and agriculture (Albert and Minc 2004, Meadows *et al.* 2005, Trebitz *et al.* 2007, Trebitz and Taylor 2007, Uzarski *et al.* 2009, Wilcox and Meeker 1991). For instance, during times of high water levels waterfront land owners often put in sea walls to protect against shoreline erosion while during times of low water levels, land owners cut boat channels within vegetation or deepen existing boat channels to maintain boat access to the open water. Comparable to the conditions predicted by climate change science, the water levels of the Laurentian Great Lakes are at a near record low and are predicted to decline (Angel and Kunkel 2010, Mortsch and Quinn 1996, Lofgren *et al.* 2002). Low water levels have consequently, increased the rate of fragmentation within coastal wetlands which can partly be attributed boat channels (Uzarski *et al.* 2009).

Great Lake Coastal wetlands are a dynamic ecosystem due to their hydrologic variability caused by water level fluctuations within the Great Lakes. The Great Lakes are subject to water fluctuations on three major temporal scales, short term, seasonal, and inter-annual fluctuations (Bedford 1992, Keddy and Reznicek 1986, Gathman *et al.* 2005, Trebitz 2006, Uzarski 2009). Short term fluctuations include storm action, ice flow, and seiche events that expose nearshore emergent marshes to periodic disturbance regiemes (Trebitz 2006). Superimposed upon short term fluctuations are seasonal fluctuations. Seasonal fluctuations are dependent on the amount of precipitation of the previous year and include the accumulation of snow packs and the severity of the lake surface freezing in the winter (Uzarski 2009). Usually, water levels in the Laurentian Great Lakes reach their seasonal maximum during the mid to late summer months and their seasonal lows during the winter months (Uzarski 2009). Lastly, inter-annual water fluctuations are dependent upon the current year's weather patterns and are the most unpredictable. These types of fluctuations are thought to have the most control in determining the lateral boundaries of wetland vegetation zones (Gathman *et al.* 2005).

Plant communities respond to the hydrology of their environment and change in conjunction with the fluctuating water levels. Plants more tolerant of inundation will be found more lakeward while species less tolerant of inundation will be found more landward (Keddy and Reznicek 1986, Gathman *et al.* 2005, Wilcox and Nichols 2008). Within coastal wetlands, plant communities can be categorized into vegetation zones, which include: submerged/floating zone, emergent zone, wet meadow zone, and shrub/swamp zone (Uzarski 2009). As the water levels shift landward or lakeward, plant zones will expand or contract along this continuum of the fluctuating water levels. However, these shifts occur in a mosaic type pattern, as opposed to entire vegetation zones shifting as a whole, due to individual plant species having different inundation tolerance thresholds (Gathman *et al.* 2005). During low levels, plant communities will shift lakeward, displacing plant communities further down the environmental gradient. Conversely, when water levels are high, plant communities will shift landward displacing communities farther up the environmental gradient (Mortsch 1998). This continuous shift in plant species, initiated by changes in hydrology, is what preserves a diverse plant community by not allowing any one species to dominate a given area (Chow-Fraser *et al.* 1998, Keddy and Reznicek 1986). These shifts however, can only occur under specific conditions and any disruption by human development or habitat alteration may result in changes in the composition of plant communities (Bedford *et al.* 1976, Herrick and Wolf 2005, Kercher *et al.* 2004, Wilcox 1995).

Unregulated water fluctuations provide the natural disturbance needed for the formation of wetland plant zones and are critical in maintaining the integrity of Great Lakes coastal wetlands by promoting diversity (Gathman *et al.* 2005, Keddy and Reznicek 1986, Wilcox and Meeker 1991). Disruptions in this natural process give a competitive advantage to species intolerant of water level change and its associated stressors, frequently resulting in monocultures. Many environmental services are provided by wetland plant communities such as ground water recharge, filtration, nutrient storage and cycling, flood control, erosion control, and habitat for aquatic, terrestrial and avian species (Woodward and Wui 2000). However, current low water levels have exposed wetland vegetation to increased human disturbance while jeopardizing these environmental services.

The Laurentian Great Lakes have been experiencing prolonged low water levels which have raised public concerns regarding recreational boating, shipping, lakefront property, and natural resources (Uzarski *et al.* 2009, Wilcox and Nichols 2008). Lakefront home owners with docks, marinas, and shipping channels have required vegetation removal as well as dredging to maintain access to the open water. Shoreline areas have been overgrown with vegetation as the germination of the exposed seed bank promotes new growth to new emergent species that have been suppressed due to previous high water levels. The new vegetation growth encourages many of these coastal homeowners to repeatedly mow, burn, spray or manually remove the vegetation in effort to keep their view and maintain access to the open water (Uzarski *et al.* 2009,Wilcox and Nichols 2008). Physical disturbances resulting in the direct removal of competing species have been shown to increase the availability of shared resources as well as initiating shifts in biological communities due to habitat alterations (Turkington *et al.* 1993, Uzarski *et al.* 2009, Wilson and Tilman 1993).

Wetlands can act as "sinks", collecting materials from the surrounding terrestrial landscape, making them inherently susceptible to invasive species, however, increased human disturbance has also been thought to aid in their spread and establishment (Albert and Minc 2004, Herrick and Wolf 2005, Kercher *et al.* 2004, Minchinton and Bertness 2003, Wilcox 1995). There are many studies that suggest that areas with increased disturbance are more likely to be susceptible to the establishment of invasive plant species (Albert and Minc 2004, Herrick and Wolf 2005, Kercher *et al.* 2004, Minchinton and Bertness 2003, Trebitz and Taylor 2007, Wilcox 1995, Woo and Zedler 2002, Zedler and Kercher 2004). Disturbances altering hydrologic regimes and nutrient levels are common environmental changes that have been found to coincide with shifts in community composition and assist in the spread of invasive species (Kertcher *et al.* 2004, Trebitz and Taylor 2007, Herrick and Wolf 2005). These types of disturbances are frequently encountered in the lower lakes as well as the southern parts of Lakes Huron and Michigan. This disturbance gradient is also seen in the frequency of exotics within wetlands (Trebitz and Taylor 2007). Many exotic species are considered to be invasive and are problematic because of their competitive ability which enables them to displace native species. Invasive species have been documented to have negative repercussions on flora richness, faunal habitat (overly dense growth, monocultures), forage value (less desirable plants for waterfowl, support less macroinvertabrates), and ecosystem function such as nutrient cycling (Zedler and Kercher 2004).

Agricultural land use in the adjacent watersheds of Great Lakes coastal wetlands has been a substantial source of wetland degradation in the southern areas of the Great Lakes basin. Agricultural practices have been associated with increased sedimentation and nutrient loading along the Great Lakes shoreline which can have detrimental impacts on the macrophyte flora of aquatic systems (Lougheed *et al.* 2001, Trebitz and Taylor 2007). Many agricultural areas have channelized drainage ditches to efficiently remove excess water from crop fields. Drainage ditches are abundant in agricultural areas, where they empty along the shoreline of the Great Lakes and often into wetlands. Drainage ditches are associated with increased sedimentation and nutrient loading which alter natural environmental conditions. Disruption in the biological process of a system potentially gives species that are more tolerant to stressful abiotic conditions an advantage over species less tolerant, thus, provoking the establishment and spread of invasive species (Turkington *et al.* 1993, Wilson and Tilman 1993). This is a concern because many invasive species are of little ecological value to native wildlife inhabiting wetlands (Odum 1987, Thiet 2002).

Great Lake coastal wetlands are of great value to wildlife. The utilization of wildlife inhabiting coastal wetlands is influenced by high primary productivity and diversity (ILERST 1981, Jaworski *et al.* 1981, Mortsch 1998; Weller 1978). There has been 80+ fish species documented utilizing wetlands during some part of their life history with extensive use for spawning and nursery habitat (Jude and Pappas 1992, Wilcox 1995). Coastal wetlands also provide habitat for 80-90 bird species for cover, migrating, and staging areas (ILERSB 1981, Prince *et al.* 1992, Weeber and Valianatos 2000). Furthermore, there have been over 250 identified taxa of invertebrates, 20+ species of mammals, and many species of reptiles and amphibians that have also been documented utilizing coastal wetlands (Burton *et al.* 1999, 2002, 2004; Cardinale *et al.* 1997, 1998, Gathman *et al.* 1999, Kashian and Burton 2000). These coastal environments are of great importance to many forms of wildlife at some point in their life histories and changes in their structural habitat from human intervention may have deleterious consequences.

Study Objectives

Vegetation is a vital component in determining the structure and function of wetlands. Vegetation type is often correlated with physical and chemical conditions as well as the wildlife inhabiting them. The importance of wetlands to the Laurentian Great lakes ecosystems makes it important to understand the impacts humans can have on these coastal environments. Approximately 50% of all of Michigan's wetlands have already been lost since European settlement; this loss includes 70% of the state's Great Lakes coastal wetlands (Cwikiel 1998). The remaining coastal wetlands experience accelerated rates of fragmentation during times of low water levels. With water levels predicted to continue to decline with climate change (Angel and Kunkel 2010, Lofgren *et al.* 2002, Mortsch and Quinn 1996), wetland fragmentation caused from boat channels will most likely continue to increase due to the common interest of waterfront property owners wanting personal docks for their watercrafts as well as access to the open water. The main objective of the study was to determine if the disturbance caused from boat channels had an effect on the structure of wetland flora and its associated abiotic components.

The second objective of the study was to investigate possible effects that drainage ditches may have on the flora of coastal wetlands. This objective was later developed to take advantage of having many of the sampling sites being near drainage ditches. With the ongoing battle with invasive species in many coastal wetlands, giving more insight to the direct consequences of land practices may lead to better management practices. There have been numerous studies documenting plant responses to increased nutrients (Kertcher *et al.* 2004, Trebitz and Taylor 2007, Herrick and Wolf 2005); however, little has been done focusing on the direct effects of agricultural drainage ditches on wetland vegetation. Therefore, along with investigating the effects of boat channels within coastal wetlands, this study also addressed community structure and its associated physical/chemical characteristics located at the mouths of drainage systems.

The intensity of disturbance that Great Lakes coastal wetlands have been experiencing is at an accelerated rate. Increasing public awareness of the importance of these systems and the repercussions of human disturbance is the best way to protect them. Thus, the main purpose of this study was to further understand the impacts of anthropogenic disturbance in Great Lakes coastal wetlands. It is our hope that the results of this study will help in developing better management practices and assist in providing information to managers, legislators, and scientists in order to make the best possible decisions for maintaining the quality of Great Lakes ecosystems.

CHAPTER II

METHODS AND MATERIALS

Site selection

Study sites included fringing coastal wetlands with surface water connection to the Great Lakes. All study sites were along Michigan's shoreline and were greater than 4 ha. Sampling was conducted in 2009, 2010, and 2011. In 2009, study sites were selected haphazardly on the condition of having a boat channel. In 2010 and 2011, sites were selected randomly by pooling all of Michigan's coastal wetlands and randomly drawing25 study sites in 2010 and 45 were drawn in 2011. Of these randomly selected study sites, the ones sampled were based on the condition of having a boat channel. Study sites ranged across three different regions, Saginaw Bay, Northern Lake Huron, and Northern Lake Michigan (Figure 1). Each study site consisted of a paired reference and disturbed site resulting in 19 paired sites, and a total of 38 individual sites.

Data collection was within a delineated five meter by five meter sample plot. For disturbed sites, sample plots were placed in the center of the vegetation zone adjacent to the boat channel. If the boat channel was not dredged, the plot was placed at the edge of the vegetation in junction with the boat channel. For boat channels that were dredged, the sample plot was placed on top of the topographic incline of the channel edges where the bathymetry plateaued and the water levels within the sample plot were relatively consistent. The incline was considered part of the boat channel, regardless of vegetation being present. It was important to sample on the margins of the incline in order to not sample within the disturbance. For reference sites, sample plots were placed in the next closest intact wetland, from the boat channel, that was not subject any visible disturbance. Water depth was kept constant, within a range of 10 cm, between each paired disturbed and reference site. Due to hydrology of a wetland being the major determinant of vegetation type, sampling relatively similar water depths allowed for an accurate comparison between disturbed and undisturbed sites. Paired reference and disturbed sites, ranged between 100-1000 meters apart.

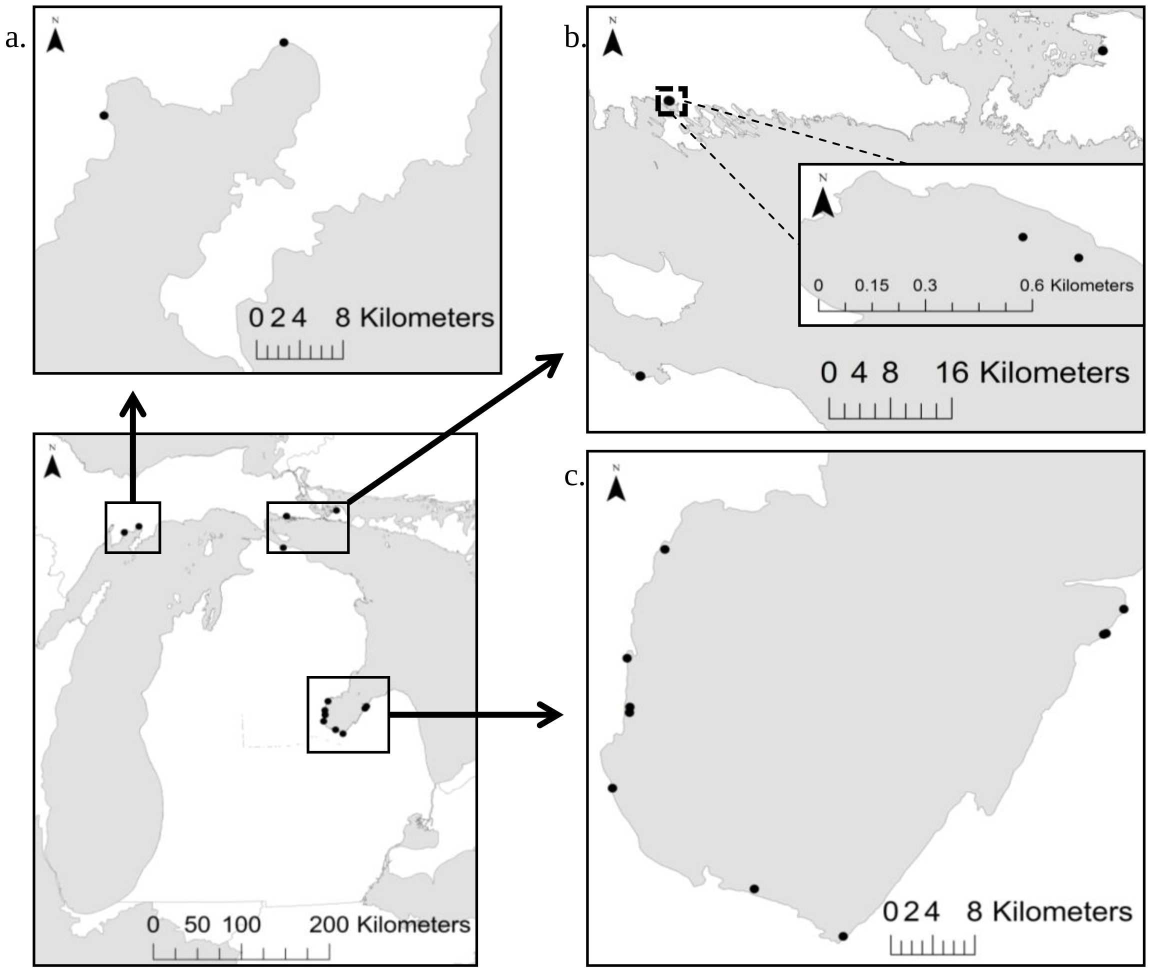

Figure 1. Sites sampled during the years of 2009, 2010, and 2011. There were two paired sites sampled in northern Lake Michigan (a), four paired sites sampled in northern Lake Huron (b), and 13 paired sites sample in Saginaw Bay (c). There were three sample locations in Saginaw Bay that were resampled in separate years and treated as independent sites during analysis. A total of 19 paired sites were sampled.

Disturbance Quantification

A disturbance index for boat channels was created to quantify the level of disturbance the adjacent plant communities were exposed to. The criterion used was based on the presence of dredging, the degree of vegetation removal and the width of the channel. This separated the boat channels into three different disturbance levels. Level one boat channels were the smallest and had the lowest physical disturbance to the adjacent plant communities and little substrate disruption. The boat channels were created by the removal of aquatic vegetation by the prop wash of small watercraft boat traffic. These boat channels were typically in front of waterfront homes and small infrequently used boat launches. Level two boat channels were larger in size and were subjected to channel substrate dredging. These were typically associated with private and public marinas. The channels were marked with buoys; however, they were all less than 30 meters wide. Level three boat channels were channels greater than 30 meters wide and were dredged deep enough to navigate large boats. These channels were sometimes associated with industrial shipping. Only one level three disturbance was encountered while sampling.

Vegetation sampling

Vegetation data were collected at each site within three haphazardly placed 0.5 m^2 quadrats, located within a 5 m^2 delineated sample plot. Stem densities were taken for each plant species that was within the quadrat. Stem density was determined by the number of plant stems per quadrat. However, when submergent vegetation was too dense to get a stem density, percent cover was used which was then substituted for stem density in the analysis. It was thought to be the closest representative of stem density. This was experienced on only two occasions. Species were identified in the field and unidentified species were collected and later identified in the lab.

Chemical and physical measurements

Basic chemical/physical parameters were measured *in situ* for each reference and disturbed site using a Multiparameter Water Quality Sonde (YSI model 6600 V2). These measurements were taken in the center of the 5 m^2delineated sample plot. The parameters measured included temperature (°C), pH, dissolved oxygen (mg/L), turbidity (NTU), chlorophyll-*a* (ug/L), oxidation-reduction potential (mV), and specific conductance (µS/cm).

Two water samples were collected in 200 mL acid washed bottles and were stored on ice to later determine alkalinity and measure dissolved nutrients. One water sample was used to determine alkalinity by performing a titration using 100 mL water sample with 0.02 N H_2SO_4 to a pH of 4.5. The amount of sulfuric acid used in the titration was multiplied by 10 to determine the amount of $CaCO_3$ (mg/L) in the water column. These titrations were performed within 24 hours of collection. The remaining water sample was used to determine dissolved nutrients. This was filtered through a 0.45 µm Millipore filter and then placed back on ice to be taken to the laboratory. In the laboratory, soluble reactive phosphorus (SRP), NO_3-N, and NH_4-N levels were measured using a BRAN+LUEBBE QuAAtro analyzer.

Percent organic matter was also determined for each site to estimate biological production. Soil samples were collected using a 47 mm diameter core sampler, using the top 10 cm of substrate. After the soil sample was collected it was placed on ice to reduce respiration when taken back to the laboratory. Each sediment core was oven-dried at 60°C in the laboratory for approximately 24 hours or until a constant weight was achieved. Soil samples were then weighed, and ashed at 550ºC for an additional 24 hours to burn the organic material in the sample. The loss in weight on ignition was used to determine the total organic matter in the soil. Additional physical measurements included water depth and organic depth. Water depth was documented using an aluminum meter stick at each quadrat within the 5 m^2 delineated sample area to measure from the surface of the substrate to the surface of the water. Organic depth was determined by pushing the meter stick through the sediment until reaching a resistant layer.

Modified Effective Fetch

The distribution of aquatic plants is strongly influenced by hydrology which is, in part, affected by wave exposure. Therefore, a modified effective fetch was calculated using procedures recommended by the British Columbia Estuary Mapping System to determine the degree of wave exposure each site was subjected to (Resources Inventory Committee 1999). Using Google Earth™, fetch distances were measured along three angles relative to the shoreline: 90˚ (perpendicular), 45˚ to the left of perpendicular and 45˚ to the right of perpendicular. Each determined fetch was then used in calculating the modified effective fetch:

Equation 1:

$$F_e = \frac{\cos(45^\circ) * F_{45L} + \sin(90^\circ) * F_{090} + \cos(45^\circ) * F_{45R}}{\cos 45^\circ + \sin 90^\circ + \cos 45^\circ}$$

where F_{45L} = fetch distance along the 45˚ angle left of the perpendicular angle, F_{090} = fetch distance along the 90˚ angle (perpendicular), and F_{45R} = fetch distance along the 45˚ angle right of the perpendicular angle.

Statistical Analysis

Relationships within the plant community were explored using non-metric multi-dimensional scaling (NMDS) in an effort to determine differences in magnitude between paired reference and disturbed sites as well as identifying other community relationships among wetlands sampled that were not driven by paired reference and disturbed sites. The average stem density for each species was used as the input data for the plant community. The Bray-Curtis distance measure was used to perform the NMDS with a maximum of 400 iterations, 40 runs with real data, and 50 randomized runs for the Monte Carlo permutation procedure using PC-ORD (version 4.34, MjM Software). However, instances where NMDS failed to find a stable solution within the dataset (i.e., trends in the data set were not different from random data), a correspondence analysis was then used in an effort to determine gradients within the data. Data were also analyzed at a genus resolution to alleviate the problem of rare species overwhelming the analyses, more specifically for the correspondence analysis. Each dimension was then correlated with the physical and chemical components using either a Pearson or Spearman correlation, depending upon distribution of the data, to relate the abiotic variables to the plant community using SAS version 9.1 (SAS Institute Inc., Cary, NC, USA). Bonferroni corrections were not made due to the analysis being exploratory. Therefore, it is important to note that there may be spurious correlations.

NMDS was followed up by principal components analysis (PCA) to determine gradients in the abiotic community, further assisting in relating the abiotic and biotic communities. PCA was performed using SAS version 9.1 (SAS Institute Inc., Cary, NC, USA). All chemical/physical parameters as well as effective fetch, organic depth and water depth were used in determining the principle components (PCs). A Scree diagram was used along with the amount of variation each PC explained within the dataset to determine the number of dimensions to use in the analysis. Eigenvectors were used in determining which variables most influenced each PC.

The steps taken while performing the NMDS and PCA ordination procedures were an iterative process in an effort to target any differences between reference and disturbed sites.

Sites were partitioned into groups that met a specific criteria based on what the NMDS was stratifying the sites by. This was done in an effort to eliminate possible components that could prevent NMDS from detecting differences between reference and disturbed sites. Data analysis was then repeated on these partitioned groups. Disturbed sites were pulled into the analysis if their paired reference sites met the group's specifications. This partitioning of data was continued until all options were exhausted. Differences among sites were investigated using multi-response permutation procedures (MRPP). A multi-response blocked procedure (MRBP) was used to detect differences between reference and disturbed sites. For the analysis, each paired reference and disturbed site was a block.

Geographic region, effective fetch, the presence of drainage ditches, and the level of disturbance were also investigated during analysis for the potential of having effects on the biota and abiotic parameters. Sites were categorized into two separate groups, Saginaw Bay sites (13 paired sites) and northern sites (6 paired sites). The northern sites included all sites sampled in northern Lakes Huron and Michigan. Effective fetch was categorized into three separate groups, sites with an effective fetch greater than 35 km, sites with an effective fetch between 35 km and 200 km, and sites with an effective fetch greater than 200 km. The effective fetch groups were determined by where the largest breaks in the data were when ranking the sites in ascending order based on their modified effective fetch distance. This was done to determine if there were any trends in the plant data or physical/chemical data associated with modified effective fetch distances. Many of the boat channels sampled in this study were located at the mouth of drainage systems and rivers. These sites were taken into account and separated during analysis in an attempt to expose any affects that these outlets may have on the adjacent wetland biota and their abiotic environment.

Matched pair statistical tests were performed to reduce the among-site variability and isolate the treatment (boat channels). Therefore, paired-t tests and Wilcoxon signed-ranks tests were performed using Minitab version 14 (Minitab Inc., U.S.A.) with an alpha level of 0.05 to detect any differences in the abiotic parameters and biotic communities between reference and disturbed sites. The statistical procedure used depended on the distribution of the data. Differences between reference and disturbed sites in species richness of exotics and the overall species richness were investigated using Wilcoxon signed-ranks tests and differences in stem density of exotic species and the overall stem densities were investigated by using parametric paired-t tests.

CHAPTER III

RESULTS

Ordination Procedures at a Species Resolution

All Vegetation and All Sites

The NMDS procedure was conducted on 24 plant species that incorporated all species sampled and all 38 sampling sites (Tables 1 and 2). Three dimensions were most appropriate in explaining the gradients in the plant community with stress stabilizing at 11.7 after 33 iterations. Total variation explained by the three-dimensional solution, was 86%. Dimension one accounted for 42% of the variation in the data set and was positively correlated with water depth (r = 0.51, p = 0.001) and geographic region (r = 0.504, p = 0.001). Dimension one was negatively correlated with effective fetch (r = -0.39, p = 0.02) and dissolved oxygen (r = -0.372, p = 0.02). Dimension two accounted for 24% and was positively correlated with oxidation reduction potential (r = 0.379, p = 0.02) and negatively correlated with turbidity (r = -0.329, p = 0.04). Dimension three explained an additional 20% of the data set and had a positive correlation with pH (r = 0.319, p = 0.05), temperature (r = 0.542, p = 0.0004), total percent organics (r = 0.418, p = 0.01), and stem density (r = 0.431, p = 0.01). Dimension three was negatively correlated with turbidity (r = -0.374, p = 0.021), specific conductance (r = -0.630, p < 0.0001), alkalinity (r = -0.581, p = 0.0001), chlorophyll *a* (r = -0.405, p = 0.01), NO_3 (r = -0.478, p = 0.002), organic depth (r = -0.427, p = 0.01), and the presence of drainage ditches (sites within 900 meters of a drainage ditch; r = -0.509, p = 0.001).

Sites were strongly stratified within the NMDS ordinations by dominant plant species. Dominant species were defined at a site by a species having the highest proportional stem density and were dominant at four or more of the sites sampled. The four dominant species included *Schoenoplectus acutus*, *S. pungens*, *S. tabernaemontani*, and *Typha angustifolia*. Sites were also separated by dominant genera, being *Typha spp*. and *Schoenoplectus spp.*, which was best represented in dimension three (Figure 2).

Table 1. Stem densities for all taxa from Saginaw Bay sites sampled in 2009, 2010, and 2011. * = sites within 900 m of a drainage ditch.

Year	Paired Site	Site Type	Code	*Asclepias incarnata* (L.)	*Ceratophyllum demersum* (L.)	*Juncus effusus* (L.)	*Lythrum salicaria* (L.)	*Nuphar variegata* (Durand)	*Phragmites australis* (Cav.)	*Sagittaria latifolia* (Willd.)	*Sagittaria* sp.	*Schoenoplectus acutus* (Bigelow)	*Schoenoplectus pungens* (Vahl.)	*Schoenoplectus* sp.	*Schoenoplectus tabernaemontani* (C.C. Gmel.)	*Typha angustifolia* (L.)	*Typha latifolia* (L.)	*Typha* sp.
2009	Filion Rd	Disturbed*	FLD	-	-	-	-	-	-	1.33	-	-	-	-	-	16.00	-	-
		Reference*	FLR	-	-	-	-	0.33	-	-	-	-	-	-	-	-	-	9.00
	Bayshore Marina	Disturbed	BSD09	-	-	-	-	-	4.00	-	-	-	25.00	-	-	-	-	-
		Reference	BSR09	-	-	-	-	-	0.33	-	-	6.00	16.00	-	-	-	-	-
	Coggins	Disturbed*	CGD	-	0.33	-	-	-	5.00	-	1.67	-	-	-	-	-	4.00	-
		Reference*	CGR	-	-	-	-	-	-	-	-	7.33	-	-	-	-	11.33	-
	Eagle Bay	Disturbed	EBD	-	-	-	1.33	-	-	-	-	-	26.33	0.67	-	-	-	-
		Reference	EBR	0.33	-	10.33	-	-	3.67	-	-	-	12.00	-	-	-	-	-
	Gambills	Disturbed*	GBD09	-	-	-	-	-	-	-	-	-	19.00	-	-	-	-	-
		Reference*	GBR09	-	-	-	-	-	-	-	-	-	22.67	-	-	-	-	-
	Pinconning	Disturbed	PND	-	-	-	-	-	0.33	-	-	-	7.00	-	9.33	-	-	-
		Reference	PNR	-	-	-	-	-	-	-	-	-	42.33	-	-	-	-	1.00
2010	Linwood	Disturbed*	LWD10	-	-	-	-	-	1.33	-	-	-	-	-	-	3.00	-	-
		Reference*	LWR10	-	-	-	-	-	-	-	-	-	71.00	-	-	-	-	-
	Bayshore Marina A	Disturbed	BSDA10	-	-	-	-	-	-	-	-	-	17.00	-	-	-	-	-
		Reference	BSRA10	-	-	-	-	-	-	-	-	-	25.67	-	-	-	-	-
	Bayshore Marina B	Disturbed	BSDB10	-	-	-	-	-	1.00	-	-	-	8.67	-	-	-	-	-
		Reference	BSRB10	-	-	-	-	-	-	-	-	-	25.67	-	-	-	-	-
2011	Quanacasee	Disturbed*	QSD	-	-	-	-	-	-	-	-	-	-	-	-	10.67	-	-
		Reference*	QSR	-	-	-	-	-	-	-	-	-	-	-	-	11.67	-	-
	Linwood	Disturbed*	LWD11	-	-	-	-	-	-	-	-	-	67.67	-	-	-	-	-
		Reference*	LWR11	-	-	-	-	-	-	-	-	-	22.00	-	-	-	-	-
	Finn	Disturbed*	FND	-	-	-	-	-	-	-	-	-	-	-	-	16.00	-	-
		Reference*	FNR	-	-	-	-	-	-	-	-	-	-	-	-	18.67	-	-
	Gambills	Disturbed*	GBD11	-	-	-	-	-	-	-	-	-	33.33	-	-	-	-	-
		Reference*	GBR11	-	-	-	-	-	-	-	-	-	37.00	-	-	-	-	-

Table 2. Stem densities for all taxa from northern Lake Michigan and northern Lake Huron (northern sites) sampled in 2010 and 2011. There were no sites selected in these regions in 2009. * = sites within 900 m of a drainage ditch.

Year	Paired Site	Site Type	Code	*Carex aquatalis* (Wahlenb.)	*Carex stricta* (Lam.)	*Juncus balticus*(Willd.)	*Juncus brevicaudataus* (Engelm.)	*Phragmites australis*(Cav.)	*Potamogeton illinoensis* (Morong)	*Potamogeton Oakesianes* (J.W. Robbins)	*Sagittaria latifolia* (Willd.)	*Schoenoplectus acutus* (Bigelow)	*Schoenoplectus pungens*(Vahl.)	*Schoenoplectus subterminalis*(Torr.)	*Schoenoplectus tabernaemontani* (C.C. Gmel.)	*Spargonium eurycarpum* (Engelm.)	*Typha angustifolia* (L.)	*Vallisneria americana* (Michx.)
2010	Ogontz Bay	Disturbed*	OBD	-	-	-	-	-	-	-	-	25.00	-	-	-	0.67	-	-
		Reference*	OBR	-	-	-	-	-	-	-	-	6.00	-	-	-	-	-	-
	Cheboygan	Disturbed	CBD	8.00	10.00	-	-	2.00	-	-	-	-	4.33	-	2.00	-	0.67	-
		Reference	CBR	-	-	-	-	-	-	-	-	-	9.00	-	-	-	-	-
	Gardens Corne	Disturbed	GCD	1.33	-	-	-	-	-	-	0.67	-	1.33	-	47.00	-	-	0.03
		Reference	GCR	1.00	-	1.67	0.67	-	-	-	-	-	62.67	-	-	-	-	-
	Hessel A	Disturbed	HSDA	-	-	-	-	-	-	-	-	12.67	-	-	-	-	-	-
		Reference	HSRA	-	-	-	-	-	-	1.33	-	20.00	-	4.30	-	-	-	-
	Hessel B	Disturbed	HSDE	-	-	-	-	-	0.04	1.00	-	6.67	-	73.00	-	-	-	-
		Reference	HSRB	-	-	-	-	-	-	1.33	-	20.00	-	4.30	-	-	-	-
2011	Paw Point	Disturbed	PPD	-	-	-	-	-	-	-	-	-	-	-	32.67	-	-	-
		Reference	PPR	-	-	-	-	-	-	-	-	-	-	-	6.67	-	-	-

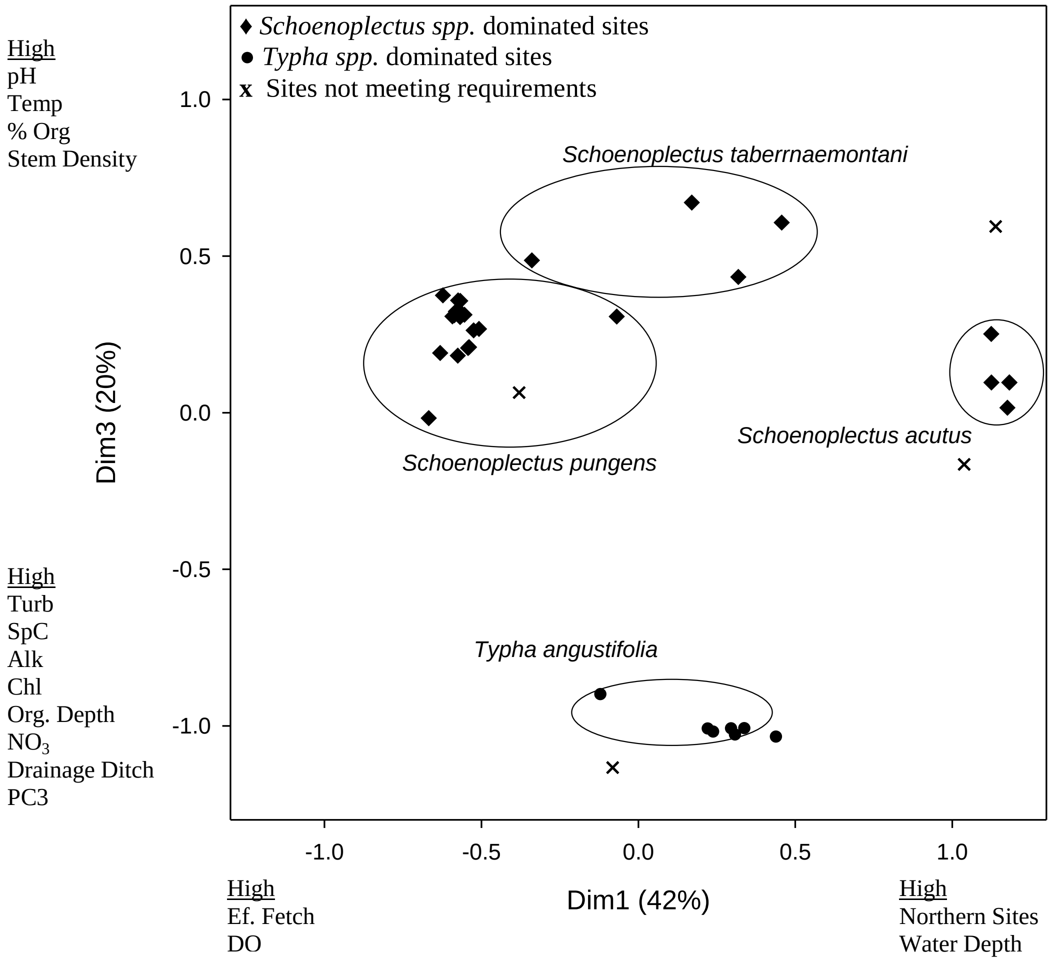

Figure 2. NMDS analysis of plant data from all Saginaw Bay and northern sites sampled in 2009, 2010, and 2011. Grouping of sites were based on dominant plant species. Dimension one was responsible for separating the different *Schoenoplectus* species and Dimension three was responsible for separating *Typha spp*. from *Schoenoplectus spp*.

Indicated by the MRPP, the separation of sites was driven by a combination of effects attributed by geographic region, effective fetch, and the presence of drainage ditches (sites within 900 meters of a drainage ditch). There was significant grouping of sites between geographic region (Saginaw Bay sites and northern sites) (A = 0.056, T = -4.105, p = 0.01) effective fetch (A = 0.085, T = -5.14, p = 0.001), and the presence and absence drainage ditches

(*A*= 0.027, *T* = -2.370, *p* = 0.03). The MRBP indicated that plant communities were not different between reference and disturbed sites.

Using the first two PCs from the principal component, 37% of the variation within the data was accounted for. PC1 accounted for 23% of the variation and best represented the stratification of sites which was based on a gradient of productivity. PC1 was positively related with turbidity, specific conductance, alkalinity, chlorophyll, organic depth, and NO_3 and negatively related with temperature, water depth, percent organics, and stem density. PC2 accounted for 14% of the data and was positively related with alkalinity, redox potential, and NO_3 and was negatively related with turbidity, pH, and chlorophyll. PC1 was negatively correlated with dimension 3 from the NDMS (r = -0.769, p <0.0001).

MRBP indicated no difference between reference and disturbed sites in the abiotic data. Sites within 900 km of drainage ditches were found to be driven by different abiotic variables than sites greater than 900 km away from drainage ditches (*A* = 0.029, *T* = -2.218, *p* = 0.03; Figure 3). Also, there was a significant grouping of sites based on effective fetch (*A* = 0.055, *T* = -2.83, *p* = 0.01). All sites dominated by *Typha spp.* within Saginaw Bay were within 900 m of a drainage ditch. The only sites near drainage ditches that were not dominated by *Typha spp.* were sites with an effective fetch greater than 200 km. Sites within Saginaw Bay with an effective fetch greater than 200 km had physical/chemical conditions more similar to those of the northern sites, therefore, not as influenced by variables representative of high nutrients and lower water clarity. All sites having an effective fetch less than 35 km were sites located in northern Lakes Michigan and Huron.

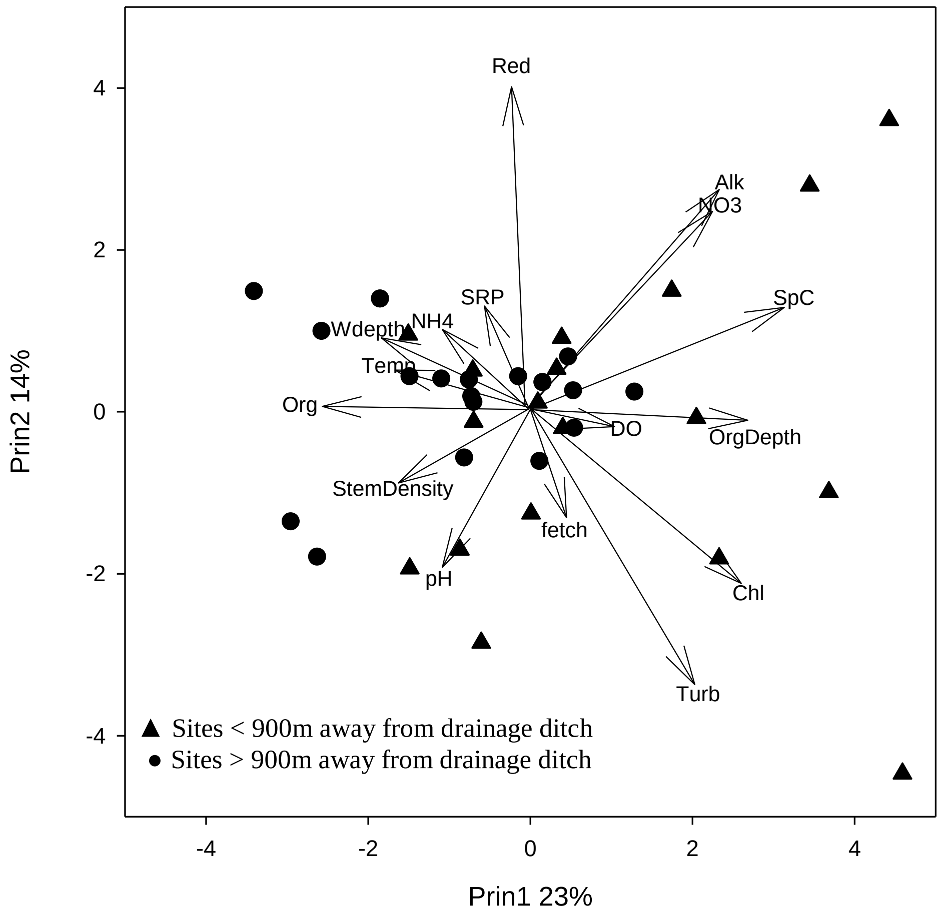

Figure 3. PCA for chemical physical data from all Saginaw Bay and northern sites sampled in 2009, 2010, and 2011. PC1 best represents a productivity gradient separating sites with drainage ditches and sites without.

Schoenoplectus spp. Dominated Sites

Due to the strong separation of sites between genera (*Schoenoplectus spp.* and *Typha spp.*), NMDS was next performed on only *Schoenoplectus spp.* dominated sites. Sites dominated by *Schoenoplectus spp.* were chosen because there were more sites dominated by this genus than by *Typha spp.* The NMDS was performed on 20 plant species and 30 sites. A three dimensional solution best explained the variation stabilizing at a final stress of 8.3 after 27 iterations with 91% of the variation explained. Dimension one accounted for 48% of the variation and was positively correlated with geographic region ($r = 0.56$, $p = 0.001$) and negatively correlated with effective fetch ($r = -0.432$, $p = 0.02$), dissolved oxygen ($r = -0.418$, $p = 0.05$), specific conductance ($r = -0.418$, $p = 0.02$), and pH ($r = -0.489$, $p = 0.01$). Dimension two accounted for 22% of the variation and was positively correlated with effective fetch ($r = 0.43$, $p = 0.012$) and specific conductance ($r = 0.746$, $p < 0.0001$) and was negatively correlated with water depth ($r = -0.454$, $p = 0.01$) and geographic region ($r = -0.7$, $p < 0.0001$). Dimension three accounted for 21% and was positively correlated with dissolved oxygen ($r = 0.362$, $p = 0.05$) and negatively correlated with alkalinity ($r = -0.498$, $p = 0.01$), oxidation reduction potential ($r = -0.374$, $p = 0.04$), and water depth ($r = -0.466$, $p = 0.01$).

Sites also grouped together based on dominant species with the three dominant *Schoenoplectus* species being *S. pungens*, S. *acutus*, *and S. tabernaemontani* (Figure 4). *S. pungens* was only found in Saginaw bay while S. *acutus* and *S. tabernaemontani* were only found in the northern sites with the exception of encountering *S. tabernaemontani* at one site in Saginaw Bay. *S. tabernaemontani* was documented at the Pinconning disturbed site which was a protected sand-spit embayment wetland sampled in Saginaw Bay. Dominant species looked to be a function of geographic region and effective fetch. There was significant grouping based on geographic region ($A = 0.162$, $T = -10.189$, $p < 0.001$; Figure 5) and effective fetch ($A = 0.169$, $T = -7.384$, $p < 0.001$; Figure 6). There was no significant grouping between reference and disturbed sites indicated by the MRBP.

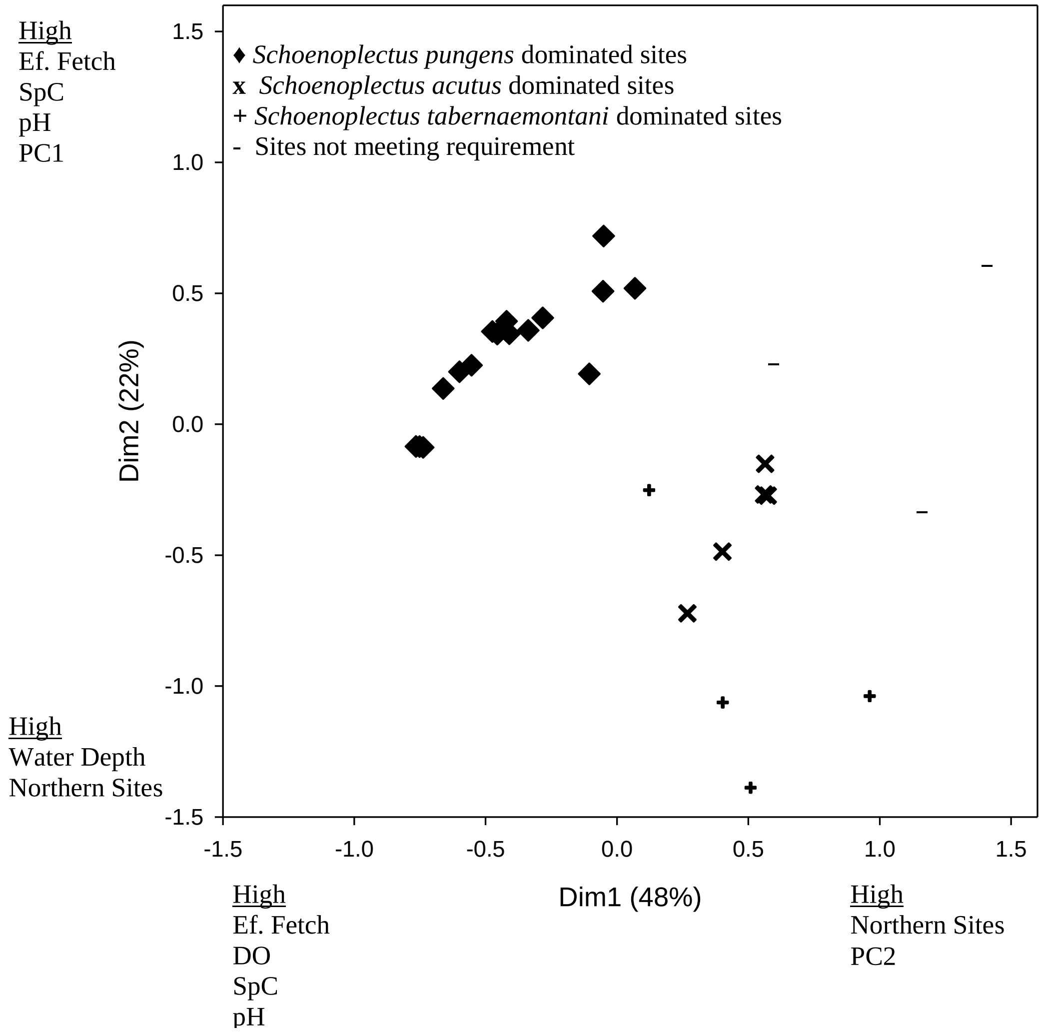

Figure 4. NMDS analysis of *Schoeonoplectus spp.* dominated sites sampled in 2009, 2010, and 2011, showing stratification of sites by dominant *Schoenoplectus* species, *S. pungens*, *S. acutus*, and *S. tabernaemontani*. Dominance was defined having the highest proportional stem density at four or more sites.

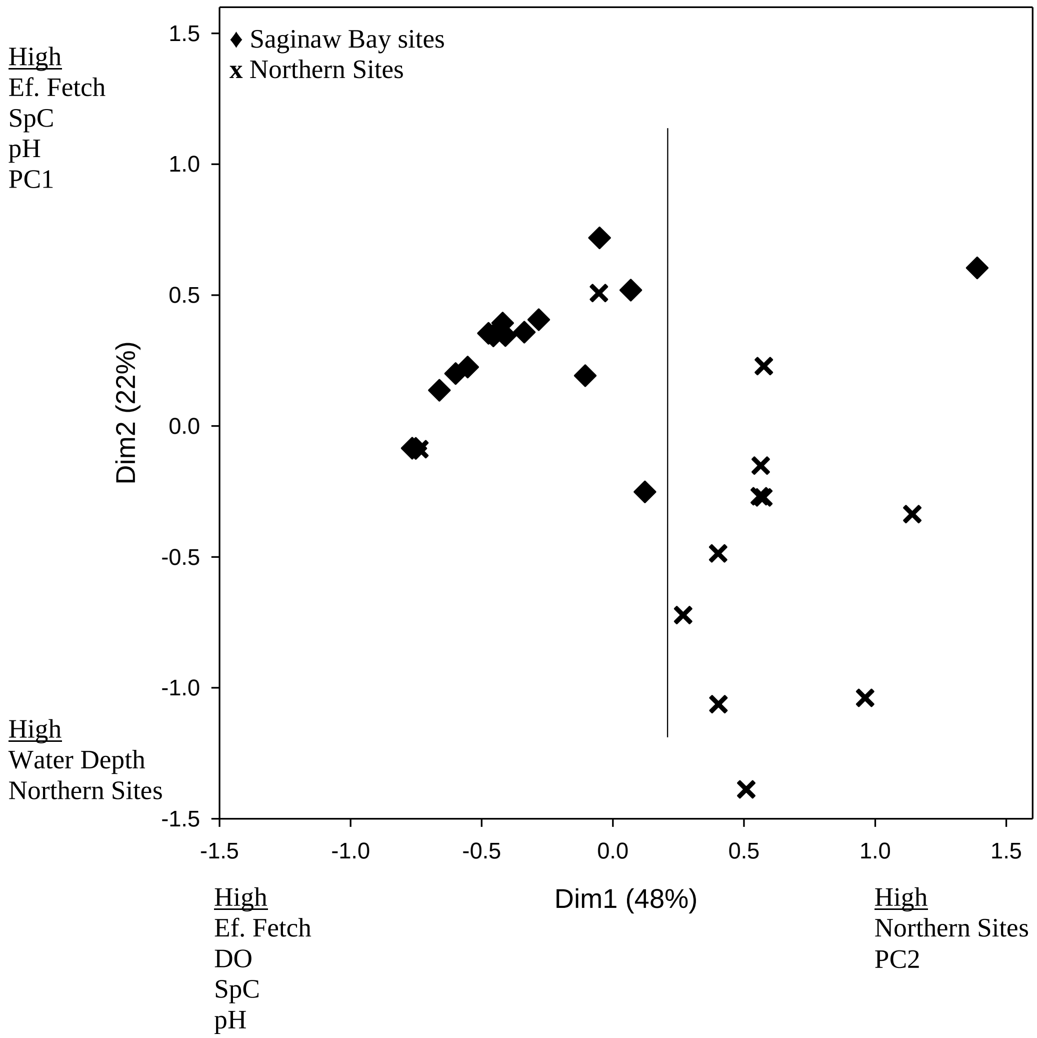

Figure 5. NMDS analysis of *Schoeonoplectus spp.* dominated sites sampled in 2009, 2010, and 2011, showing stratification of sites based on geographic region. The two geographic regions include Saginaw Bay sites and northern sites. The northern sites include all sites sampled in the northern Lakes Huron and Michigan.

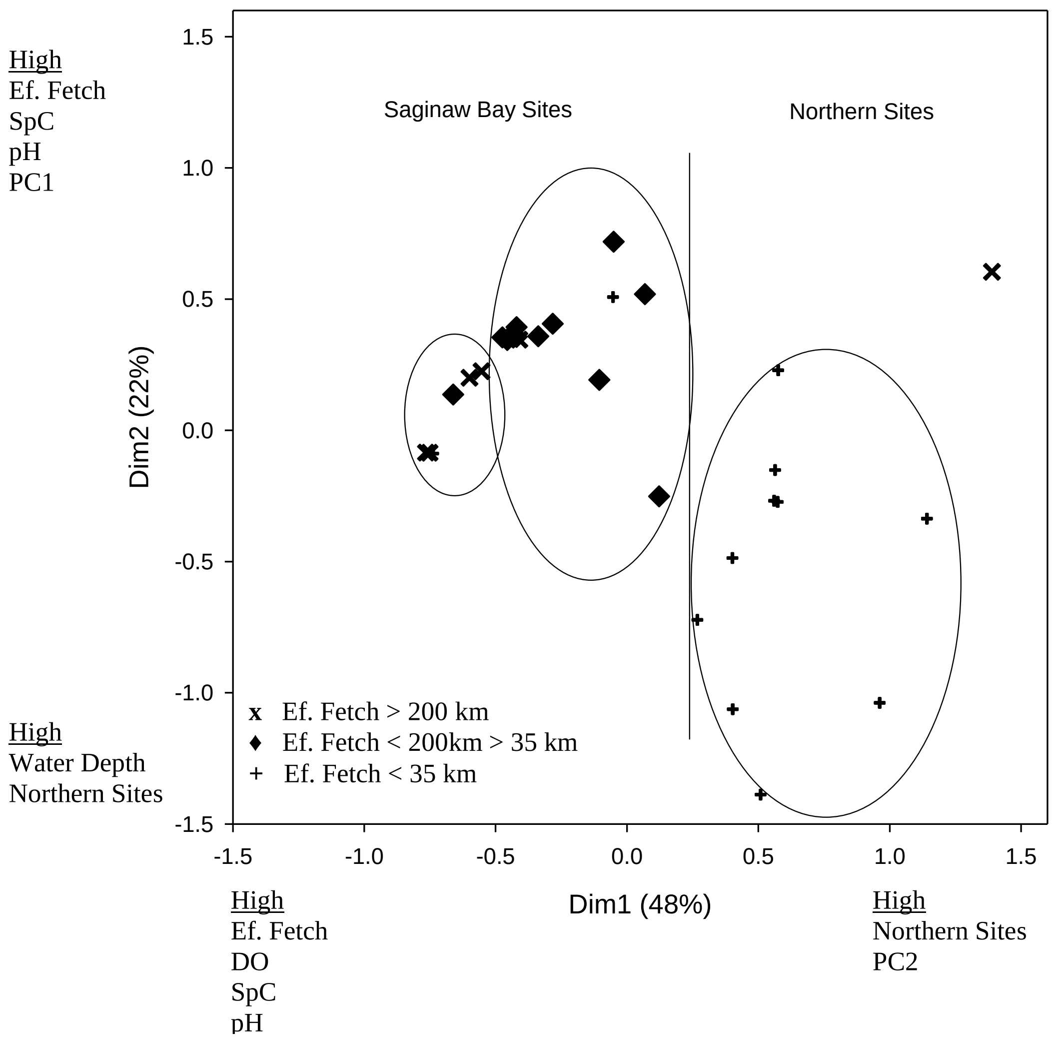

Figure 6. NMDS analysis of *Schoeonoplectus spp.* dominated sites sampled in 2009, 2010, and 2011, showing the stratification of sites based on geographic location and effective fetch. Saginaw bay sites include two effective fetch classes, sites with an effective fetch greater than 200 km, and between 35 km and 200 km. All northern sites had an effective fetch less than 35 km.

The first two PCs from the PCA accounted for 32% in the abiotic variables. PC1 explained 18 percent of the variation and was positively related with dissolved oxygen, turbidity, specific conductance, alkalinity, chlorophyll, and organic depth. PC1 was negatively related with pH, water depth, and percent organic. PC2 accounted for 14% of the variation in the abiotic data and was positively related with alkalinity and oxidation reduction potential and negatively related with effective fetch, dissolved oxygen, turbidity, and NO_3. PC1 was positively correlated with dimension two of the NMDS ($r = 0.434$, $p = 0.02$). PC2 was positively correlated with dimension one ($r = 0.442$, $p = 0.01$) and negatively correlated with dimension three ($r = -0.553$, $p = 0.002$) of the NMDS. MRPP revealed differences in the abiotic community between sites within 900 m of drainage ditches and sites greater than 900 m from drainage ditches ($A = 0.046$, $T = -2.42$, $p = 0.03$). Grouping of reference and disturbed sites were not detected by the MRBP.

All Vegetation in Saginaw Bay

Strong stratification of sites based on geographic region led to the analyses of the Saginaw Bay sites alone. The Saginaw Bay region was chosen because more sites were sampled there. NMDS was performed on all vegetation within Saginaw Bay which included 15 plant species and 26 sites. A two dimensional solution best explained the variation within the data stabilizing at a final stress of 10.24 after 20 iterations. The two dimensional solution accounted for 87% of the variation in the dataset. Dimension one accounted for 66% of the variation and was positively correlated with temperature ($r = 0.51$, $p = 0.01$), percent organic ($r = 0.53$, $p = 0.01$), and stem density ($r = 0.472$, $p = 0.01$). Dimension one was negatively correlated with turbidity ($r = -0.469$, $p = 0.02$), specific conductance ($r = -0.564$, $p = 0.003$), alkalinity ($r = -0.679$, $p = 0.0001$), chlorophyll ($r = -0.487$, $p = 0.01$), organic depth ($r = -0.637$, $p = 0.001$), NO_3 ($r = -0.394$, $p = 0.05$), and the presence of drainage ditches ($r = -0.517$, $p = 0.01$). Dimension two accounted for 21% of the variation in the data and was positively correlated with temperature ($r = 0.43$, $p = 0.03$), and NO_3 ($r = 0.471$, $p = 0.02$). Again, there was no separation among sites based on reference and disturbed sites. The greatest differences between sites was seen in dimension one and was attributed to dominant genera, *Schoenoplectus spp.* and *Typha* *spp*. All sites dominated by *Typha spp*. were associated with drainage ditches (drainage ditches within 900 m). Sites associated with drainage ditches that were not dominated by *Typha spp*. had an effective fetch greater than 200 km and were dominated by *Schoenoplectus pungens* (Figure 7).

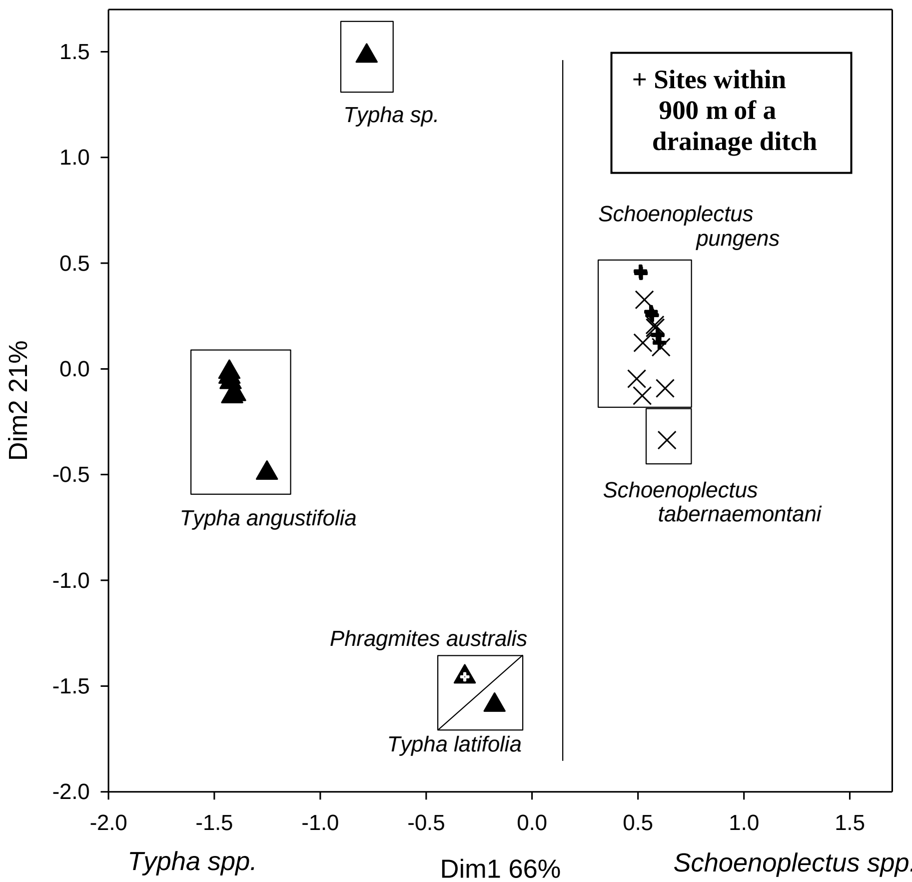

Figure 7. NMDS of Saginaw Bay sites incorporating all vegetation sampled in 2009, 2010, and 2011. Stratification of sites was based on dominant genera, *Typha* and *Schoenoplectus*, which is best represented in dimension 1. Sites were also grouped based on dominant species which was defined by the species having the greatest proportional stem density. The *Phragmites* dominated site was almost equally represented by *Typha latifolia*. Also shown, is the separation of *Schoenoplectus* dominated sites near drainage ditches that had an effective fetch greater than 200 km.

Principal components one and two from the PCA accounted for 41 percent of the variation in the abiotic data. Principal component one was positively related with turbidity, specific conductance, alkalinity, chlorophyll *a*, organic depth, and NO_3. Principal component one was negatively related with effective fetch, percent organic, and stem density. Principal component two was positively related with redox potential and water depth and negatively related with turbidity and chlorophyll *a*. Principal component one was negatively correlated with dimension one from the NMDS ($r = -0.771$, $p < 0.0001$).

There was strong separation in the PCA of sites according to there locality relative to the Saginaw River. Sites located on the eastern shore of the bay were driven by productivity and had elevated levels of NO_3, turbidity, specific conductance, chlorophyll *a* and a deep organic depth. Sites within 900 m of a drainage ditch and an effective fetch less than 200 km were dominated by *Typha angustifolia* and were located on the eastern side of the bay. Sites with drainage ditches on the western shore of the bay that were not driven by productivity had an effective fetch greater than 200 km and were dominated by *Schoenoplectus pungens*. These sites had elevated percent organics, stem densities, pH levels, and temperatures.

Schoenoplectus spp. Dominated Sites within Saginaw Bay

Due to the differences among sites being attributed to dominant species, *Typha spp.* and *Schoenoplectus spp.* and not reference and disturbance, NMDS was then performed on only *Schoenoplectus* dominated sites within Saginaw Bay. However, NMDS failed to retrieve a stable solution. Failing to find a stable solution led to performing a correspondence analysis which also failed to provide reliable results explaining the variability within the dataset due to the high number of rare species. Rare species overwhelmed the analysis and was likely masking differences among sites.

Ordination Procedures at a Genus Resolution

All Genera All Sites

To reduce the number of rare species the data were next analyzed at a genus resolution. NMDS was performed on all 38 sites and 14 genera. A two dimensional solution best explained the variation within the dataset stabilizing at a final stress of 7.8 after 70 iterations and accounting for a total of 94% of the variation. Dimension one accounted for 72% of the variation and was positively correlated with pH (r = 0.408, p = 0.01), temperature (r = 0.551, p = 0.0003), percent organic (r = 0.328, p = 0.04), and stem density (r = 0.713, p <0.0001). Dimension one was negatively correlated with specific conductance (r = -0.437, p = 0.01), alkalinity (r = -0.4, p = 0.01), organic depth (r = -0.409, p = 0.01), and NO_3 (r = -0.366, p = 0.02). Dimension two accounted for 22% of the variation in the data and was positively correlated with temperature (r = 0.52, p = 0.001), percent organic (r = 0.455, p = 0.004), and geographic region (r = 0.349, p = 0.03). Dimension two was negatively correlated with turbidity (r = -0.473, p = 0.003), specific conductance (r = -0.599, p < 0.0001), alkalinity (r = -0.527, p = 0.001), chlorophyll *a* (r = -0.478, p = 0.002), organic depth (r = -0.391, p = 0.02), NO_3 (r = -0.486, p = 0.002), and the presence of drainage ditches (r = -0.505, p = 0.001). NMDS failed to detect differences between reference and disturbed sites indicated by the MRBP. Sites were stratified based on dominate genera consisting of *Typha* and *Schoenoplectus.* All *Typha* dominated sites were within 900 m of a drainage ditch (Figure 8).

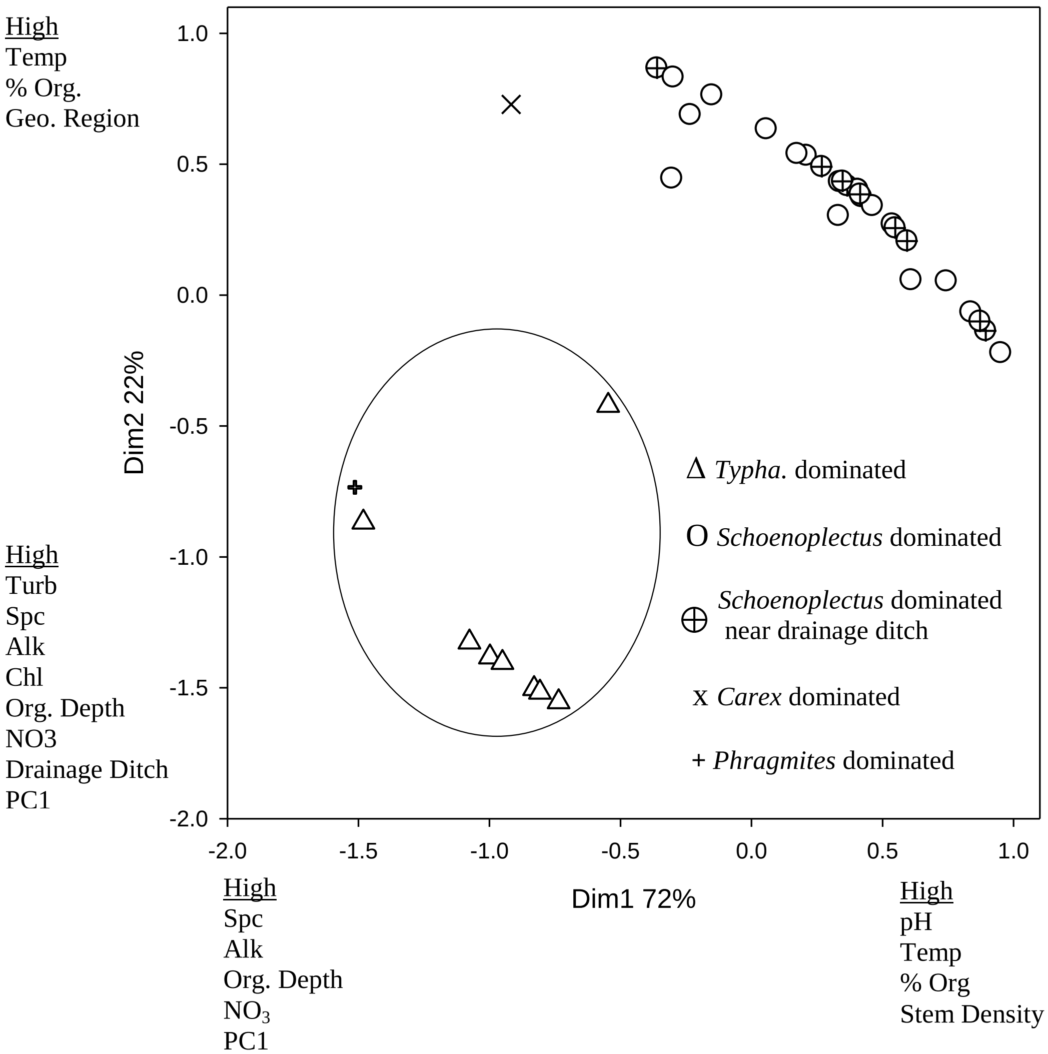

Figure 8. NMDS analysis of all sites, Saginaw Bay and northern sites, using all plant species at a genus resolution. Separation of sites was based on dominant genera, *Typha* dominated sites and *Schoenoplectus* dominated sites. All sites circled were within 900 m of a drainage ditch. *Schoenoplectus* dominated sites that were within 900 m of a drainage ditch all had an effective fetch greater than 200 km. Dominance was defined by having the highest proportional stem density.

The PCA analysis was analogous to the PCA analysis that incorporated all vegetation and all sites at a species resolution. Principal component one was negatively correlated with dimension one (r = -0.633, p <0.0001) and two (r = -0.73, p <0.0001) of the NMDS.

Schoenoplectus spp. Dominated Sites

In an effort to detect difference between reference and disturbed sites, *Typha* dominated sites were removed from the analysis and the NMDS was performed using only *Schoenoplectus* dominated sites. However, NMDS failed to stabilize suggesting that patterns in the data did not exist. Again, failure to find a stable solution led to performing a correspondence analysis. The CA also failed in accurately explaining the variability in the dataset due to rare species overwhelming the analysis; this likely masked the differences among sites.

Matched Pair Statistical Tests

All Sites

Paired-t tests revealed significant differences within the abiotic data between reference and disturbed sites. Turbidity was found to be higher at disturbed sites with an average of 10.39 NTU (SE = 4.51 NTU) and lower at reference sites with an average of 4.10 NTU (SE = 1.58 NTU, $p = 0.05$). Alkalinity was lower at disturbed sites with an average of 132.74 mg/L (SE = 8.01 mg/L) and higher at reference sites with an average of 145.42 mg/L (SE = 8.05 mg/L, $p = 0.003$). Water temperature was documented to be lower at disturbed sites with an average of 25.01 ºC (SE = 0.539 ºC) and higher at reference sites with an average of 25.65 ºC (SE = 0.584 ºC, $p = 0.001$).

Invasive species were present at 10 of the 19 paired sites. Three invasive species were encountered during sampling, *Lythrum salicaria*, *Phragmites australis*, and *Typha angustifolia*. One of the paired sites had to be omitted from the analysis when comparing exotic species richness and densities between reference and disturbed sites because of the presence of an immature *Typha* species at a disturbed site that we were unable to identify as it was lacking fruit.

Without distinguishing characteristics, we were unable to determine if it was an invasive *Typha* species (i.e., *T. angustifolia, T. X glauca*) or the native *Typha* species (i.e., *T. latifolia*). Species richness of exotics had a tendency to be higher at boat channels (p = 0.059). Due to the high site variability among wetlands, an increase in sample size would have likely made this significant. No differences were detected in the stem density of exotics (p = 0.23), the overall species richness (p = 0.156), and the overall stem density (p = 0.75) between reference and disturbed sites.

Omitting sites with Drainage Ditches

Analyses were further performed on sites without drainage ditches, which included 10 total sites, to determine if they were causing the differences detected at disturbed sites. Paired-t tests revealed the same abiotic variables being different between reference and disturbed sites. Turbidity was found to be higher at disturbed sites with an average of 5.76 NTU (SE = 1.62 NTU) and lower at reference sites with an average of 3.13 NTU (SE = 1.11 NTU, p = 0.025). Alkalinity was found to be lower at disturbed sites with an average of 118.50 mg/L (SE = 8.03 mg/L) and higher at reference sites with an average of 134.30 mg/L (SE = 7.91 mg/L, p = 0.003). Temperature was found to be lower at disturbed sites with and average of 25.64 ºC (SE = 0.588 ºC), compared to an average of 26.53 ºC (SE = 0.683 ºC) at reference sites (p = 0.003).

The overall species richness of sites was not different between reference and disturbed sites (p = 0.62) as well as stem density (p = 0.65). Investigating species richness and stem density of invasive species was inconclusive. After removing sites without drainage ditches the number of paired sites with invasive species was four, which was not enough to support any reliable conclusions due to a low power of detection.

CHAPTER IV

DISCUSSION

The overall structure of plant communities appeared to be driven predominately by the combined effects of geographic region, nutrient enrichment, and effective fetch. The differences detected within the physical/chemical environment between reference and disturbed sites were not large enough to cause any detectable changes in the overall plant community. Large scale impacts seemed to override any potential impacts caused by boat channels. Disturbance from agricultural land use had the greatest repercussions in the physical/chemical environment which was also found to be associated with changes in wetland vegetation.

NMDS ordinations were stratified by dominant taxon which was evident on both a species resolution and a genus resolution. At a species resolution, the dominant species included *Schoenoplectus acutus, S. pungens, S. tabernaemontani, and Typha angustifolia* with *Schoenoplectus spp*., and *Typha spp.* being the dominant genera. Sites sampled in Saginaw bay were typically dominated by either *S. pungens* or *Typha spp.* and the northern sites were typically dominated by either *S. tabernaemontani* or *S. acutus*.

It was not surprising to see differences in wetland plant communities between the two geographic regions sampled (northern sites and Saginaw Bay) because of the great diversity in their physical environments. Environmental conditions within Saginaw Bay region are considerably different than those of the northern regions. The northern sites seemed to experience less human disturbance due to the low density of people (Albert and Minc 2004, Lougheed *et al.* 2001). There was much less development from urbanization and less agriculture increasing the nutrient and sediment input within the systems. Sites sampled within Saginaw Bay were more exposed to shoreline development and agriculture activity and had a higher population of waterfront property owners. Aquatic plants in the near shore areas were subject to increased sedimentation and nutrient enrichment from fertilizer and animal waste run-off from agricultural activity (Albert and Minc 2004). Adjacent land use of aquatic systems has been shown to greatly influence their physical/chemical conditions (Carey *et al.* 2011, Lougheed *et al.* 2001).

The PCA performed on all vegetation and all sites revealed that sites within Saginaw Bay, that were associated with drainage ditches, had a deeper organic depth and higher $NO_{3,}$ specific conductance, dissolved oxygen, chlorophyll-*a*, and turbidity levels which was represented in PC1. Collectively, these variables indicated high productivity and thus, lower water quality than sites without drainage ditches. Only two of the northern sites were associated with drainage ditches, however, they were not driven by variables representing a low water quality. Sites within Saginaw Bay were generally representative of variables associated with increased nutrients and decreased water clarity with drainage ditches amplifying these conditions. Saginaw Bay sites with water quality more similar to the northern sites were either located on the western side of the bay where agriculture activity was less severe, had an effective fetch greater than 200 km (which were also on the western side of the bay), or the adjacent land was heavily forested.

The influx in nutrients within Saginaw Bay, which was greatly influenced by the presence of drainage ditches, was likely to be the culprit of the increased abundance of *Typha spp.* Every site that was dominated by *Typha spp.* was associated with a drainage ditch. This supports other studies that have witnessed *Typha spp.* to increase greatly in coverage when exposed to increased nutrients (Albert and Minc 2004, Trebitz and Taylor 2007). The only sites within 900 m of a drainage ditch without *Typha spp.* had an effective fetch greater than 200 km.

Effective fetch was another geographic difference between the northern and Saginaw Bay sites. Effective fetch is a surrogate of wave action and has been shown to impact plant community composition (Azza *et al.* 2007, Baldwin *et al.* 2010). Saginaw Bay sites all had a greater effective fetch than the northern sites, all being greater than 35 km. The northern sites all had an effective fetch less than 35 km. Within Saginaw Bay there were two effective fetch size classes, sites with an effecting fetch between 35 and 200 km and sites with an effective fetch greater than 200 km. Effective fetch likely explained why sites within 900 m of a drainage ditch did not include *Typha spp*. All the sites that were within 900 m of a drainage ditch with an effective fetch greater than 200 km did not include *Typha spp.* A higher effective fetch was thought to increase the mixing of the pelagic water with the inflow of the water from the drainage ditches, in turn, diluting the concentration of nutrients that enter the system from the drainage ditches. Increased wave exposure may have also limited the establishment of *Typha spp.,* and collectively, with reduced nutrient levels, may provide conditions more tolerable for *Schoenoplectus spp*.

Schoenoplectus spp. are known for being tolerant of high wave action which is why they were a dominant genera at many of the sites because sampling took place in the emergent zone of the wetlands. All sites dominated by *Schoenoplectus pungens* had an effective fetch greater than 35 km. *Schoenoplectus acutus* and *Schoenoplectus tabernaemontani* had an effective fetch less than 35 km suggesting that *S. pungens* may be more resilient to increased stress from wave action. *S. pungens* is also known as one of the most common sedges in the Great Lakes region (Voss and Reznicek 2012). There was one exception in Saginaw Bay where one site was dominated by *Schoenoplectus tabernaemontani,* which was in a protected sand-spit embayment wetland (Pinconning Park). However, it is difficult to conclude that effective fetch is the primary factor determining the occurrence of the *Schoenoplectus spp.* There are other geographic differences between the northern and Saginaw Bay sites known to effect distribution patterns of aquatic macrophytes such as climate and geology (Smith *et al.* 1991, Minc 1997). Other regional differences observed in the study included water quality (better water quality at the northern sites), and water depth (deeper water depths at the northern sites). *S. acutus* is known to be more tolerant of deeper water depths which may have been a possible explanation of only encountering *S. acutus* in the northern sites (Voss and Reznicek 2012). A study done by Mitsh and Svengsouk (2001) looked at the relationship between *Typha latifolia* and *S. tabernaemontani* in nutrient enriched areas and documented *S. tabernaemontani* increasing in biomass while *T. latifolia* decreasing in biomass along a decreasing gradient of nutrient concentrations. The Mitsh and Svengsouk (2001) study supports the prevalence of *S. tabernaemontani* in the northern sites where nutrient levels were not high as opposed to Saginaw Bay sites. Trebitz and Taylor 2007, also documented *S. tabernaemontani* to be more prevalent in upper latitudes. Unfortunately, there is not much information within the literature on the life histories of *Schoenoplectus spp.* to help identify the major determinants responsible for their individual distribution.

Using univariate methods, differences between reference and disturbed sites in the abiotic conditions were detected. Boat channels were associated with high turbidity and alkalinity and low water temperatures. Boat channels were most likely acting as a conduit for increased water movement between the adjacent land and the pelagic water. With less of a buffer from wave action or water movement by vegetation, particulates in the water column are unable to settle out, therefore, increasing turbidity. Increased water movement within the boat channel may have been leading to more mixing of ground water with the pelagic water resulting in lower temperatures and lower alkalinity levels at disturbed sites. These abiotic differences within wetlands however, were not thought to have a large enough impact to alter the plant communities inhabiting these areas. The major disturbance impacting their environmental conditions were attributed to agricultural run off with drainage ditches further intensifying the problem.

Invasive species are an environmental concern for wetlands due to their vulnerability to invasion (Sutherland 2004, Zedler and Kercher 2004). Saginaw Bay sites hosted the majority of the invasive species encountered which is what was expected due to the increased amount of human disturbance the bay has been subjected to. A study by Trebitz and Taylor (2007) had also documented and increase in invasive species in the lower areas of the Great Lakes Basin. Furthermore, Trebitz and Taylor (2007) had also found that *P. australis, L. salicaria, and Typha* are more likely to be present in areas of increased agricultural which were the three invasive species found within Saginaw Bay in this study. Lougheed *et al.* 2001 had also documented an increase of *Typha spp.* in the lower latitudes as opposed to the northern latitudes which was thought to be due to water quality. Of the northern sites, Cheboygan was the only site to have had invasive species. Cheboygan, also had the highest disturbance level (level three), therefore, most likely experienced a great amount of disturbance from boating traffic which could have facilitated the establishment of *Phragmites australis and Typha angustifolia*.

This study revealed a tendency in invasive species to be higher at boat channels sites which supported the studies documenting an increase in invasive species in areas subject to anthropogenic stress (Albert and Minc 2004, Herrick and Wolf 2005, Kercher *et al.* 2004, Minchinton and Bertness 2003, Trebitz and Taylor 2007, Wilcox 1995, Woo and Zedler 2002, Zedler and Kercher 2004). There was not one reference site in the study that had a higher number of invasive species than its paired disturbed site. Boats may be acting as vessels in transporting exotics by facilitating better dispersal mechanisms as well as adding increased disturbance from prop wash, further assisting in better establishment of invasive species. However, impacts from drainage ditches (nutrient enrichment) seemed to be taking precedent in determining the likelihood of invasive species colonization over boat channels, particularly with *Typha spp*.

Limitations and Future Research

It must be taken into consideration that many of the boat channels that were sampled in this study were associated with channelized drainage ditches that were draining the adjacent upland. There is a possibility that these drainage ditches may increase the chance for plant dispersal via water. Any propagule, seed, or whole plant dropped by waterfowl or animal into these drainage ditches with the potential of being deposited at the where they empty out within a wetland, thus, increasing the likelihood of the establishment of invasive species. This was not possible to explore due to the limited number of boat channels without drainage ditches. Therefore, future research may take this into account and sample boat channels that were not a part of drainage ditches.

Conclusions

The importance that Great Lakes coastal wetlands have in maintaining the environmental quality of the Great Lakes is of increasing awareness to the public and management. Great Lakes coastal wetlands have been under extreme levels of anthropogenic stress which has led to the loss of approximately 70 % of the states coastal wetlands (Cwikiel 1998). Therefore, it is important to understand current detrimental disturbances from human activities in order to protect these systems from further degradation. Overall, this study has shown that large scale impacts have more of an influence on plant community structure than potential impacts caused from boat channels. Boat channels did have the tendency to have a higher number of invasive species, however, drainage ditches showed a greater threat to wetland plant communities. With prolonged low water levels, combating the potential effects of boat channels may be difficult due to waterfront property owners maintaining access to the open water. But knowing the potential impacts associated with them may assist in establishing proper management protocols if necessary. However, the impacts associated with drainage ditches are more pressing than the impacts of boat channels, especially in regards to invasive species. Invasive species have been an ongoing problem within coastal wetlands and must be addressed in order to maintain and preserve the integrity of the coastal wetlands that remain.

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