STUDY FINAL REPORT

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Period Covered:	**October 1, 2007 – September 30, 2008**		

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Analysis of Vegetation in adjacent Diked-Undiked Coastal Wetlands

by Dennis Albert

Michigan Natural Features Inventory

October 2008

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INTRODUCTION

Plant sampling was initiated as part of a study to understand the response of wetland birds and vegetation to diking of Great Lakes coastal wetlands. Plant sampling was conducted at the same points as avian sampling to provide context for the avian inventories.

Dikes have long been viewed as important for maintaining wetland functions critical to waterfowl in wetlands along the southern Great Lakes coast. This importance cannot be denied in an environment where industrial development has hardened and eroded shorelines and where agricultural sediments have altered the water quality and sediment accumulation dynamics of near-shore areas (Albert and Minc 2001, Minc 1997). Recent studies have identified maintenance of native wetland plants as another benefit of diked coastal wetlands, especially in periods of extended low water (Galloway et al. 2006, Thiet 2002). Maintenance of native wetland plants is one of the focal subjects for this study.

The importance of dikes for maintaining plant diversity in more northern Great Lakes coastal wetlands has not been as well documented, and recent studies in Green Bay point to less effective maintenance of native wetland plant species than in southern wetlands (Herrick and Wolf 2005). Ecological studies and casual observations in northern Lake Huron and Michigan marshes during the early stages of the current Great Lakes low-water indicate that there has been less aggressive colonization of marshes by reed, narrow-leaved cattail, and hybrid cattail than in southern Great Lakes wetlands (Albert et al. 2006, Albert 2005). In the northern Great Lakes, these invasive plants appear to be restricted to areas of intense industrial or agricultural management, such as Green Bay, where there is both intense agricultural and industrial management, in Cheboygan and Escanaba (Michigan), where there is industrial development, and in Munuscong Bay (MI), a watershed with intensive agricultural runoff.

Some of the only diked marshes in northern Michigan are at Escanaba and Munuscong Bay, areas where agricultural and industrial runoff has created excessive sediment accumulation combined with heavy nutrient loading. The result of these sediment and chemical changes has been the development of massive cattail beds both inside and outside diked areas. The DNR wetland impoundments at the mouth of the Munuscong River were not successful for maintaining open marsh conditions, partially because the pumps were inadequate for maintaining high water conditions during Great Lakes low-water periods, partially because of the porous nature of the dikes. Without active water-level manipulation, the dikes provided limited habitat diversity for waterfowl or other wetland dependant birds. Unfortunately, absence of vegetation data collection in the impounded marshes prior to breaching limits our ability to evaluate the effect of the breaching on vegetation dynamics. However, aerial photography may allow long-term evaluation of the patchiness within the diked and adjacent undiked wetland, and future vegetation sampling may provide insights into the effectiveness of the dike breaching.

One of the questions of most interest to the wetland managers was the change resulting from rapid expansion of *Phragmites australis* (reed) during recent low-water conditions.

Researchers recognize that there are two genetically distinct populations of reed, a native genotype that is not aggressive and a non-native genotype that is highly aggressive, which likely arrived in the eastern U.S. in ballast in the late 19th or early 20th century (Saltonstall 2008, Norris et al. 2008, Chambers 1999). Invasive non-native reed initially invades open, moist sediments as seed, but once established, its dense surface roots and rhizomes control below-ground habitat, while its dense above-ground vegetation reduces above-ground competition (Saltonstall 2008). In 1999, as water levels began to expand, reed beds expanded rapidly along southern Great Lakes shorelines, especially in the St. Clair River Delta, where there has been active research directed at controlling reed expansion by herbicide and controlled burning (Kafcas and Schafer 2007). In the remainder of the report, the common name reed will often be used instead of the scientific name.

The project proposal called for the comparison of wetland vegetation within the diked wetland to wetland vegetation in the adjacent undiked wetland. Comparisons were proposed for 1) plant diversity and plant structural diversity, 2) quantification of living plant biomass and partially decomposed plant materials in the sediment in diked versus undiked marsh, 3) evaluation of pre-dike vegetation inside the diked wetland through investigation of rhizomes, 4) evaluation of biomass distribution above and below ground for exotic and native plants, and 5) evaluation of the sites where reed established in both diked and undiked wetlands.

PROJECT LOCATION

The wetlands included in this study occur along Saginaw Bay in Lake Huron, and in northern Lake St. Clair. On Saginaw Bay, sampling was conducted within and outside the dikes at both Fish Point and Wigwam Bay. On Lake St. Clair, sampling was focused on two islands within the St. Clair River Delta, Harsens Island and Dickinson Island, where most of the Harsens Island sampling occurred within dikes, while paired sampling in undiked marsh occurred along the shore of Dickinson Island. Sampling locations along the St. Clair River Delta and Saginaw Bay in Lake Huron, where both Mike Monfils' study of bird response and this study of plant response to diking were conducted, are shown in Figure 1. For this study, plant sampling was only conducted at a subset of Monfils' sites, Wigwam Bay, Pinconning, Fish Point, and St. Clair Flats. At Pinconning only sampling of bulrush structure was conducted. Figures 2-4 show the sampling sites with plot locations. Based on interpretation of early aerial photographs, all of these sites were originally dominated by a mix of densely vegetated emergent marsh and wet meadow prior to dike construction in the 1950s and 1960s.

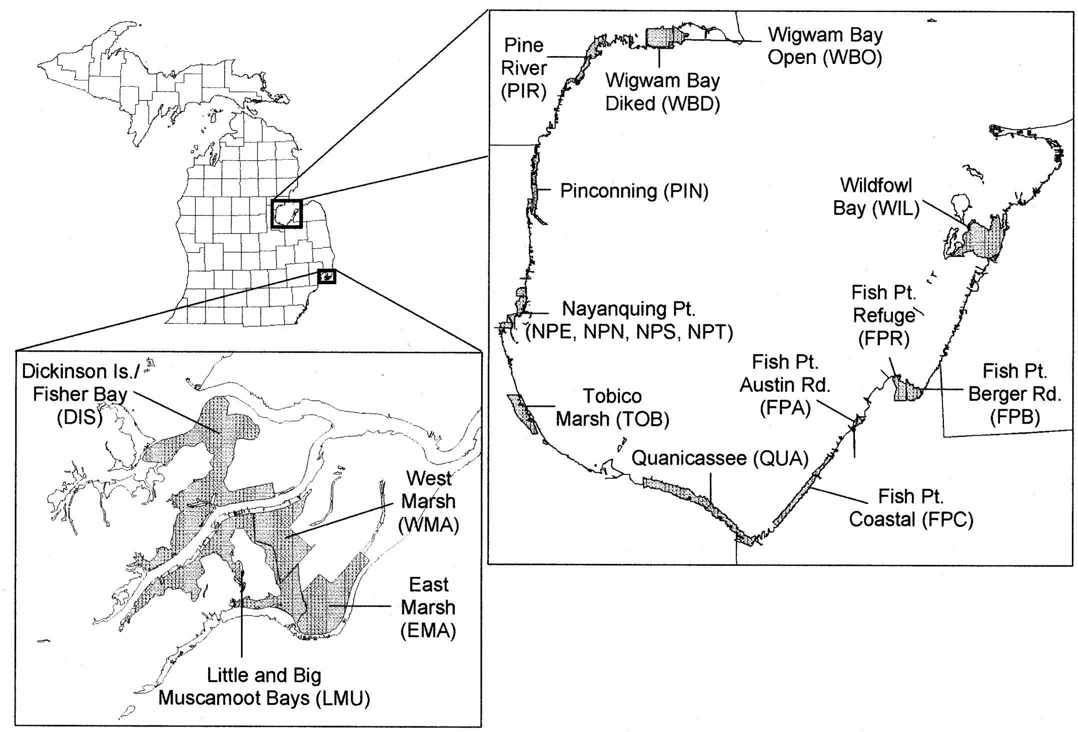


Figure 1. Sampling locations on St. Clair River Delta and Saginaw Bay. Plant sampling was conducted at Dickinson Island and West Marsh on the St. Clair River Delta, as well as at Wigwam Bay, Fish Point, and Pinconning on Saginaw Bay (modified from Monfils and Brown 2008).

METHODS

Plot location. A grid was placed over aerial photos of Harsens Island and Dickinson Island on the St. Clair River delta (Figures 2a and 2b) and on Fish Point (Figure 3) and Wigwam Bay along Saginaw Bay (Figure 4). Sampling plots were randomly located on the grid. Sampling points were used for both faunal and vegetation sampling.

Vegetation plots. Vegetation, water depth, and sediment depth were sampled at each sampling point with equal or similar numbers of plots in diked and undiked sites. Along Saginaw Bay, five diked plots and five undiked plots were sampled at Fish Point and the same number of diked and undiked plots were sampled at Wigwam Bay. On the St. Clair River delta, 13 plots were sampled in the undiked marsh along Dickinson Island, while 11 were sampled in the diked wetlands of Harsens Island. Water depth was recorded in centimeters with a metal tape measure. If water was below the soil surface, depth to water was recorded as a negative number. The maximum depth of roots and rhizomes below the sediment surface was also recorded in centimeters. Number of live and dead stems were recorded for the primary dominant plant species, *Phragmites australis* (reed),

Figure 2a. Dickinson Island's undiked wetland site. Most of the plots are located in Phragmites stands, gray green in this photo. Other plots occur in bulrushes or submergent vegetation, which appear as almost black in color.

Figure 2b. Harsens Island diked wetland in the St. Clair River Delta. Most of the plots within the dike contain cattails, while the plots just west of the dike are dominated by reed.

Figure 3. Fish Point diked wetland to the west, with undiked plots to the east. Within the dikes, plots 5, 15, and 22 are in open water, while plot 16 is located in reed and plot 33 in cattail. Outside the dikes, plots 1, 7, 28, and 39 contain significant amounts of reed, while plot 13 contains significant amounts of bulrush. Narrow-leaved cattail is common in plots 1, 7, and 13 as well. Plots FID1 and FID2 are in wet meadow dominated by prairie grasses.

Figure 4. Wigwam Bay is located at the mouth of the Rifle River. The western diked area contains submergent vegetation in open water, as in plots 2 and 45, with cattail-dominated emergent marsh in plots 6 and 24, while plot 86 is grass- and sedge-dominated wet meadow. Plots WD1, 2, and 3 are grass- and sedge-dominated sites in deep water. Outside the dikes, plots 9, 26, and 28 are in emergent marsh or wet meadow with a strong component of reed, while plot 34 contains both reed and significant amounts of bulrush. Plot 30 is located in a grass- and sedge-dominated wet meadow. Plots WD4, 5, and 6 are grass- and sedge-dominated wet meadow with no reed.

Typha angustifolia (narrow-leave cattail), *T. latifolia* (broad-leaved cattail), *Schoenoplectus acutus* (hardstem bulrush), *S. pungens* (three square), and *Schoenoplectus tabermontani* (softstem bulrush).

Centered on each sampling point, plant stem counts and coverage values were collected at 5 additional, randomly located plots within the same vegetation type. These data were collected in 50 cm X 50 cm plots.

Further samples were collected from specific vegetation types where additional data were needed to expand the number of data points for a vegetation type. These types included native plant communities dominated by sedges and grasses, as well as bulrushes. Also additional sampling was conducted in areas where analysis of aerial photography indicated that reed might have first established.

A long-term marsh transect at Dickinson Island was resampled in July 2005 to evaluate the amount of reed establishment that had occurred during the 1999 to 2005 low-water period. Coverage of plants was recorded (%) at regular intervals along the sampling transect, and both the number of sampling plots dominated by reed and the percent cover of reed were compared for each transect sampling date.

Biomass sampling. Live and dead above-ground plant material and below-ground roots and rhizomes were collected, dried, and weighed for the dominant plant species that occurred within the initial 30 cm X 30 cm vegetation plot, with roots and rhizomes collected to 45 cm below the ground surface. The most important species for analysis were reed, narrow-leaved cattail, 3-square bulrush, hardstem bulrush, as well as the combined category of grass-sedge. Plant specimens were dried for at least 24 hours at 65 degrees Centigrade, using MSU Forestry Center drying ovens. Length of rhizome was also calculated for each of the major emergent species noted above.

Photograph interpretation for reed establishment. Aerial photographs of each sampling site were analyzed using stereoscopes and stereo photo pairs, in an attempt to identify the approximate time and location of reed's arrival on the St. Clair River Delta and Saginaw Bay. Copies of aerial photographs from as early as1938, and at time intervals until the present, were obtained from the Michigan State University Aerial Photo Archives.

Bulrush rhizome study. Rhizomes of 3-square bulrush were excavated at Pinconning to determine if the structure and growth rate of bulrush was altered by water-level differences. Samples were collected during 2006 and 2007 in deep water (permanently flooded), near the waters edge (fluctuating), and on the dry edge of the beach (dry). This sampling was exploratory in nature and the data were not statistically analyzed. However, these preliminary analyses resulted in the initiation of a 2008 NSF REU study by Lukas Bell-Dereske of 3-square bulrush in the same zones at two similarly structured marshes, Cecil Bay near the Straites of Mackinac and Cheboygan Bay on Lake Huron. The results of this study will be briefly discussed in this report.

RESULTS

Plant diversity.

The plant species present in the vegetation subplots was recorded for each of the sampling sites by hydrologic condition, ie. diked vs undiked (Tables 1 through 6). These data were then summarized to compare the number of species present for diked and undiked condition at each sampling site (Table 7). At all three sites (Dickinson-Harsens Island, Fish Point, and Wigwam Bay), native plant diversity was higher in diked wetlands than in undiked wetlands, although major differences in diversity were only seen between Dickinson Island and Harsens Island on the St. Clair River delta, where there were 26 plants encountered in the undiked Dickinson Island plots and 38 plants species in the diked Harsens Island plots. Twenty of the native plants in the Harsens Island dikes (Table 2) are typical “wet meadow” plants, while only two “wet meadow” plants were found on Dickinson Island plots (Table 1), reflecting the low coverage of reed in the dikes, which allows wet meadow plants to persist. In contrast, high coverage of reed in most of the Dickinson Island plots reduced diversity in the wet meadow zone, where reed populations cover most of the landscape and characterized most plots. Dickinson Island had nine unshared species characteristic of emergent marshes, with bulrush species (*Schoenoplectus* spp.) being especially common. There were three unshared emergent species found only in Harsens Island dikes, where high coverage of cattails reduced emergent plant diversity and coverage, especially for bulrushes. Of the eleven species shared by the diked and undiked plots, five were wet meadow species and six were submergent or floating species. Originally both sites contained large amounts of wet meadow habitat, as well as both open and dense emergent marsh (Figures 5 and 6). Dickinson Island originally had permanently flooded habitat that supported abundant submergent and floating plants; the creation of the Harsens Island dikes created permanently flooded habitat where permanent flooding was not originally common, while greatly reducing the amount of wet meadow habitat.

Table 1. Plants present within the vegetation plots on Dickinson Island undiked wetlands. Numbers represent number of subsamples containing the species.

	PLOTS												
SPECIES	**Plot 2**	**Plot 13**	**Plot 16**	**Plot 17**	**Plot 25**	**Plot 32**	**Plot 34**	**Plot 45**	**Plot 47**	**Plot 48**	**Plot 59**	**Plot 61**	**Plot 63**
Calamagrostis canadensis							1				1		
Carex diandra	1						1						
Cephalanthus occidentalis									4				
Chara sp.					4							2	
Cirsium palustre										2			
Eleocharis quadrangulata			2										
Eleocharis smallii		1	3									1	1
Juncus balticus		1											
Juncus canadensis	4												
Leersia oryzoides									1				
Lemna minor				2								1	
Lycopus uniflorus							1						
Lythrum salicaria											3		
Najas flexilis					1							1	
Nuphar advena											1		
Nuphar variegata													1
Nymphaea odorata		2			1						1		
Phragmites australis	5	1	5			5	5	5	5	5	1		5
Polygonum punctatum									3				
Pontedaria cordata			1		3								
Potamogeton gramineus			3										
Potamogeton pectinatus		1											
Sagittaria latifolia		5			5								
Schoenoplectus acutus	1	5	3	5	5		1				4	5	
Schoenoplectus pungens			3				1				2		
Scheonoplectus tabermontani	2		1										
Triadenum fraseri									1				
Typha angustifolia					1				2		3		
Vallisneria americana				5									
Zizania aquatica		3			1								

Table 2. Plants present within vegetation plots on Harsen's Island diked wetlands. Numbers represent number of subsamples containing the species.

	PLOT										
SPECIES	**Plot 3**	**Plot 5**	**Plot 12**	**Plot 14**	**Plot 17**	**Plot 21**	**Plot 23**	**Plot 26**	**Plot 37**	**Plot 42**	**Plot 56**
Asclepia incarnata	2										
Boehmeria cylindrica	4							1			
Calamagrostis canadensis	2								5		
Campanula aparinoides									2		
Carex aquatilis								1			1
Carex stricta									2		
Chara sp.		1		5							1
Cicuta bulbifera	4										3
Cirsium palustre										2	
Cirsium sp.										2	
Echinochloe walteri										1	
Eleocharis quinquefolia	2										
Eleocharis sp.	1										
Erechtides hieracifolia						1		1			1
Eupatorium perfoliatum										1	
Galium trifidum										2	
Hypericum majus	1										
Impatiens capensis								3		2	
Leersia oryzoides	1										
Lemna minor											1
Lycopus americanus										2	
Lycopus uniflorus	1							2	4		
Lysimachia thyrsiflora										1	
Mentha arvensis								1	2		
Myriophyllum heterophyllum		1									
Nuphar variegata				1		1					
Nymphaea odorata		1						1			1
Phragmites australis			5			5			2	4	
Pilea pumila										1	
Polygonum persicaria										1	
Potamogeton gramineus		4									
Potamogeton natans		1		1							
Potamogeton pectinatus				1							
Potamogeton richardsonii				2							
Scutellaria galericulata	2								1	2	
Solanum dulcimara										1	1
Sparganium chlorocarpus						1					
Sparganium minimum		1									
Triadenum fraseri									1		
Typha angustifolia	5	4			5	2	5	5		2	5
Typha latifolia									5		
Utricularia intermedia		2									
Verbena hastata	2										

Table 3. Plants present within the vegetation plots on Fish Point undiked wetlands. Numbers represent number of subsamples containing the species.

	PLOTS				
SPECIES	**Plot 1**	**Plot 7**	**Plot 13**	**Plot 28**	**Plot 39**
Boehmeria cylindrica	1				1
Calystegia sepia					1
Carex aquatilis	3			1	
Carex crinita	1				
Carex sp.	1				
Carex vulpinoides	1				
Cicuta bulbifera	5	3			
Cirsium palustre					1
Cladium mariscoides				4	
Eleocharis smallii	5	5	2	2	
Galium trifidum		4			
Impatiens capensis					1
Juncus balticus		3	2	1	
Juncus effusus		2		5	
Leersia oryzoides	2	5			
Lycopus americanus	1				
Lythrum salicaria	2	2			
Phragmites australis	5	5	1	5	5
Polygonum punctatum	4				
Populus tremuloides				1	
Rumex orbiculatus					1
Salix sp				1	
Schoenoplectus acutus		3	2		
Schoenoplectus pungens	4	4	5	3	
Scheonoplectus tabermontani	3		3		
Typha angustifolia	3	5	5		2
Zizania aquatica				1	

Table 4. Plants present within the vegetation plots on Fish Point diked wetlands. Numbers represent number of subsamples containing the species.

	PLOTS				
SPECIES	**Plot 5**	**Plot 15**	**Plot 16**	**Plot 22**	**Plot 33**
Calamagrostis canadensis			4		
Carex bromoides					1
Carex lacustris			3		
Carex stricta			2		
Ceratophyllum demersum	1				
Chara sp.				5	
Chelone glabra			2		
Cicuta bulbifera					1
Cyperus strigosus					1
Galium trifidum					1
Lathyrus palustris			2		
Lemna minor	5	2			
Lycopus americanus					1
Myriophyllum spicatum		5			
Nymphaea odorata	1				
Phragmites australis			4		
Polygonum lapathifolium			5		
Polygonum sp.					3
Potamogeton natans				1	
Potamogeton pectinatus	1				
Potamogeton zosteriformis		1		1	
Rumex maritimus					1
Salix exigua			2		
Scutellaria galericulata			1		
Spirodela polyrhiza	4	1			
Typha angustifolia					5
Urtica dioica			1		
Vallisneria americana		3			

Table 5. Plants present within the vegetation plots on Wigwam Bay undiked wetlands. Numbers represent number of subsamples containing the species.

	PLOTS				
SPECIES	**Plot 9**	**Plot 26**	**Plot 28**	**Plot 30**	**Plot 34**
Agrostis hyemalis			1		
Asclepia incarnata			2		
Bolboschoenus fluviatilis				2	
Calamagrostis canadensis	3	2	1	5	
Calystegia sepia		4	1	4	
Campanula aparinoides		2	1	3	
Carex aquatilis	1	1			
Carex stricta			1	2	
Carex retrorsa	1				
Carex viridula					3
Cicuta bulbifera	3				
Cirsium arvense		3	4		
Cirsium palustre	1	1	1		
Conyza canadensis		1			
Dulichium arundinacea	1				
Eleocharis obtusa					4
Eleocharis smallii	3				1
Eupatorium perfoliatum	1				
Galium trifidum				1	
Impatiens capensis				5	
Juncus acuminatus					2
Juncus effusus					1
Juncus nodosus		2	1	2	1
Lathyrus palustris		2	1	2	
Leersia oryzoides	3				
Lycopus americanus	1				
Lythrum salicaria	3				1
Panicum sp.				1	
Phragmites australis	2	5	5		4
Polygonum lapathifolium				1	
Potamogeton natans					1
Rubus strigosus			1		
Salix petiolaris				2	
Schoenoplectus pungens					5
Scheonoplectus tabermontani	3				
Sparganium eurycarpum	1				
Thelypteris palustris				2	
Typha angustifolia	5				
Verbascum thapsis		1			
Verbena hastata		4			

Table 6. Plants present within the vegetation plots on Wigwam Bay diked wetlands. Numbers represent number of subsamples containing the species.

	PLOTS				
SPECIES	**Plot 2**	**Plot 6**	**Plot 24**	**Plot 45**	**Plot 86**
Alnus rugosa		2			
Bidens frondosus			3		
Bidens vulgaris		5			
Calamagrostis canadensis					4
Calystegia sepia					3
Carex lacustris		4			
Carex sp.			2		
Carex stricta					3
Ceratophyllum demersum	5				
Chelone glabra		2			1
Cicuta bulbifera		3	1		1
Coreopsis tripteris					1
Elodea canadensis	1				
Epilobium coloratum			1		
Epilobium leptopyllum		1			
Fraxinus pensylvanica			4		
Galium trifidum		5	4		
Impatiens capensis		2	5		
Lemna minor				1	
Lycopus rubellus		1	2		
Lycopus uniflorus					4
Lysimachia thyrsiflora					1
Myriophyllum exalbescens	1				
Nymphaea odorata	3			3	
Polygonum lapathifolium			2		
Rumex orbiculatus		1			
Scutellaria galericulata					1
Scutellaria lateriflorus		3	2		
Spirodela polyrhiza	4				
Thallictrum dioicum		2			
Thelypteris palustris					4
Triadenum fraseri					5
Typha angustifolia			5		
Typha latifolia		2			4
Verbena hastata					1
Zizania aquatica	2			4	

Table 7. Summary of the number of plants present at each sampling site.

SITE	HYDROLOGY	NATIVE PLANTS (#)	INVASIVE PLANTS (#)
St. Clair R. Delta – Dickinson Island	Undiked	26	4
St. Clair R. Delta – Harsen's Island	Diked	38	5
Shared species # (%)		11 (17)	3
Fish Point	Undiked	23	4
Fish Point	Diked	25	3
Shared species # (%)		3 (7)	2
Wigwam Bay	Undiked	34	6
Wigwam Bay	Diked	35	1
Shared species # (%)		9 (15)	1

Dickinson Island and Harsens Island sites share three of the six invasive plants, with two of these, narrow-leaved cattail and reed being common on both the diked and undiked sites. Reed has expanded into much of the Dickinson Island marsh during the recent dry conditions, out-competing and replacing the wide-spread narrow-leaved cattail in many areas. In contrast, within the Harsens Island dikes narrow-leaved cattail has remained dominant in deeper water, with reed more restricted to drier portions of the wetland. It appears that flooded conditions restrict reed's ability to replace narrow-leaved cattail, while it is able to rapidly replace it in the drier conditions outside of the dike. It is unclear how important herbicide treatment and controlled burns have been for restricting reed expansion, but based on our sampling, they are effective management techniques in the short term. Long-term transects at Pinconning marsh on Saginaw Bay have demonstrated that the stem density of narrow-leaved cattail is greatly reduced during low-water conditions and that many herbaceous and shrub species are able to move into narrow-leaved cattail stands during these dry periods (author, unpublished research). It appears that reed may also be more competitive than narrow-leaved cattail in these drier conditions.

At Fish Point, 25 native plant species occurred in the diked wetland plots, while 23 native species occurred in the undiked plots (Table 7). Three invasive species occurred in the diked plots, and four in the undiked plots. Only three native species were shared by the diked and the undiked plots, but both sets of plots contained abundant wet-meadow plants, thirteen in the diked and fifteen in the undiked plots (Tables 3 and 4). Ten submerged or floating species occurred in the dikes due to the permanently flooded conditions within portions of the dikes, while only one occurred in the undiked plots. There were six native emergent plant species in the undiked wetland, with none in the diked plots**.** In summary, it appears that areas of unflooded wet meadow persist in both the diked and undiked marsh, but that flooded portions of the diked wetland now supports many submergent and floating species. Sampling in the undiked marsh was concentrated in the wet meadow and the emergent marsh, with no sampling directed specifically at the open water outside of the dikes, where one would expect submergent or floating species. Therefore the reduced submergent and floating plant diversity at Fish Point is likely an

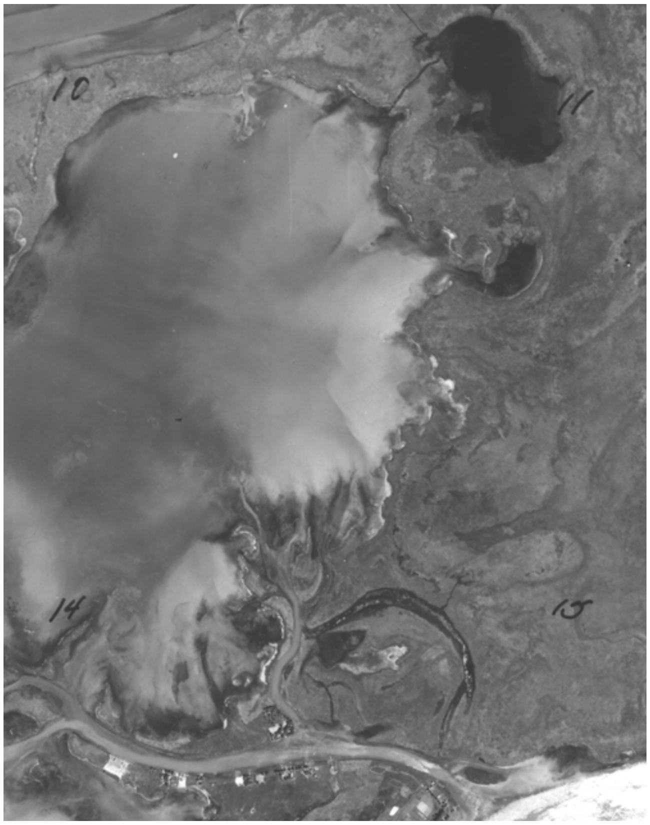


Figure 5. West end of Dickinson Island, where all of the sampling plots for this study were located, on 1941 aerial photograph. There is little sign of land management, with the exception of buildings along channels.

Figure 6. West end of Harsens Island, where all of the sampling plots were located, in a 1941 aerial photograph. There has been little and management, except along the main channels of the St. Clair River.

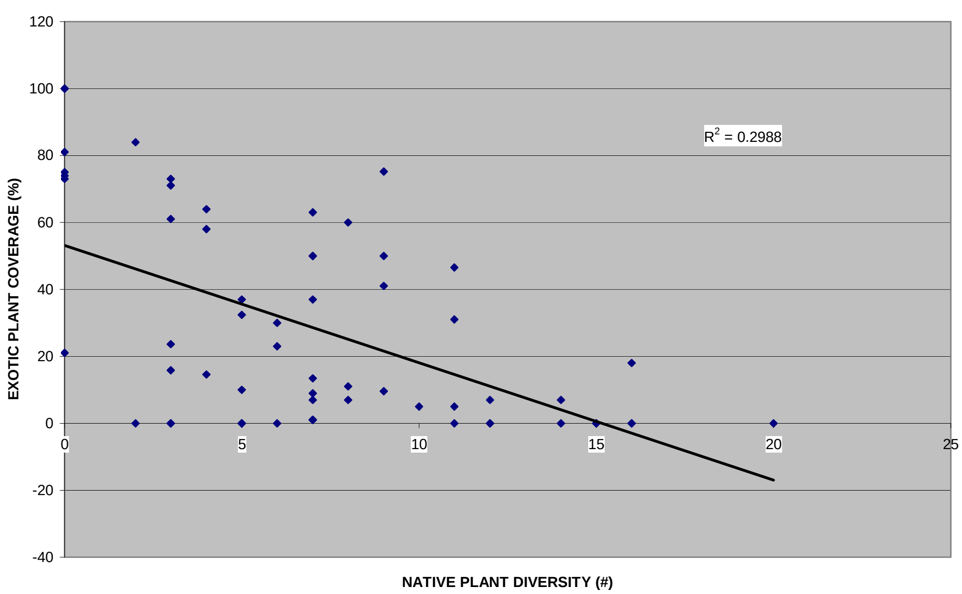
artifact of sampling. Two of the five invasive species at Fish Point were shared by the diked and undiked sites, reed and narrow-leaved cattail. While both species were wide spread in the undiked plots, each occurred only once in the diked plots. Based on both photo interpretation and visits to the site, cattail stands and Phragmites stands were likely under-represented in plots inside the dikes.

At Wigwam Bay, there were 35 native plant species and one invasive species inside the diked marsh, with 34 native plant species and 6 invasive species in the undiked marsh (Table 7). Nine species (15%) were shared by the diked and undiked plots, and all were wet-meadow plants (Tables 5 and 6). The only shared invasive species was narrow-leaved cattail, and it was present in only one diked and one undiked plot. Flooding within the dike appears to have increased submergent and floating plant representation, while emergent plants are more common in the unflooded environment outside of the dikes.

An overall pattern seen in the plant data is that as reed increases in dominance, the overall native plant diversity dropped. This pattern will likely be stronger in the future, as many of the native plant stands are in the process of being replaced by reed, so there are still remnant native plants remaining in the stands.

If native plant diversity is compared to overall dominance of exotics, lumping the two primary exotics at our site, reed and narrow-leaved cattail, a statistically significant drop (p <.0001) in native plant diversity is seen (Figure 7). The low R^2 value (.299) probably reflects the variability in the stands dominated by these species. Reed and narrow-leaved cattail also respond somewhat differently in the low-water conditions that characterized our study. Phragmites expands aggressively during low-water conditions, while narrow-

FIGURE 7. RELATIONSHIP OF NATIVE SPECIES DIVERSITY TO EXOTIC PLANT COVERAGE



leaved cattail stands tend to be less dense and productive during dry periods, when many other emergent species, such as goldenrods, asters, nightshade, willows, and tree seedlings become scattered through the cattail stands. In contrast, during wet periods these cattails would be dense and almost monocultures.

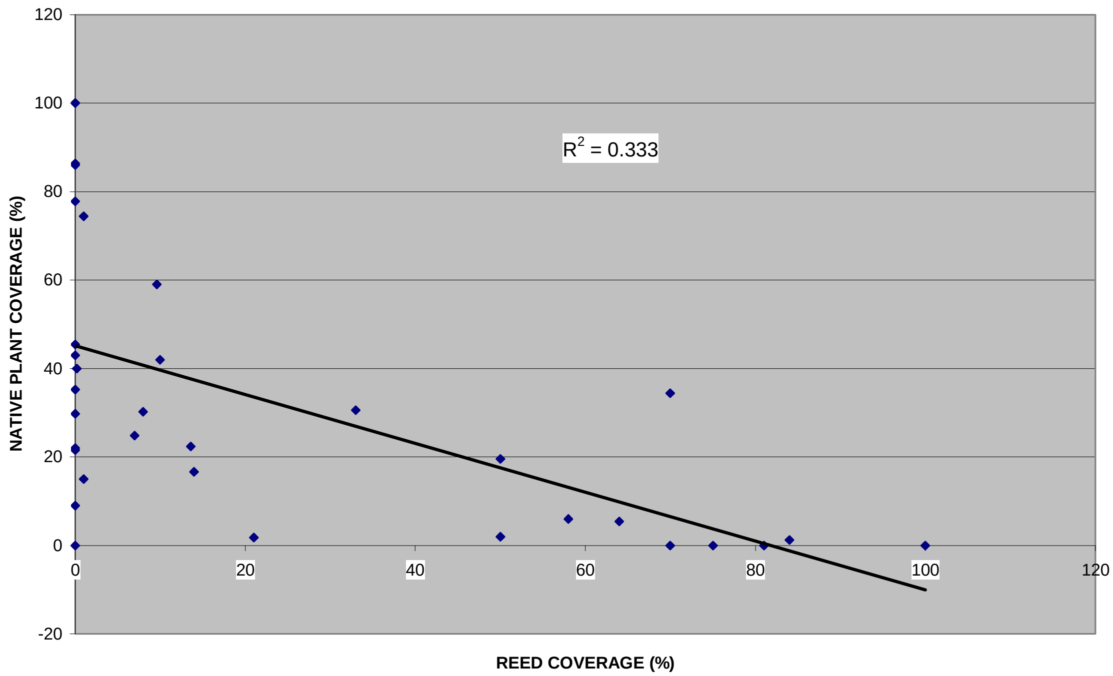
The mean number of plants that occur in diked versus undiked plots was compared for each sampling site (Table 8). There was no statistical different between the mean number of native plants found in diked and the number found in undiked vegetation plots for any of the three sampling sites, however, the greatest difference between the two conditions was seen at Fish Point. In contrast, for invasive (exotic) plants, there was a statistically significant different between the number of species for diked and undiked plots at all three sampling sites. The least difference between the two conditions was seen on the St. Clair River Delta, where either reed or narrow-leaved cattail were regularly present in most of the Harsens Island diked sites, whereas many of the Dickinson Island plots dominated by submerged plants had no invasive species. Both invasives were also common in the undiked Fish Point plots, while the flooded diked sites had neither cattail nor reed. Wigwam Bay diked sites had the lowest coverage of invasive species, while there were one or more invasive in most undiked sites.

Native plant cover. Native plant cover was also compared to the above-ground coverage of reed, where native plant and reed coverage were measured as the mean percent coverage of all plants growing in the five vegetation subplots (Figure 8). Native plant coverage decreased significantly as reed coverage increased ($R^2 = 0.333$, $p < .0001$). All of the plots that were dominated by another invasive species, such as narrow-leaved cattail or Eurasian milfoil were removed from the data set prior to this analysis.

Table 8. Mean number of native and invasive species present in each vegetation sampling plot by hydrologic condition. Bolded conditions are statistically significant at the 0.05 level.

SITE NAME	DIKED # of Plant species	UNDIKED # of Plant species	PROBABILITY (p)
		NATIVE SPECIES	
St. Clair River Delta	1.84	1.77	0.84
Fish Point	2.52	3.7	0.06
Wigwam Bay	4.76	3.84	0.17
		INVASIVE SPECIES	
St. Clair River Delta	**1.0**	**0.77**	**.04**
Fish Point	**0.56**	**1.8**	**<.001**
Wigwam	**0.32**	**1.48**	**<.001**

Figure 8. Relationship of native species coverage to reed coverage



In 2006 and 2007, additional sampling was conducted at all of the sites. These sampling points were not randomly identified, but were instead focused on plant communities that were under-represented in the original sampling plots. These plant diversity data were not included with the randomly sampled sites from 2005, but they demonstrated some trends. The most dense stands of reed on Harsens Island, considered to be some of the longest established sites in the study, had very low levels of native plant diversity, whether they were in flooded or dry sites. Small remnant wet meadow sites within the Harsens Island dike had similar levels of native plant diversity to other flooded wet meadow at Wigwam Bay. Wet meadow sites at both Fish Point and Wigwam Bay contained some lakeplain prairie species, adding to overall plant diversity at these sites.

Expansion of Phragmites (Reed).

One of the strongest patterns seen along the Great Lakes in recent low-water years has been the expansion of reed into all types of marsh habitat. The Great Lakes have experienced an abnormally low water level period since 1997, when the water levels began to drop to their current low levels, with a drop of about 1.1 meters between 1997 and 2000 (NOAA 2008, Sellinger 2008). The associated trend of reed expansion was documented in this study, especially at Dickinson Island in the St. Clair River Delta. The vegetation plots in this study were sampled to provide representation for all of the zones or vegetation types present in the wetlands. On Dickinson Island, 10 of 13 plots contained reed, demonstrating the level of expansion of this aggressive introduced plant (Table 1). Within the dikes of Harsens Island, only 4 of 11 plots contained reed, while *Typha angustifolia* (another introduced species) dominated 6 of the 11 plots (Table 2). It appears that reed does not out-compete already established narrow-leaved cattail stands within the flooded dikes.

In the undiked wetlands at Fish Point on Saginaw Bay, two sites were dominated by reed and two by a mix of reed and narrow-leaved cattail (Table 3). In the diked plots at Fish Point, only one plot was dominated by reed, another by narrow-leaved cattails, and one by a mix of narrow-leaved cattail and bulrushes (Table 4). Reed does not yet appear to have expanded as aggressively at Fish Point as on the St. Clair River Delta. However, the submergent plots was dominated by *Myriophyllum spicatum* (Eurasian milfoil), another aggressive exotic plant.

In Wigwam Bay undiked wetlands, three were dominated by reed and a fourth by narrow-leaved cattail (Table 5). The diked wetlands had no reed, although one of the sampled plots was dominated by narrow-leaved cattail. While there are large clones of reed outside of the dikes, this plant has not expanded as rapidly as on the St. Clair River Delta. Small patches of native *Phragmites australis,* a much smaller and less aggressive species than the exotic variety of reed.

A comparison of the number of reed stems in diked and undiked plots showed a statistically significant difference, with the number of stems and populations much higher outside of the dikes. This will be discussed in more detail under the heading of “Dominant plant relationships to hydrologic condition”. From the data collected in this study, it appears that reed has been less aggressive within the diked wetlands, where there is water-level control. However, reed's overall coverage within dikes is likely underestimated, as there have been controlled burns and herbicide treatments within the Harsens-Island dikes to reduce reed coverage.

Evaluation of patterns within the diked portion of Harsens Island was made more difficult by some herbicide treatment of reed prior to our vegetation; two of our plots, HA21 and HA42 (Figure 2) had high reed rhizome weights but only dead stems in both the biomass plot and the vegetation plots. Outside of the dikes, on both Dickinson and Harsens Island, reed has been rapidly invading portions of the marsh previously dominated by narrow-leaved cattail, native broad-leaved cattail (*T. latifolia*), or other native emergent species, primarily bulrushes. The previous dominance of cattails or bulrushes can be established from the organic sediments that continue to contain small numbers of partially-decomposed cattail stem-bases or bulrush rhizomes.

Reed in a long-term transect. The expansion of reed was best demonstrated on a transect across the Dickinson Island marsh, where sampling was conducted beginning in 1988, followed by resampling of the transect in 1994, 1999, and finally in 2005, as part of this study. In 1988, no reed was encountered in the first 24 sampling points, stretching across 800 meters of marsh, although it was recorded as being present immediately outside of one of the plots. In the 1990s reed was present on 10% to 28% of sampling points, but during the 2005 resampling of the transect, reed was found to dominate 67% of the sampling points. Average coverage in 1988 was less than 1% (a nominal value of 0.25% was given for any species within a meter of a sampling plot to provide a more comprehensive species list that included uncommon species), with 4 to 11% coverage in the 1990s, and 42% in 2005, demonstrating a major increase in reed dominance across the entire marsh by 2005, following an extended period of low water conditions. Along this same transect, the number of bulrush-dominated plots declined dramatically, and it remained a dominant only where there was relatively deep water and some wave activity.

Comparison of plant biomass in diked and undiked zones.

Total biomass data shows interesting trends, but the successional nature of the present environment does not allow for simple interpretation (Figures 9 through 11). The complicated differences reflect a combination of hydrologic, management, and successional factors.

St. Clair River Delta. On the undiked wetland of Dickinson Island (Plots 1-13 on Figure 9), the biomass of one site (plot 8 on table) is completely dominated by reed, while in several other plots (plots 1, 3, 6, 7, and 13) reed has almost completely replaced bulrushes, and in plots 9 and 10, reed has largely replaced cattails. In the undiked Dickinson Island plots, only plots 4, 5, and 12 contain no reed.

Historically, bulrushes (*Schoenoplectis acutus* and *Schoenoplectus pungens*) and broad-leaved cattail (*Typha latifolia*) were likely the dominant plants in the emergent marsh

Figure 9. Total plant biomass for St. Clair Delta (Michigan) plots, 2005. Plots 1-13 were in undiked area. Plots 14-24 were in diked area. Phrag=*Phragmites*, Typ=*Typha*, Sch Pun= *Schoenoplectus pungens*, Sch Acu=*Schoenoplectus acutus*, Gramino=Graminoid, Submrg=Submerged vegetation.

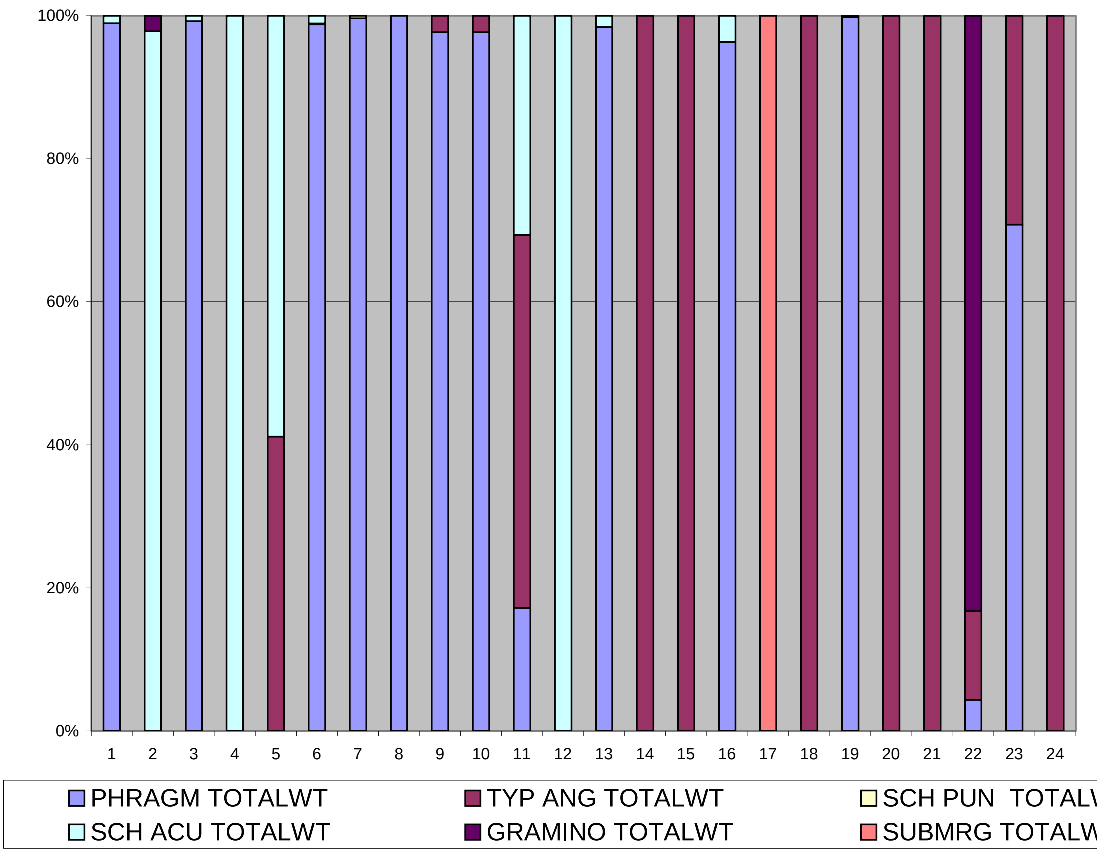


Figure 10. Total plant biomass in plots at Fish Point, Michigan, 2005.
Plots 1-5 undiked, plots 6-10 diked. Abbreviations are same as in Fig. 1.

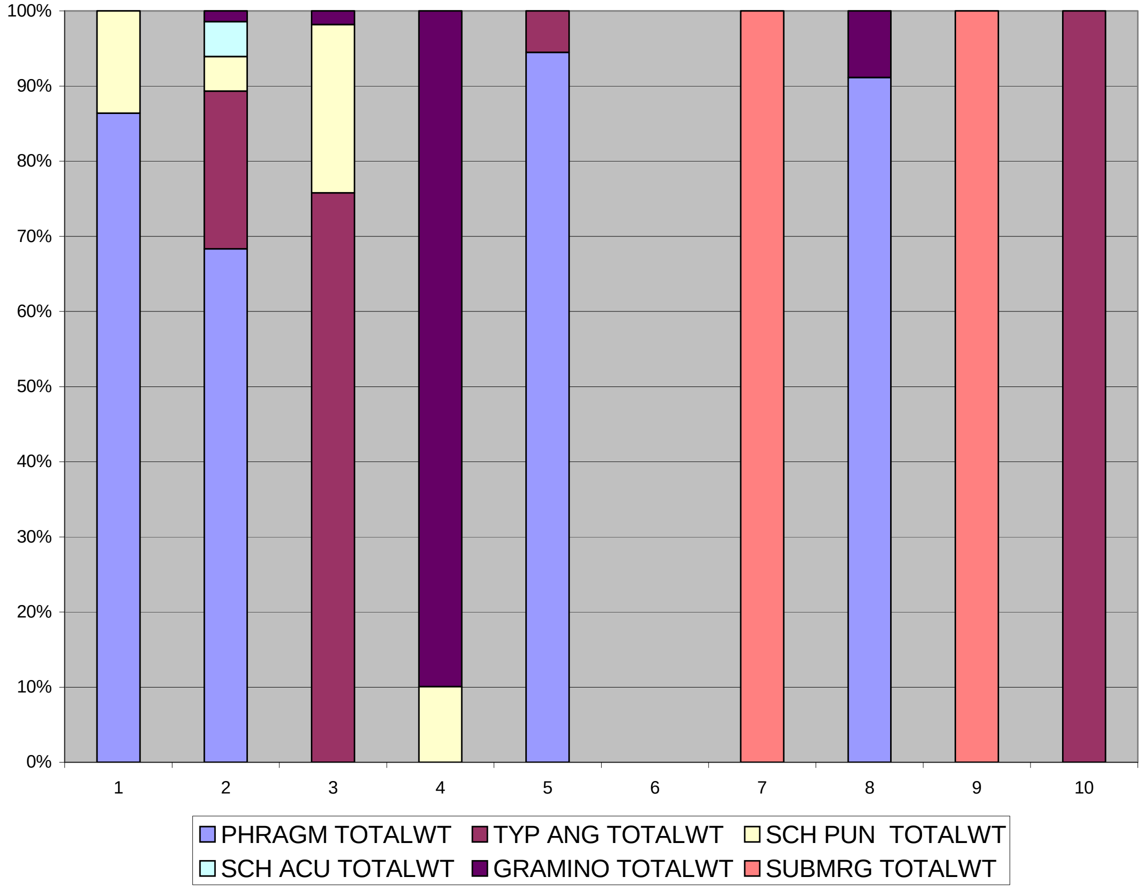
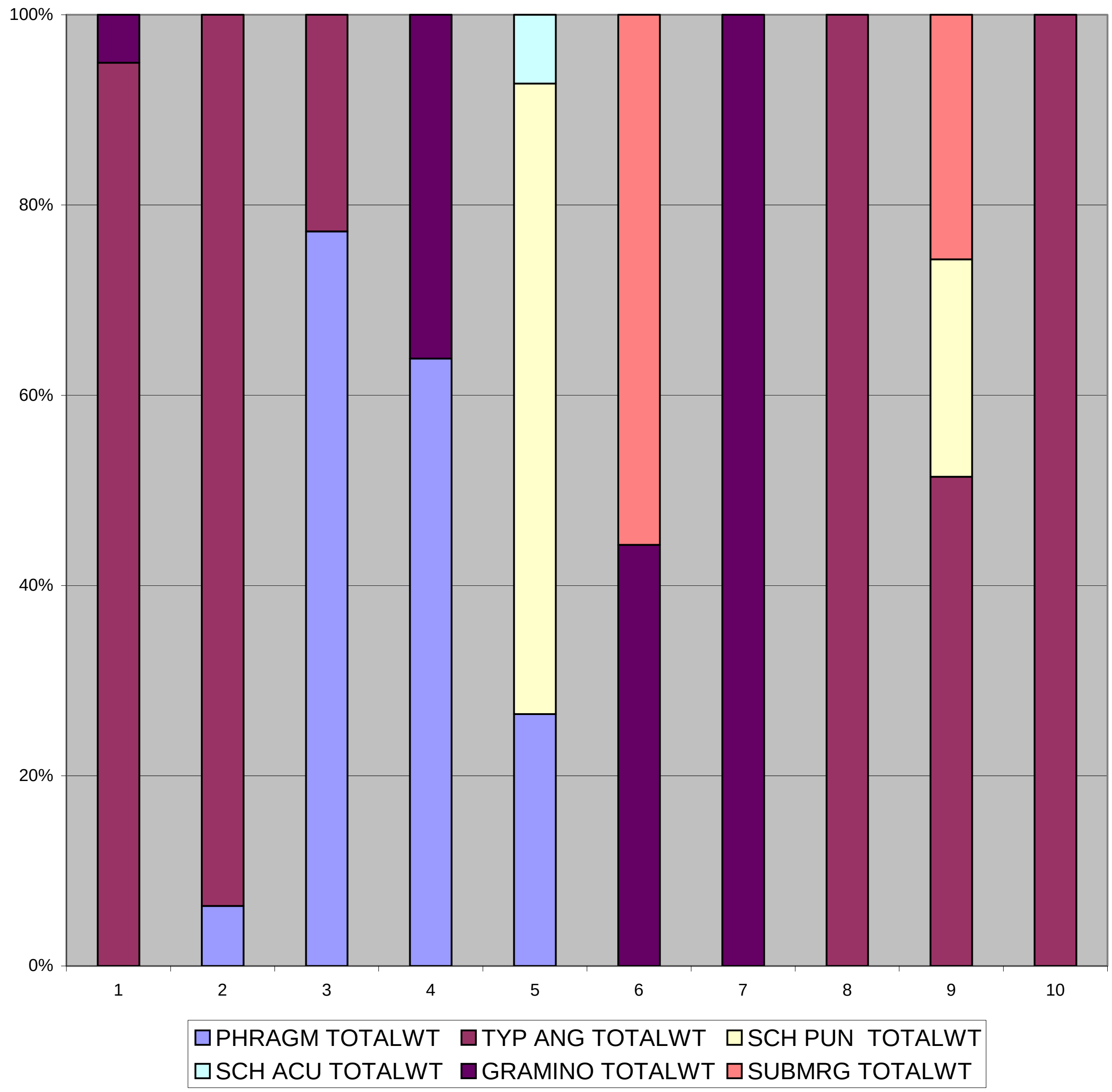


Figure 11. Total plant biomass in plots at WigWam Bay, Michigan, 2005. Plots 1-5 undiked, 6-10 diked. Abbreviations same as in Fig 1.



before being first replaced by narrow-leaved cattail, an introduction from the eastern U.S., and then later by reed. For the drier wet-meadow zone, sedges (*Carex stricta*, *Carex aquatilis*, and other *Carex* species) and grasses (*Calamagrostis canadensis* and others) were the dominants. Based on historic photo analysis (for example, Figures 5 and 6), prior to dike construction wet meadow and cattail marsh appear to have been present on much of the diked marsh, and the deeper-water bulrush zone was more localized.

For the diked plots on Harsens Island (plots 14-24 on Figure 9), reed is not as aggressively replacing cattails or bulrushes as in the undiked wetlands. Reed was replacing cattails in plot 19 and 23 and bulrushes in plot 16, but cattails were primarily dominant in plots 14, 15, 18, 20, 21, and 24. Actual reed biomass is difficult to interpret in plots 19 and 23, as both sites were treated with herbicide to kill reed. Grass dominated plot 22 is being colonized by both cattails and reed. In many of these reed- or cattail-dominated stands, there is almost no above-ground bulrush, but instead only remnant fragments of rhizome remain in the underlying mineral soils. Where cattail once dominated sites, the small remnant cattail stem-bases persist in the lower organic soils, below most of the reed roots and rhizomes.

Relating vegetation differences to hydrology was not simple on either diked or undiked St. Clair River Delta plots. The maximum water depth encountered in plots within the dikes was 70 cm, and only one of the eleven diked vegetation plots had standing surface water. In contrast, eight of the thirteen undiked vegetation plots on Dickinson Island had standing water, although water depths were less than the 70 cm within the dikes.

Saginaw Bay. For Saginaw Bay sites, reed dominance was not as prevalent as on the St. Clair River Delta. At both Fish Point (Figure 10) and Wigwam Bay (Figure 11), there were greater levels of reed on the undiked plots (plots 1-5 for both Figures 10 and 11) than on diked plots. At both of these Saginaw Bay sites, the plots tended to represent more mixed stand dominance than on the St. Clair River delta. At Fish Point, deeper water and more submergent vegetation characterized large areas and obviously reduced the area where reed could colonize. The deepest water at a sampling plot was 64 cm, and three of five diked plots were in standing water. Outside of the dikes at Fish Point sediments ranging from sand to clay over a short distance pointed to active erosion by storm waves, thus reducing the level of reed. Reed is easily eroded by wave action. Most of the reed stands at Fish Point appeared to have established much more recently than those of the St. Clair River delta, based on shallower organic soils. Two of five plots were flooded, but the water was shallow (24 cm maximum).

Wigwam Bay has little reed establishment inside the dikes, with greater levels of shrub and tree encroachment than either Fish Point or the St. Clair River Delta. Many of the reed stands in undiked areas still support other plant species, either bulrushes, cattails, or a diverse native wet-meadow assemblage of sedges, grasses, and herbs, again reflecting more recent establishment of reed. A direct comparison of reed stands inside and outside dikes was not made because the limited amount of reed within the dikes appears to be the less aggressive native genotype, while most of the reed outside the dike is the invasive European genotype. The wet meadow zone inside and outside the dikes showed major differences, with below-ground biomass within the flooded impoundments as much as ten times greater than the below-ground biomass in the dry meadow zone outside of the dikes. Water depth in plots inside the dikes were up to 54 cm deep (68 cm in one of the 2006 supplemental plots), with two of five plots flooded, while none of the plots outside of the dikes were flooded. Soils both inside and outside the dikes were sandy, probably reflecting the location of the wetland at the mouth of the Au Gres River, but inside the dikes organic deposits were thicker than in undiked sites, as a result of impounded conditions which reduce organic decomposition.

Decomposed plant material. As part of our sampling, we collected decomposed plant material in our 0.04 m^3 below-ground sampling plot. Only course organic material greater than 1.5 to 2 mm in diameter were retained by the screening used to trap both organic material and intact roots and rhizomes. Highly decomposed, fine organic materials were not collected. Our mid-summer sampling showed little accumulation of partially-decomposed organic material in bulrush-dominated emergent-marsh plots (maximum 10.3 percent) or in grass- and sedge-dominated wet-meadow plots (maximum 13.4%). Most of the organic material associated with these species was either mixed into the mineral soils or was silt-sized and could not be collected. In contrast reed was found to have up to 30.2% partially-decomposed dead biomass and narrow-leaved cattail up to 56.4%. Slow decomposition, which results in thick organic soil accumulation, is well-documented for both reed and cattail in wetland literature (Gessner 2000, Freyman 2008), and is recognized as a major factor in limiting competition from most other emergent plant species (Graneli 1989, Tuchman et al 2008, Angeloni et al 2006, Freyman 2008).

Both reed and cattail litter decompose slowly to form a thick layer with little plant establishment. The lower layers of reed litter often contain the remnants of cattail rhizomes, documenting that cattails were the previous dominants until they were out-competed. Occasionally bulrush rhizomes are also found in the mineral soil or lower organic soil below the thick reed litter, although it appears to survive better beneath cattails, and often persists with scattered live plants remaining in the stands.

Plant tissue decomposition is much more rapid for grasses and sedges if they are growing in non-saturated conditions. At Wigwam Bay, flooded sedge roots did not appear to break down rapidly, but actively growing roots appear to have grown into the old, partially decomposed root mass, making it difficult to separate live and dead roots. In contrast, on nearby dry sites the same species have decomposed significantly, so that almost no organic soil zone is recognizable. Instead, the organic material has been incorporated into an organic-rich mineral soil horizon (A horizon).

Organic soil depth was consistently greater in the diked wetlands than in the undiked wetlands, with the greatest average accumulation of organic soils in the Harsens Island and Wigwam Bay sites (33 cm and 28.6 cm respectively), with only 15 cm at Fish Point. Undiked Dickinson Island and Wigwam Bay had 14 cm and 11 cm of organic material accumulation, while none of the undiked Fish Point plots had measureable surface organic soil horizons. Deep organic soils are consistent with cattail dominance (Freeman 2008).

Dominant plant relationships to hydrologic condition.

General observation was that reed was more common in shallow water or in dry habitat, than in the flooded dikes. Wilcoxon/Kruskal-Wallis Rank Sum tests showed a statistically significant difference ($p < .0008$) between the number of reed stems in drier undiked plots and wet diked plots (Figure 12), with up to 32 stems in undiked plots, but a maximum of 9 stems in a diked site. The mean number of stems in undiked plots was 8.3, while the mean in diked plots was 0.85 (excluding the two Harsens Island diked plots where reed had been herbicided from analysis). In contrast, comparison of the number of cattail stems showed no statistical difference ($p = 0.09$) between diked and undiked plots (Figure 13), although the highest number of cattail stems occurred in flooded diked plots. Bulrushes were present in statistically higher numbers ($p = 0.03$) in undiked plots than in diked plots, with no diked plots containing bulrushes (Figure 14). Subsequent sampling in 2006 and 2007 showed that there were small clones of hardstem bulrush within Harsens Island dikes, but these were very localized.

Several parameters of reed biomass accumulation were compared to water depth, but none showed strong linear relationships. For example, the relationship between water depth and the weight of reed rhizomes was examined, and no strong statistical relationship was found (Figure 15, $R^2 = 0.0255$, $p = 0.61$). One pattern that does show in Figure 15 is that reed grows well on relatively dry sites. At one reed site we dug 134 cm before reaching water. However, reed can grow into deep water, and it was found growing in 44 cm of water in protected channels along the edge of the Harsens Island dikes. Reed's ability to tolerate deep water will be easier to evaluate during higher Great Lakes water levels. Reed's dense surface root and rhizome mat may float when water levels rise – this survival strategy has been seen in both bulrushes and sedges during 1987 high water conditions (Albert et al 1987). However, based on the author's observations in Saginaw Bay in 1997 high-water conditions, reed's dense root mass is easily eroded by wave action if there is no protection provided by a physical barrier, such as a dike or sand spit.

Above-ground vs. below-ground biomass ratios.

One question this study attempted to answer was whether there was a difference between the ratios of above-ground and below-ground biomass of the dominant native and invasive plants of the coastal wetlands. Analysis of the data for all plots containing reed showed a statistically significant difference in biomass between the above-ground and the below-ground components ($R^2 = 0.476$, $p = <.0001$), with roughly twice as much below-ground biomass as above-ground biomass (Figure 16). Upon closer inspection of Figure 16, it is evident that the ratio is not constant for all plots, but that there are at least two different sub-populations. These sub-populations represent populations of reed of different age, with increased below-ground biomass for older clones. Most of the well established, older clones have below-ground biomass over 400 grams and above-ground biomass above 300 grams. The plots sampled represent both wet sites and dry sites.

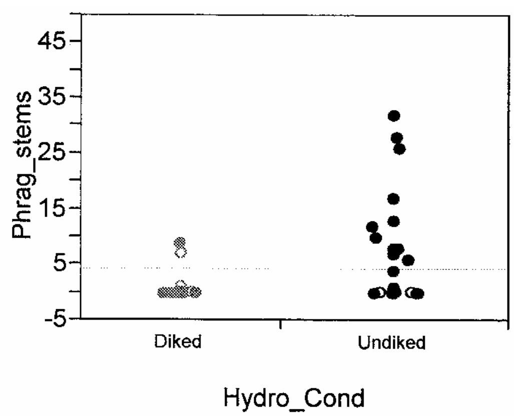


Figure 12. One-Way Anaysis comparing the number of reed stems (Phrag_stems) present in each hydrologic condition: diked and undiked.

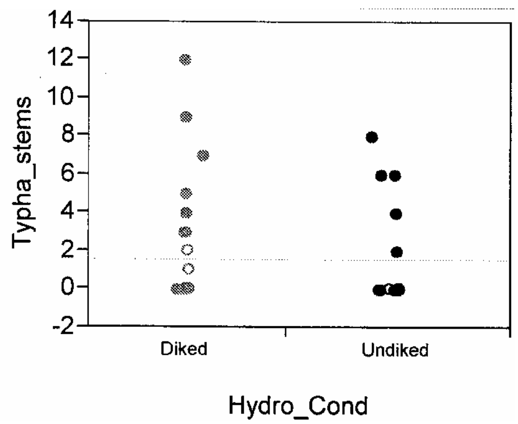


Figure 13. One-Way Anaysis comparing the number of cattail stems (Typha_stems) present in each hydrologic condition: diked and undiked.

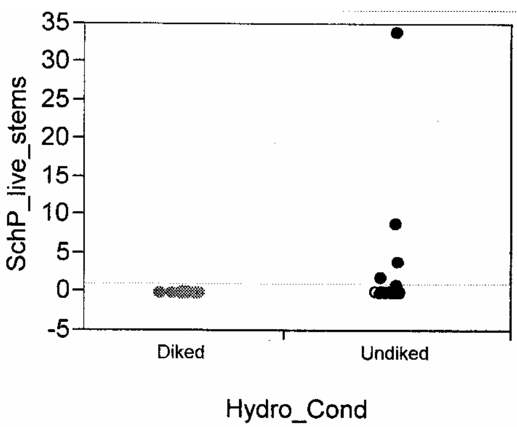


Figure 14. One-Way Anaysis comparing the number of bulrush stems (SchP_live_stems) present in each hydrologic condition: diked and undiked.

Figure 15. Relationship between water depth and weight of phragmites rhizome.

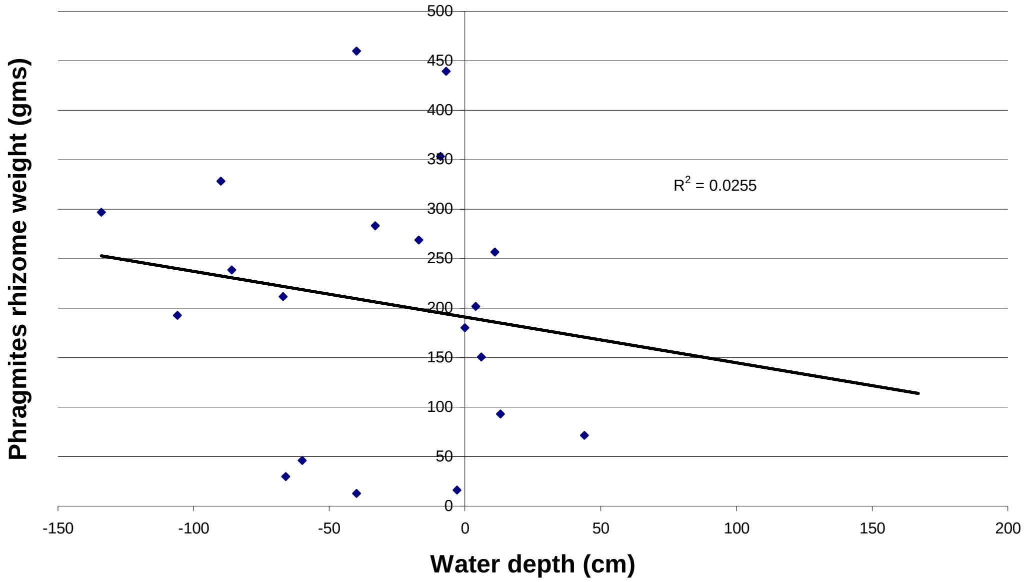
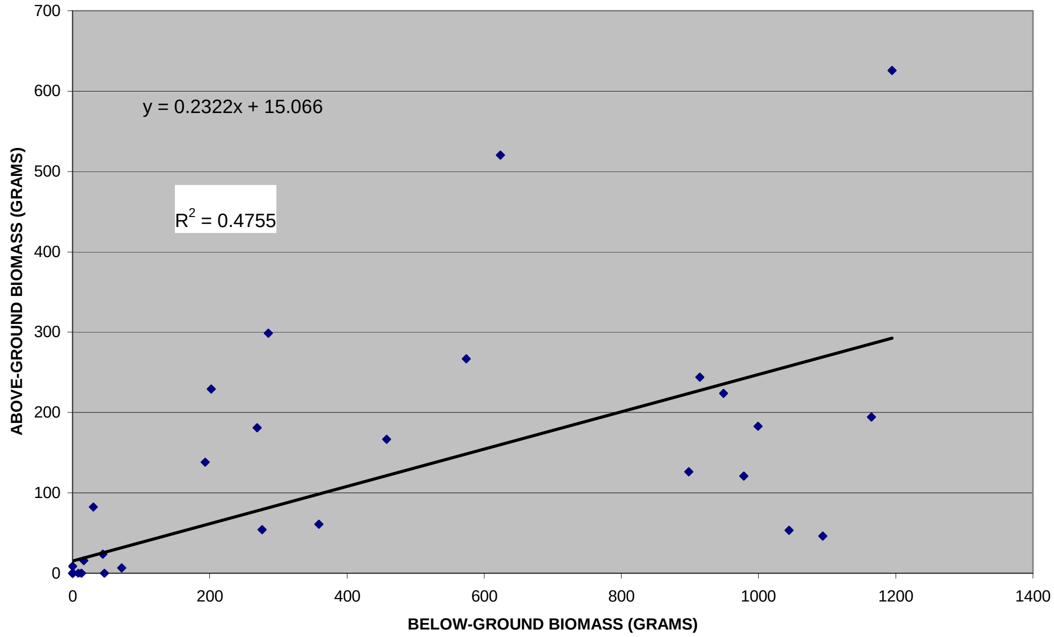


Figure 16. Ratio of above-ground to below-ground biomass of *Phragmites australis* (reed).



The mature stands that are on dry sites, such as old beach ridges or spoil piles, have high below-ground biomass and low above-ground biomass, probably as a result of the current drought conditions. The mature reed stands on wet sites, have an increased ratio of live above-ground biomass. Most of these reed sites are on Harsens Island or Dickinson Island. The majority of newly established clones, which tend to have low below-ground biomass (below-ground biomass less than 400 grams and above-ground biomass less than 300 grams), are located close to the water table and as a result may not require as much root biomass to support abundant above-ground growth.

For narrow-leaved cattail, the ratio of below-ground to above-ground is similar to that seen for reed (Figure 17; $R^2 = 0.71$, $p < 0.0001$), with above-ground biomass (y) roughly one third that of the below-ground biomass (x): $y = .3201x + 7.6108$. Based on the author's experience, this ratio also varies, with above-ground biomass increasing during wetter years and decreasing dramatically in dry years. During periods of high Great-Lakes water level, above-ground biomass may increase several fold and pass that of the below-ground component. From cattail-dominated plots it is obvious that cattail has expanded into some moist habitats previously dominated by bulrushes, as dead or low-productivity rhizomes of either hardstem or three-square bulrush occur in the mineral soils beneath some cattail stands.

Studies of freshwater estuary along the Atlantic Ocean have shown native graminoides to have a greater percentage of their biomass below ground (Gallagher and Plumley 1979). Our study has shown similar results in Saginaw Bay and St. Clair River Delta wetlands (Figure 18), where below-ground biomass of sedges(*Carex stricta* and *C. aquatilis*) and grasses (*Calamagrostis canadensis*) is often four to five times that of above-ground biomass ($y = .1239x + 49.215$; $R^2 = .3419$, $p < .0001$). In extreme cases, where sedges and grasses are growing in standing water within dikes, root and rhizome biomass can be as much as ten times that of above-ground biomass. We are using the term above-ground to mean the photosynthesizing stems and leaves, as opposed to the roots and rhizomes, which actually grow in loose organic material within standing water. In these flooded environments, the greatest graminoid biomasses have been encountered, with extremes of 1975.0 grams in a 0.04 m^3 plot, nearing the maximum biomass found for cattails. In this flooded plot, 16% of the biomass was above-ground (stems and leaves). In another flooded plot, less than 2% of the biomass was above-ground. Above-ground biomass of sedges and grasses ranges from 11% to 38% of total biomass on dry wet-meadow sites, and these dry sites tend to have lower biomass, ranging from roughly 350 to 600 grams. Dry sites contain abundant, finely decomposed organic material mixed with surface mineral soils, indicating that old roots and rhizomes decompose much more rapidly in an aerobic environment.

Similar comparisons of above- and below-ground biomass for hardstem bulrush showed the ratio of below-ground biomass to above-ground biomass was nearly seven to one (Figure 19; $y = .1496x + .7125$; $R^2 = .08334$, $p = < 0.0001$). All of the hardstem bulrush plots had standing water. Biomass was less than 500 grams for most plots, with the maximum of 1106 grams in a diked Harsens Island plot. Hardstem bulrush biomass was

Figure 17. Ratio of above-ground to below-ground biomass of *Typha angustifolia* (narrow-leaved cattail).

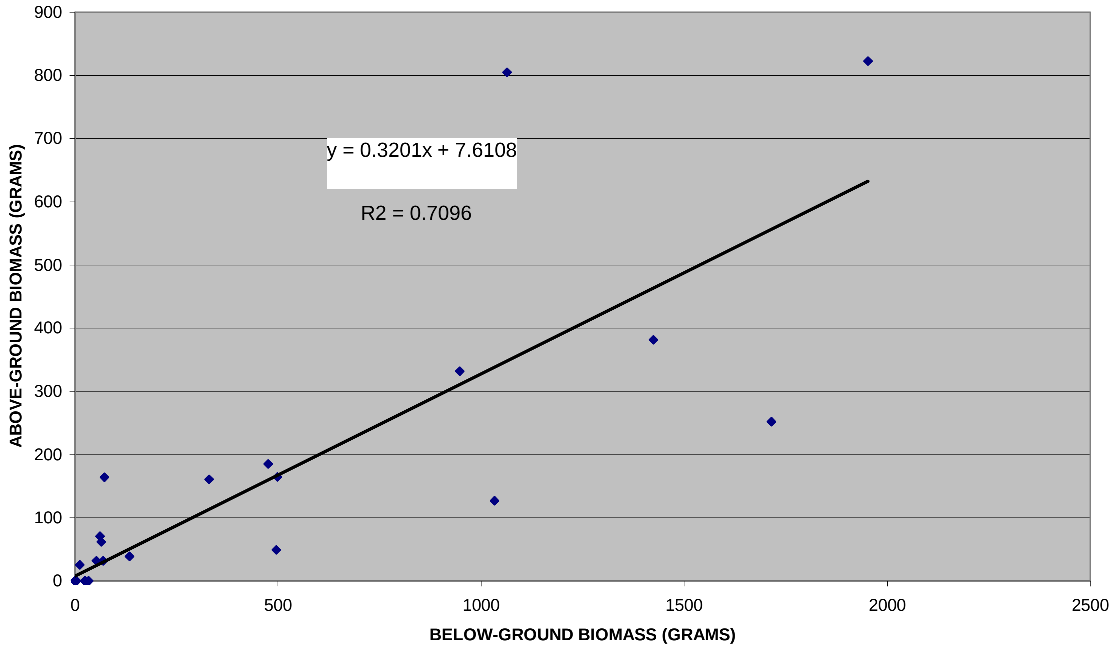


Figure 18. Ratio of above-ground to below-ground biomass of graminoid vegetation

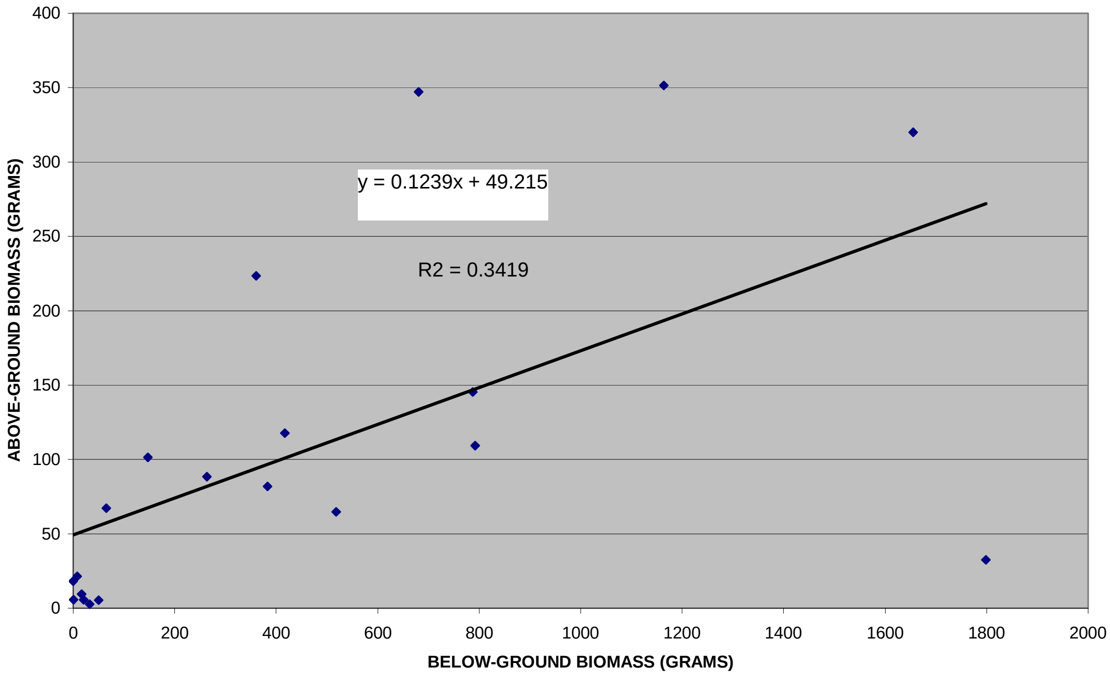
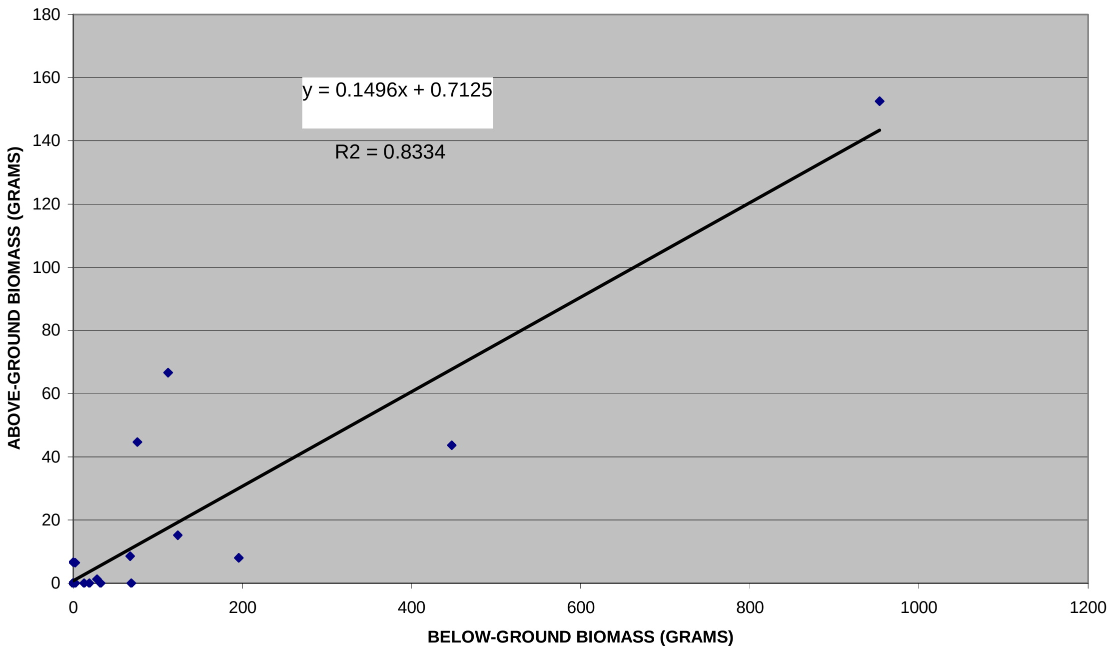


Figure 19. Ratio of above-ground to below-ground biomass of *Schoenoplectus acutus* (hardstem bulrush).



much reduced in plots where there was competition with either cattail or reed, in which case much of the biomass was below-ground rhizomes, probably produced prior to or immediately following reed or cattail dominance of the site.

Biomass comparisons of three-square bulrush (*Schoenoplectus pungens*) plots are limited by the relatively small number of plots where this species occurred (9). For three-square, roughly three-quarters of biomass is located below-ground (Figure 20; y = .2378x - 0.0026; R^2 = 0.3341, p <0.0001). The maximum biomass encountered in a single plot was 79.9 grams, less than 5% of the maximum biomass of reed, cattail, or graminoids. An identically sized plot in Grand Traverse Bay contained 176.0 grams of three-square, which may be nearing the maximum biomass for this species (Albert 2005). The low overall biomass of this species, combined with its concentration of biomass in the underlying mineral soils, accounts for its inability to successfully compete against either cattails, reed, or grasses and sedges in the wet meadow and drier emergent marsh zones.

Photos of bulrush rhizomes and above-ground stems (Figures 21-23) demonstrate that the above-ground portion of bulrushes is much shorter and less dense than that of either reed (Figure 24) or cattails (Figure 25), however the below-ground rhizomes are long-lived and comprise a larger percentage of the overall biomass than in either cattails or reed (Table 9), which have their biomass concentrated much more above-ground. The rhizomes of reed (Figure 26) can also be dense and extending into underlying mineral soil, with fine roots forming in the thick organic duff created by the plant over many years.

TABLE 9. Maximum biomass in a 0.04 m^2 plot (30 cm x 30 cm x 45 cm) for dominant marsh plants. Biomass is broken down into above- and below-ground fractions.

SPECIES	Total Biomass (gm/0.04m^3)	Below-Ground Biomass (gm/0.04m^3)	Above-Ground Biomass (gm/0.04m^3)	Percent Above-Ground Biomass (%)
Narrow-leaved cattail	2775.5	1952.9	822.6	30
Reed	1820.5	1194.8	625.7	34
Sedge/grass	1975.0	1655.1	319.9	16
Hardstem bulrush	1103.3	953.7	149.6	14
Three-square bulrush	70.9	66.1	4.8	7
Wild rice	132.4	65.1	67.3	51

The overall biomass of sedges (*Carex stricta*, *C. lasiocarpa*, and *C. aquatilis*) and grasses (*Calamagrostis canadensis*) in the flooded dikes at Wigwam Bay, Fish Point, and Harsens Island were similar in magnitude to those of cattail and reed, but with a much higher ratio of below-ground to above-ground biomass. Decomposition is slow in the flooded sedge meadow, resulting in thick, dense root and rhizome mass (Figure 27). In contrast, sedges and grasses in the dried meadow zone had greatly reduced below-ground biomass, partially because of extreme levels of root decomposition in the dry, aerated wet-meadow zone outside of the dike.

Maximum biomass for each species. Table 9 summarizes the maximum biomass for each major vegetation type, separating the amount into an above- and below-ground biomass component. From these comparisons it can be seen that the maximum biomass of narrow-leaved cattail (2775.5 gm), reed (1820.5 gm), and sedge/grass (Carex stricta/Calamagrostis canadensis) (1975.0 gm) in the 0.04 m^3 soil samples can be similar. The total biomass of hardstem bulrush can also be relatively high (1163.3 gm), while the biomasses of three-square bulrush and wild rice are much lower (70.9 gm and 132.4 gm respectively). The highest relative above-ground biomass levels are found in wild rice, reed, and narrow-leaved cattail, followed by intermediate levels for hardstem bulrush, and low levels for three-square bulrush and grass/sedge. While wild rice has a high level of above-ground biomass (51%), it is a short plant that is only found in flooded marsh, and it does not produce a dense shade. In contrast, both cattail and reed occupy the moist wet meadow or shallow emergent zones, where their dense above-ground canopy shades out most other species. Both the native sedges and grasses of the wet meadow and three-square bulrush produce an open canopy that does not compete well with tall emergents like cattail and reed. The high-biomass samples of grass/sedge encountered in this study occurred in shallow-water habitat, where the below-ground biomass was much greater than the above-ground biomass. The bulrushes, both with high ratios of below-ground to above-ground biomass, create dense root mats that are capable of withstanding high energy wave environments. Both wild rice and sedge/grass are able to withstand intermediate levels of wave energy, while cattails and reed are least tolerant of high-

Figure 20. Ratio of above-ground to below-ground biomass of *Schoenoplectus pungens* (three-square).

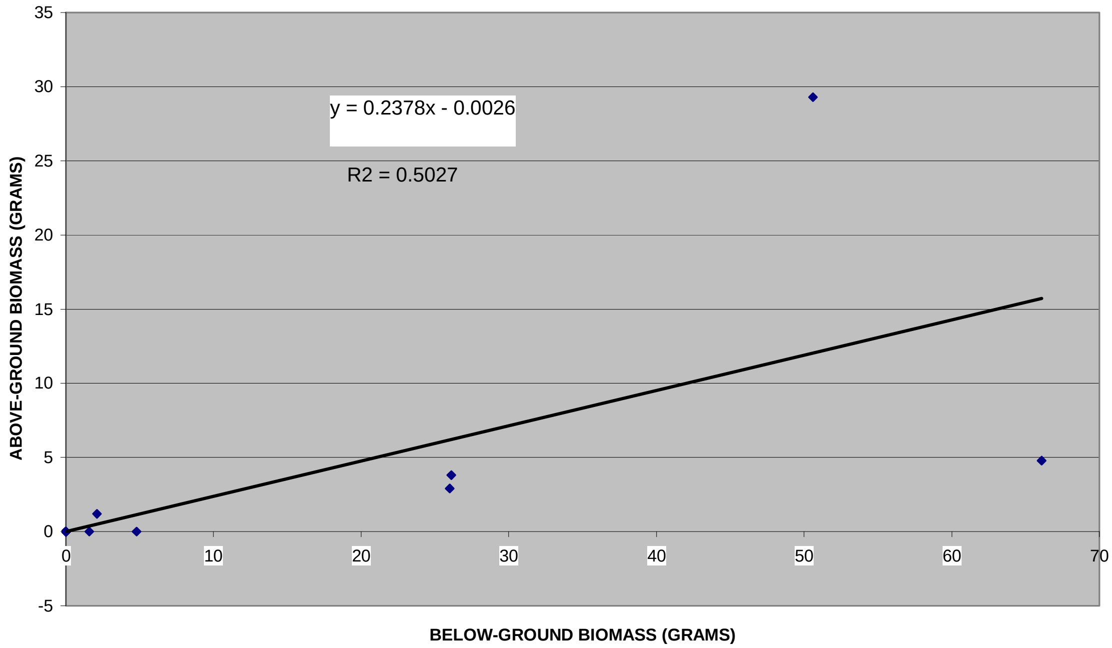


Figure 21. Bulrush (Schoenoplectus pungens) rhizomes and stems. Note the sparseness of bulrush stems, which are typically 30 to 45 cm (12 to 18 inch) apart. Fine roots have been partially removed. The thin stems are typically 60 to 90 cm (24 to 36 inch) tall in shallow water, and taller in deep water.

Figure 22. Rhizome of hardstem bulrush (Schoenoplectus acutus). While the culms and roots are much more dense than those of 3-square bulrush (Figures 21), the majority of the biomass is also below ground and the above-ground vegetation is sparse. Rhizomes are 1.5-2.0 cm in diameter, and the culms are typically less than 20 cm apart on the rhizome.

Figure 23. Dense bed of hardstem bulrush along the St. Clair River.

Figure 24. Tall stand of reed (Phragmites australis) near sampling point HB03, just west of the Harsens Island dike, growing in shallow water. Nearby, on the drier spoils pile at HB01 and HB02, there were deeper organic sediments and many more dead stems.

Figure 25. Dense narrow-leaved bulrush (*Typha angustifolia*) growing inside the Harsens Island dike.

Figure 26. Phragmites rhizomes from the outer edge of the dike at Harsen's Island.

Figure 27. Carex lasiocarpa (sedge) roots in flooded marsh at Wigwam Bay diked wetland. The shovel blade is 16 inches (40 cm) long, approximately the same depth as the saturated sedge roots.

energy open-water environments, both due to root mats concentrated in surface organic deposits and an unstable above-ground biomass.

Using rhizomes to evaluation vegetation change both inside and outside diked wetlands.

For many of the mixed stands, the length, weight, and condition of rhizomes reflects the history of the site. In plots where there are roughly equal amounts of bulrush, cattail, and reed biomass, live stems and robust rhizomes are found for all of these species. In contrast, in stands where reed is dominant, there are typically few or no live stems of bulrush or cattail, but only small amounts of decomposing or dried up bulrush or cattail rhizomes. After reed stands replace cattail, identifiable cattail biomass decreases rapidly, and often only the stem bases of the cattails remain.

The study has demonstrated that the persistence of bulrush rhizomes may be shorter than previously thought, at least where there has been both aeration and invasion of bulrush stands by either cattails or reed. However, small fragments of decomposed bulrush rhizome or cattail stem-base are found in eleven of twenty-one reed-dominated plots. Fragments of decomposed bulrush rhizome were found in the mineral soil beneath reed stands in six of thirteen Dickinson Island undiked plots, one Harsens Island diked plot, and one undiked site on the edge of Little Muscamoot Bay, just outside of the Harsens

Island dike. Small amounts of decomposed narrow-leaved cattail stem-base were found beneath reed beds in three Dickinson Island undiked plots, one Harsens Island diked plot, and in one undiked Fish Point plot.

Studies at Pinconning County Park within Saginaw Bay (Figure 1) demonstrate that bulrushes are long lived and that rhizomes are persistent and perennial, whether the plant is growing in flooded (Figure 21) or dry conditions (Figure 28). The rhizome section of the sample growing in continually flooded conditions (Figure 21) is approximately 23 years old, 3.5 m (14 ft) long, and has living stems growing along its entire length. These stems were located on shoots that were typically less than 30 cm (one foot) apart, a typical growth rate for three-square growing in standing water. The plants growing in dry conditions since at least 1999 (Figure 28), are also persistent, although their growth rate is much less during dry periods, as seen in a detailed photo (Figure 29), where nine years of growth are concentrated in less than nine centimeters. Without strong competition from invasive plants with dense vegetation, these plants have persisted for several years in an oxygenated environment. In contrast, Figure 30 shows segments of dead bulrush rhizome following invasion of reed. No living stems of bulrush were found in the plot, although a few scattered stems persisted locally beneath the expanding reed bed. This pattern of bulrush mortality following reed establishment was seen in several plots.

Further collections of 3-square bulrush rhizomes were made during the summers of 2007 and 2008, including collection of a large 90 cm X 180 cm block of rhizomes (Figure 31), with the purpose of studying the growth pattern of these important marsh plants and determining whether their rhizomes decomposed rapidly in an aerated environment. These and other rhizomes from Saginaw, Cecil, and Cheboygan Bays demonstrated that live bulrush rhizomes persist for upwards of 40 years. Paired comparisons were made from three zones; a permanently submerged zone, a zone that varied between flooded and dry conditions several times between 1999 and 2008, and a third zone that was permanently dry since 1999 (Bell-Dereske 2008). Paired t-tests showed the permanently flooded zone had rhizomes that were statistically different in growth rates from those that were present in the intermittently flooded or dry zone ($p = .001$). The permanently flooded rhizomes were similar in length and appearance to those seen in Figure 21, which had 10 to 20 cm of growth every year. In contrast, the rhizomes in the intermittently flooded and dry zone had statistically shorted annual growth rates, similar in appearance to those of the dry zone seen in Figure 28. More important for this study, was the observation that the rhizomes at none of these sites showed sign of rapid rhizome mortality or decomposition in the absence of extreme competition with other vegetation. Based on the results from the present study, it appears that rhizomes die and decompose rapidly not as a result of aeration, but as a result of being outcompeted by another species, such as narrow-leaved cattail or reed. An earlier study of Saginaw Bay aquatic vegetation for the Michigan DEQ (Albert 2005) showed that bulrush plants can also be rapidly destroyed by plowing, and that these plowed-up rhizomes decompose rapidly if the sediments are aerated.

Figure 28. Bulrush rhizomes and attached stems from edge of Pinconning marsh, where conditions had been dry for at least 7 years when rhizomes were collected. Longer rhizomes are at least 14 years old based on rhizome internodes.

Figure 29. Three-square bulrush (*Schoenoplectus pungens*) rhizomes growing along beach edge in Pinconning County Park, Saginaw Bay. Each triangle points to a stem base, showing extremely slow growth rates within the dry marsh.

Figure 30. Rhizome section of three-square bulrush (*Schoenoplectus pungens*) from beneath a recently established reed bed. No live rhizomes or stems were found within the sampling plot.

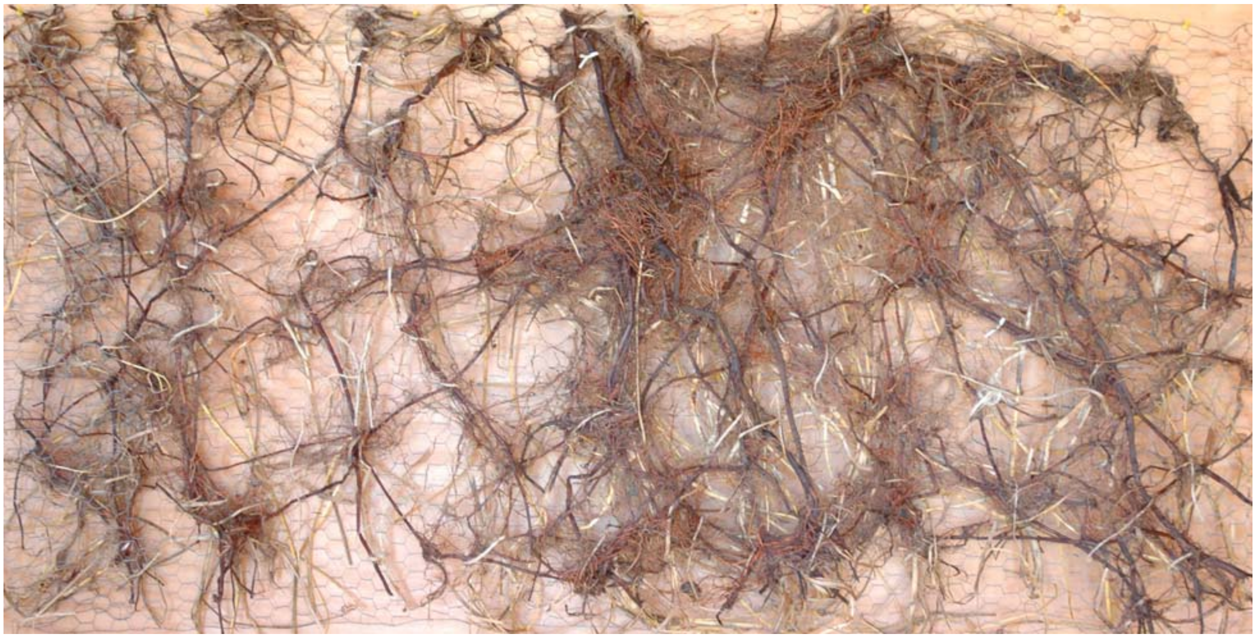


Figure 31. Bulrush (Three-square or *Schoenoplectus pungens*) rhizomes and stems covering a 3 ft by 6 ft (90 cm X 180 cm) area.

Evaluation of conditions for reed establishment and tracking change in reed colony size using historic aerial photography.

During the summer of 2006, several years of aerial photography, beginning with 1938 and continuing into the 1990s, were examined for Fish Point, Wigwam Bay, and Harsens and Dickinson islands in an attempt to better understand the establishment date and expansion history of reed. For Harsens Island and Dickinson Island we utilized photos from 1938, 1941, 1949, 1950, 1957, 1963, 1970, 1978, 1980, and 1993. Available photography was more limited for the other sites; for Fish Point we utilized photos from 1938, 1949, 1963, 1970, 1978, and 1981, and for Wigwam Bay we utilized photos from 1952, 1965, 1970, and 1978. Identification of the points where reed was introduced at any of these sites was unsuccessful, with the possible exception of areas on Dickinson Island and Harsens Island. The first photos to show a strong, uniform vegetation signature typical of reed or narrow-leaved cattail were those of the lower end of Dickinson Island on sand bars along Fisher Bay and between distributary streams within the lower delta (Figure 32). In these areas the characteristic high-reflective vegetation and expanding clonal vegetation pattern of these invasive plants were apparent on the 1978 color-infrared aerial photographs. Reed or cattail seems to have also colonized on the spoil piles between the Harsens Island dikes and Little Muscamoot Bay (Figure 33). Plot data (plants, organic soils, and rhizomes) were then reviewed for these plots, resulting in a partial re-evaluation our earlier photo interpretation. On Dickinson Island, plot 25 (Figure 2a) occupies the outer sand spit along Fisher Bay where it was assumed that either cattail or reed were growing, and it remains dominated by cattail. Other plots near the edge of Fisher Bay remain dominated by cattail, including plots 59 and 63. However, plots 2, 32, 47, and 48 are currently dominated by reed, and all of these plots contain remnants of cattail rhizomes or stem-bases, thus indicating previous dominance by cattail. Thus the indication is that narrow-leaved cattail was likely the dominant plant seen on the 1978 aerial photographs, with reed arriving later. Since both of these species are characterized by thick organic material and rooting, it is not possible to identify the dominants on the basis of deep rooting alone, unless there are remnant fragments of cattail to demonstrate its early presence.

Plots HB01 and HB02 (Figure 2b) are located on spoil piles near the Harsens Island dikes, in the area that appeared to be dominated by either dense cattail or dense reed in the 1978 color-infrared photography (Figure 33). A review of the organic material from these plots indicates that the only roots and rhizomes present are those of reed, with no signs of cattail rhizomes or stem bases. It appears that this spoil pile may have been one of the earliest points of establishment on Harsens Island, where it may have established shortly after the dikes were built.

Further investigations of the history of reed establishment were initiated by contacting early managers of the game areas, including Ernie Kafcas and Robert Humphries, as well as other biologists outside of Michigan to get a broader perspective on the introduction and spread of reed outside of Michigan. Michael Dixon, a local Harsens Island resident, remembers seeing reed first along the American side of the South Channel in the early 1970's. Other long-term residents in the area agreed that this was the approximate time of introduction. Some islanders speculated that the DNR had established the plant to provide habitat for nesting waterfowl, but this wasn't substantiated. Robert Humphries remembered first seeing reed on dredge spoils along the rebuilt South Channel road shoulder, in 1974 or 1975. All of these dates indicate that reed may well have established on Harsens Island a few years prior to the 1978 color-infrared photography.

Along the Lake Erie shoreline, the establishment date for reed may be 1971, when reed was planted extensively along Presque Isle Bay on Lake Erie by Boy Scouts. This is based on an interview of the Boy Scout leader whose troop planted the reed, by Evelyn Anderson, an Erie Daily Times environmental columnist. While I have not been able to find additional information in this regard, it is likely that other Boy Scout troops, conservation organizations, or government agencies were planting reed about the same time to reduce shoreline erosion or create wildlife habitat.

While reed became well established on dikes, channel edges, and several other linear habitats during the 1980s, it did not really expand to cover major portions of most marshes until the late 1990s. As a part of this study, we documented the expansion of reed along a vegetation transect that had been established on Dickinson Island in 1988 (Albert et al.1988). This study, described earlier in the report, documented the extent of reed expansion during the low water conditions since 1999.

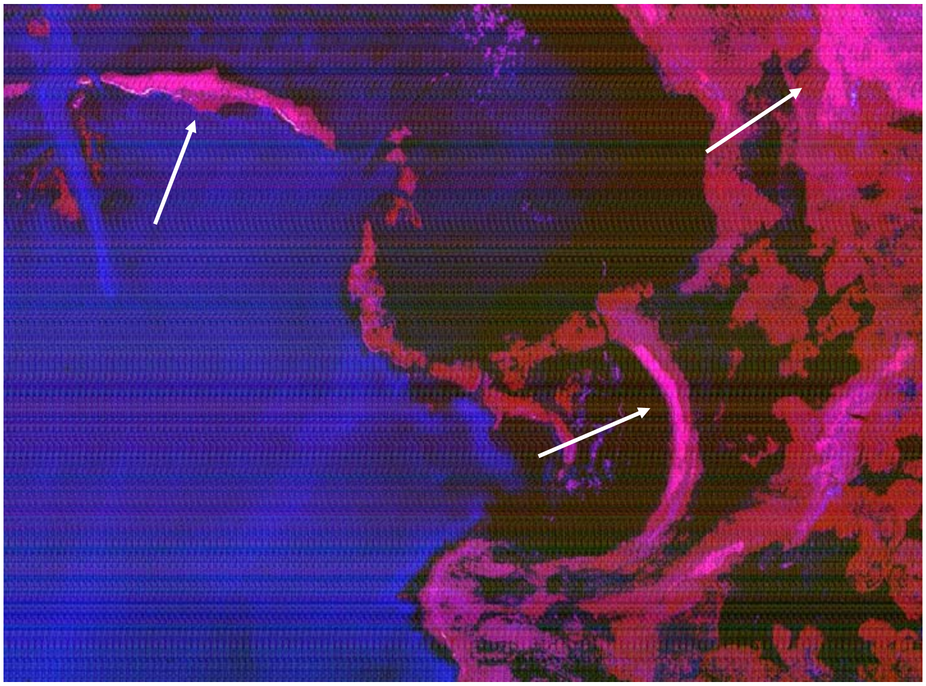


Figure 32. Southern end of Dickinson Island seen on a color-infrared aerial photograph. The bright pink areas along the edge of Fisher Bay (see arrows) are dominated by dense monocultures of vegetation, either cattails or reed.

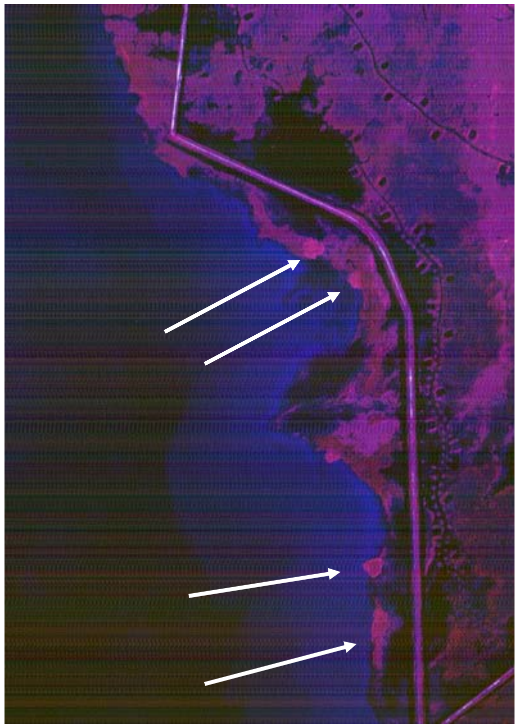


Figure 33. West shore of Harsens Island seen on a 1978 color-infrared aerial photograph. The bright pink areas between Muscamoot Bay and the dike (see arrows) are dominated by dense monocultures of vegetation, either cattails or reed.

DISCUSSION

This study focused on understanding the effects of dike construction on the wetland plants of Great Lakes coastal wetlands. Comparisons between diked and undiked wetlands included 1) plant diversity and plant structural diversity, 2) quantification of plant biomass in diked and undiked zones, 3) using rhizomes to evaluate vegetation change both inside and outside diked wetlands, 4) above-ground versus below-ground biomass ratios for dominant marsh plants, and 5) evaluation of the sites where reed established in both diked and undiked wetlands.

Plant diversity.

Our study showed that overall native plant diversity differed little between diked and undiked sites at Wigwam Bay and Fish Point, but that there were major differences between the diked and undiked sites on the St. Clair River Delta, with 38 species present in the diked plots at Harsens Island and only 26 species in the Dickinson Island undiked sites. This difference appears to be linked to increased levels of reed in most of the undiked plots of Dickinson, where reed is outcompeting native plant species. At all three sampling sites, the greatest number of native plants are plants considered to be characteristic of a "wet meadow" dominated by grasses, sedges, and forbs. This abundance of wet meadow plants probably reflects the original condition prior to diking;

on the pre-dike aerial photos, much of the three diked areas appeared to be wet meadows mixed with densely vegetated emergent marsh prior to diking.

When all three sampling sites are lumped together for analysis, native plant diversity is lower in plots with greater invasive or exotic plant species coverage. This can be seen best for reed, which dominates the greatest number of plots, but high coverage of narrow-leaved cattail also lowers native plant coverage. Reed expands aggressively during low-water conditions, resulting in increased reed coverage in undiked sites, along with lower native plant diversity.

Comparison of the mean number of native plants in plots by hydrologic condition (diked versus undiked) found no statistical difference between diked and undiked plots, although Fish Point's results were nearly significant ($p = 0.06$). In contrast, the number of invasive plants was significantly different between diked and undiked sites for all three sampling sites. Significantly less invasive species were found in diked plots at both Fish Point and Wigwam Bay, where there were more occurrences of reed and other exotics in the dry undiked plots. Individual diked Harsens Island plots contained statistically more invasive plants, but the reason for this difference is not clear.

There is not complete agreement as to the effectiveness of water control for maintenance of higher diversity of native species in recent studies of Great Lakes diked wetlands, with Galloway et al. (2006) and Thiet (2002) finding greater wetland plant diversity in diked wetlands, while Herrick and Wolf (2005) found greater amounts of invasive species in the diked wetlands of Saginaw Bay and Green Bay. Herrick and Wolf did recognize the rapid expansion of reed during the current low-water conditions. Part of the difficulty in determining the effectiveness of diked wetlands for maintenance of plant diversity is the differing amounts, types, and timing of water level control over the growing season and over a several year period. Monfils and Brown (2008) reference the different types of water-level control at the three diked wetlands studied. Harsens Island actively manages its water levels with pumps and control structures, Fish Point opportunistically pumps but is not able to pump water in the present low-water conditions, and Wigwam Bay appears to effectively control its water levels with water control structures. The wetter conditions inside of the dikes at all three sites results in reduced invasion by reed, but maintains conditions that favor invasive narrow-leaved cattail.

Undiked areas are highly vulnerable to invasion by reed during stable low-water conditions, as noted by most biologists working in the Great Lakes in recent years. Reed expands rapidly by stolons across large expanses (10 meters or more) of dry emergent marsh, where wave action would restrict its expansion in high-water years (Saltonstall 2008).

Total cover of native or invasive plants appears to be a better indicator of wetland condition than merely the number of native or invasive species in a wetland (Albert and Minc 2004, Great Lakes Wetland Consortium 2008). Native plant cover was found to decrease significantly as reed cover increased. This is consistent with results from other studies that found reed and other invasive species to be effective competitors both because of tall above-ground vegetation and high levels of biomass accumulation (Gaudet and Keddy 1988, Freyman 2008, Tuchman et al. 2008).

Bulrushes as an important native marsh plant. Bulrushes are the native plants within Great Lakes coastal marshes that this study has focused much of its attention on, as they are recognized to be important species for wave energy reduction, sediment accumulation, and wildlife habitat (Albert 2005, Webb and Cotel, 2008 submitted manuscript). The importance of bulrushes for habitat has been well documented, providing substrate for periphyton accumulation (Albert 2003), food during waterfowl migration (Thorn and Zwank 1993), fish spawn, shelter, and larval fish substrate (Castellanos and Rozas 2001, Pierce et al. 2007), general fish habitat (Bhagat et al. 2007, Uzarski et al. 2005), and invertebrate food and habitat (Castellanos and Rozas 2001). Invertebrates within bulrush beds provide important food for both fish and waterfowl (Nelson et al. 2000).

Bulrushes also provide an important wave dampening and sediment accumulation function; studies in the Les Cheneaux Islands found that hardstem bulrush (*Schoenoplectus acutus*) reduced wave height by 55 to 70%, when compared to open shoreline (Cotel et al. 2008 accepted manuscript, Webb and Cotel, 2008 submitted manuscript). Similarly wave reduction was identified as an important function of emergent vegetation on Lake Ontario's shoreline, and the effect of the vegetation was also modeled in a small wave tank (Tschirky et al. 2000). The importance of bulrushes for wave dampening and sediment accumulation will be the subject of an NSF study beginning at Oregon State University in January 2009. Recent studies in the Les Cheneaux Islands and Saginaw Bay have documented that this wave dampening results in a strong gradient in water energy, temperature, and chemistry that supports distinctive fish and invertebrate fauna (Burton et al. 2002, Cardinale et al. 1998).

It is recognized that bulrush reproduction is largely vegetative, but the growth rate of bulrushes in Great Lakes wetland and the dynamics of individual plants is not well understood (Poor et al. 2005). This study has documented that the maximum growth rate of three-square bulrush is about 20 cm per year, and that the growth rate varies greatly in zones with different moisture conditions. The greatest rate of growth, about 20 cm/year is seen in continually flooded marshes, while annual growth can be reduced to a centimeter or less in dry inner marshes (Bell-Dereske 2008).

Comparison of plant biomass in diked and undiked zones.

Plant biomass varies greatly from plot to plot at each site, but there are some visible patterns. Within the undiked Dickinson Island plots, reed either dominates or is assuming dominance over both native vegetation and narrow-leaved cattail except in flooded plots, where bulrush or floating/submergent plants remain dominant. Within the diked wetland at neighboring Harsens Island, narrow-leaved cattail remains a major dominant.

Reed is less of a dominant on both Fish Point and Wigwam Bay. Where reed has established, many of the plots still support a mix of native plants as well, pointing to more recent establishment than on the St. Clair River Delta.

Decomposing plant material. Deep organic soils formed beneath narrow-leaved cattails and reed. In contrast, bulrushes in the emergent marsh were characterized by little accumulation of organic materials, as bulrush is known to decompose rapidly (Tuchman et al. 2008). Similarly, organic material derived from sedges and grasses growing within undiked wet meadow contained thin organic soils; most organic materials were highly decomposed and mixed with surface sands.

Dominant plant relationships to hydrologic conditions.

Statistical tests verified observations that reed was much more common in shallow water or growing on dry habitat. However, cattail stems were present in similar numbers in diked and undiked habitat, but with the greatest numbers present in diked plots. Bulrushes were much more prevalent on undiked sites, typically growing in standing water. Bulrush seed reproduction is best on moist soils, which may be the reason that they are uncommon in the deeper, flooded diked wetlands, which originally supported a combination of wet-meadow species and dense emergents, such as cattails. However, once established bulrushes reproduce vegetatively within the dikes.

Using rhizomes to evaluate vegetation change both inside and outside diked wetlands.

In stands where reed has grown over native bulrushes or cattails, small fragments of bulrush rhizome persist in the mineral soils, while cattail stem-bases can often be found in the deepest layer of organic soils. Bulrush rhizome and cattail root decomposition is much more rapid beneath reed than expected, and it is unclear how long they with persist in either aerobic or anaerobic habitat.

Bulrush rhizomes were studied to determine how long they would persist in different hydrologic conditions. It was determined that unless they were invaded by cattails or reed, bulrush rhizomes were very persistent, surviving more than twenty years if the above-ground portion of the plant survived. It was also determined that the growth rate and rhizome structure appeared to be determined by a combination of water depth and sediment characteristics (Bell-Dereske 2008). Permanently flooded plants grew at a faster rate than either plants from fluctuating drainage condition or plants that had grown in dry conditions, with up to twenty times the annual growth rate in flooded conditions.

Above-ground versus below-ground biomass ratios for dominant marsh plants.

Abundant above-ground biomass is recognized as a characteristic of aggressive invasive plant species (Gaudet and Keddy 1988), but even for two of the most aggressive invasive species in the Great Lakes, reed and narrow-leaved cattail, below-ground biomass was twice that of above-ground biomass. In contrast, our study showed that native grasses and sedges of the wet meadow had four to five times as much below-ground biomass as above-ground biomass, and bulrushes averaged seven to eight times as much below-ground biomass.

Maximum biomass in a 0.04 m^3 plot was calculated for all of the dominant plants encountered at our three sampling sites (Table 9). The greatest biomass in a single plot was for narrow-leaved cattail (2776 grams), followed by native grasses and sedges, and then by reed. Total biomass of hardstem bulrush was intermediate in level, while three-square bulrush and wild rice had the lowest total biomass, 71 and 132 grams respectively.

Evaluation of the sites where reed established in both diked and undiked wetlands.

It was difficult to identify the time of establishment of reed from aerial photos, as both reed and cattail share a distinctive, dense signature similar to upland vegetation. Color-infrared photography was more effective for identifying these species than black and white photography, due to a distinctive reddish-pink color.

Ultimately, by combining the study of underlying sediments with aerial photo interpretation, two sites, Harsens Island and Dickinson Island were identified as potential sites for reed. Investigation of the sediments at these sites indicated that the possible Dickinson Island sites for reed were originally dominated by cattail, and many continue to be dominated by cattail in 2005. In contrast, the sediments on the Harsens Island spoils pile contained no sign of earlier cattail or bulrush rhizomes, and may have been colonized by reed shortly after dike construction.

Local residents, wildlife biologists, and herbarium staff all identified the approximate time of arrival as the early to mid 1970s. This agrees roughly with the aerial photo interpretation, which showed no distinct sign of reed establishment prior to the 1978 aerial photos. The most specific reference to reed introduction was on Lake Erie in 1971, where it was planted to control erosion and provide wildlife habitat.

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