EFFECTS OF HYDROLOGIC ISOLATION VIA DIKE CONSTRUCTION ON AVIAN COMMUNITIES USING GREAT LAKES COASTAL WETLANDS

FINAL REPORT

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INTRODUCTION

Great Lakes coastal wetlands provide vital breeding, migration, and wintering habitat for an array of birds. Approximately 3 – 4 million swans, geese, and ducks travel along migration corridors that cross the Great Lakes region (Bellrose 1980). Great Lakes coastal wetlands are also valuable stopover habitats for migrant shorebirds that breed in the boreal and arctic regions of North America (Brown et al. 2000). These wetlands are some of the region's largest remaining emergent marshes and provide vital nesting habitat to wetland birds, including rare and declining species such as American Bittern (*Botaurus lentiginosus*), Least Bittern (*Ixobrychus exilis*), Common Moorhen (*Gallinula chloropus*), King Rail (*Rallus elegans*), Black Tern (*Chlidonias niger*), and Forster's Tern (*Sterna forsteri*). Prince and Flegel (1995) summarized breeding bird atlas data from Michigan and Ontario and found that 89 bird species utilized coastal zone landscapes of Lake Huron, of which 80 were found in areas dominated by wetland.

Dikes and water control structures have long been used by wildlife managers to enhance wetlands for wildlife (Kadlec 1962), especially breeding and migrating waterfowl. Impounded wetlands are typically managed as hemi-marshes to maximize breeding bird use (Weller and Spatcher 1965) or shallow-water marshes dominated by moist-soil vegetation to attract migrant birds (Fredrickson and Taylor 1982). Historically, Great Lakes coastal wetlands moved landward and lakeward with the rise and fall of the Great Lakes. Between the 1950s and 1970s, many Great Lakes coastal marshes were isolated from these normal water level fluctuations through dike construction. These projects were initiated primarily to maintain elevated water depths and enhance wildlife use during periods of historic low water levels. Shoreline armoring, wetland diking and tiling to drain wetlands for agricultural use, and other land-use changes now prevent the landward movement of coastal wetlands in much of the Great Lakes (Prince et al. 1992, Gottgens et al. 1998).

The potential problems associated with isolating coastal wetlands from the Great Lakes include impaired or eliminated flood conveyance and storage, sediment control, and water quality improvement functions, altered nutrient flow, reduced or degraded habitat for shorebirds, rare species, fish, and invertebrates, and increased impacts from trapped carp (*Cyprinus carpio*) (Jude and Pappas 1992, Wilcox 1995, Wilcox and Whillans 1999). By separating coastal wetlands from the fluctuations of the Great Lakes, dike construction often stabilizes water levels. Stable water levels typically compress wetland vegetation zones and encourage dominance by shrubs and highly competitive species, such as willow (*Salix* spp.), alder (*Alnus* spp.), cattail (*Typha* spp.), reed canary grass (*Phalaris arundinacea*), and purple loosestrife (*Lythrum salicaria*). Irregular water levels may result in higher levels of diversity both within and among habitats (Keddy and Reznicek 1986, Wilcox 1993, Wilcox et al. 1993, Keough et al. 1999).

Comparisons of plant communities in diked and undiked Great Lakes coastal wetlands have yielded varied results. Herrick and Wolf (2005) observed higher amounts of invasive species in both standing vegetation and seed banks of diked wetlands in Saginaw Bay and Green Bay, but noted that current conditions in undiked wetlands appear to favor an invasive haplotype of common reed (*Phragmites australis*). Conversely, Galloway et al. (2006) found higher species richness and percent cover of native species and lower species richness and percent cover of invasive species in diked compared to undiked coastal wetlands. Herrick et al. (2007) found significantly more seeds from a greater number of species in the soils of diked compared to undiked wetlands and stated that diked wetlands may serve as "traps" for plant seeds. In comparisons of the vegetation in diked and undiked Lake Erie coastal wetlands during a high water year, Thiet (2002) found higher wetland plant diversity in diked wetlands compared to a nearby undiked site. An actively managed diked marsh in southwest Lake Erie maintained emergent vegetation, patchiness, and edge habitat similar to historic conditions during periods of high Great Lakes water levels, while the same measures declined in marshes connected to Lake Erie (Gottgens et al. 1998).

Research conducted by several authors on animal use of Great Lakes coastal wetlands provides insights into the possible effects of wetland isolation on animal communities. McLaughlin and Harris (1990) compared aquatic insect emergence in one diked and one undiked wetland on Green Bay, and they recorded more insect taxa and higher total insect biomass in the diked wetland. Burton et al. (2002) noted that both plant-community composition and exposure to wave action were important in determining invertebrate diversity and biomass in Great Lakes marshes. Invertebrates were distributed along gradients of decreased mixing of pelagic water and increases in sediment organic matter from outer to inner marsh and between littoral and adjacent inland marshes. Some invertebrates were more common on one end of these gradients, but most species were generalists found across all habitat types (Burton et al. 2002). Whitt's (1996) study of avian breeding use of Saginaw Bay coastal wetlands included study sites that were both open to and isolated from Lake Huron. Although species richness was similar between coastal and inland cattail marshes, bird densities in far shore marshes were lower than all other sites. Whitt (1996) suggested this difference may be due to the effects of storm surges during the breeding season that can destroy nests, and stated that further study is needed to compare avian use of protected marshes with those exposed to storm surges. Galloway et al. (2006) conducted a one-year study of breeding bird use of diked and undiked Great Lakes coastal wetlands along Lakes Ontario, Erie, and St. Clair. In pooled comparisons of diked and undiked sites, they observed higher abundance and species richness for several groups of birds in diked wetlands. Galloway et al. (2006) also noted the need for additional research to account for long-term variation in bird and vegetation communities associated with Great Lakes water level cycles and management activities. No research has been conducted in the Great Lakes region to assess the effects of coastal wetland diking on bird communities during migration periods.

Although some coastal impoundments have been reconnected to the Great Lakes to improve ecological functioning, no studies have been initiated to evaluate the positive or negative impacts of these actions. Similar hydrologic reconnections have been used to restore tidal marshes on the Atlantic Coast, but investigations into animal responses have been mixed. Studies conducted at a restored tidal marsh nearly 20 years after reconnection indicated the recovery of macroinvertebrate, fish, and bird populations (Swamy et al. 2002, Brawley et al. 1998). Conversely, Raposa and Roman (2001) found that in most instances a diked salt marsh provided equal or greater habitat value for fish and decapod crustacean species compared to unrestricted marsh.

Ecological studies of the effects of coastal wetland isolation are needed so that informed decisions can be made about the management and restoration of Great Lakes marshes. The goal of this project was to compare bird use, habitat composition and structure, and physical and chemical attributes of several diked and undiked coastal wetlands in Michigan to gain insights into the effects of wetland isolation. We tested the hypothesis that coastal impoundments with managed water levels provide enhanced habitat for wetland birds compared to undiked wetlands. We view this research as one of many comparisons needed over the long-term to better understand how isolated and open wetlands function during the full cycle of Great Lakes water levels.

STUDY AREA DESCRIPTIONS

We focused our research in two of Michigan's most important coastal wetland complexes, Saginaw Bay (SAG) and the St. Clair River delta, also known as the St. Clair Flats (SCF). The St. Clair Flats is a vast wetland complex located where the St. Clair River flows into Lake St. Clair. These wetlands encompass approximately 17,500 ha in the U.S. and Canada, about one-third of which is diked (Bookhout et al. 1989). Approximately one-third of the St. Clair Flats is within U.S. territory. Lake Huron's Saginaw Bay contains a substantial concentration of Michigan's coastal marshes (about 2,500 ha) (Bookhout et al. 1989), which occurs as a nearly continuous strip along the perimeter of the bay (Prince et al. 1992). These two wetland complexes were selected as study areas for several reasons: 1) they are two of Michigan's largest and most intact wetland complexes, 2) their importance as migratory stopovers for waterfowl and shorebirds, 3) they are used for breeding by several rare and declining waterbird species, and 4) the presence of both managed diked wetlands and unmanaged undiked wetlands.

Diked wetland sites were classified into three water level management categories: active, opportunistic, and passive. Active management occurred at sites where pump stations were used to manipulate water levels on a regular basis. Opportunistic water management took place at sites with pumps that can only function when Great Lakes water levels are above a minimum height. Water is pumped into the diked wetlands opportunistically when conditions allow. Passive water level management occurred at sites with dikes and water control structures, but without water pumping capabilities. Water levels in these wetlands are independent of Great Lakes levels; however, pumping is not an option and water inputs come from precipitation or through control structures. No water management took place at undiked wetland sites and water levels are dependent on Great Lakes hydrology.

St. Clair Flats

Four sites (two diked and two undiked) were investigated at the St. Clair Flats. Both diked wetlands occurred on Harsens Island, while open wetland sites were found on Dickinson Island and nearby Fisher and Goose Bays and Little and Big Muscamoot Bays (Figure 1). All sites are located in St. Clair County and are within the St. Clair Flats State Wildlife Area.

Harsens Island: Two diked wetlands, known as West Marsh (WMA) and East Marsh (EMA), were studied at St. Clair Flats (Table 1). These are the only diked coastal wetlands on the U.S. side of the St. Clair Flats, and water levels were actively managed using pumps and control structures. Many decades ago channels and small openings were dredged from the marshes to create open water areas and enhance waterfowl habitat. Although some of these areas have grown in with emergent vegetation, most are still present today. These impounded wetlands had similar vegetation communities and both were dominated by cattail (*Typha* spp.) marsh and aquatic bed zones, with smaller areas of common reed (*Phragmites australis*) and remnant wet meadows consisting of sedges (*Carex* spp.), grasses (Poaceae), rushes (*Juncus* spp.), and other forbs. Aquatic bed zones had abundant water lilies (*Nuphar variegata* and *Nymphaea odorata*) and aquatic macrophytes (e.g. *Utricularia* spp., *Myriophyllum* spp., and *Potamogeton* spp.) and stoneworts (*Chara* spp.).

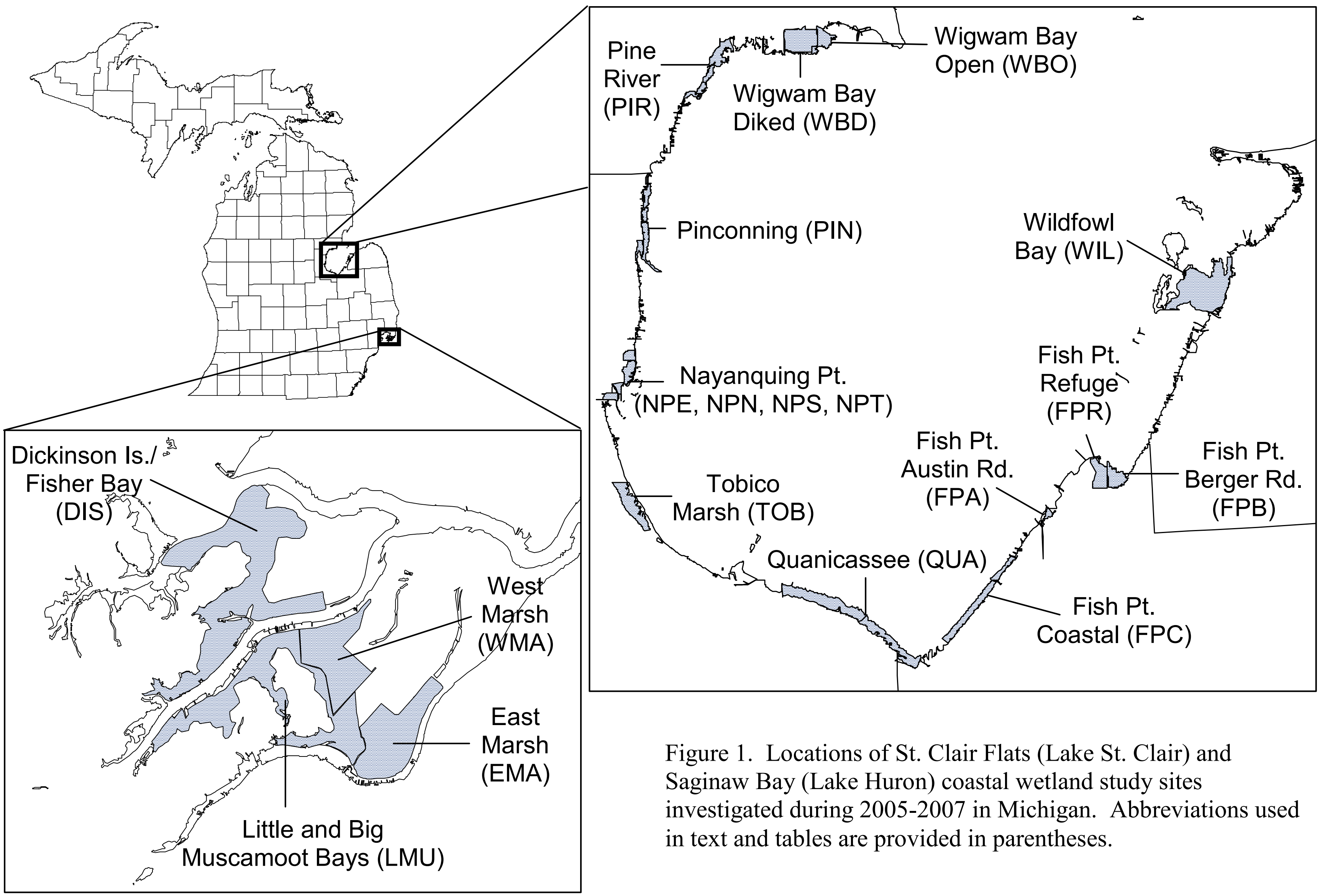


Figure 1. Locations of St. Clair Flats (Lake St. Clair) and Saginaw Bay (Lake Huron) coastal wetland study sites investigated during 2005-2007 in Michigan. Abbreviations used in text and tables are provided in parentheses.

Table 1. Study sites surveyed and activities conducted at St. Clair Flats and Saginaw Bay, Michigan during 2005-2007. Sites (see text for abbreviations) visited are indicated with an "X." Approximate areas and water management capability[1] of sites are listed.

	St. Clair Flats				Saginaw Bay														
	Diked		Undiked		Diked								Undiked						
	EMA	WMA	DIS	LMU	FPA	FPR	NPE	NPN	NPS	NPT	TOB	WBD	FPB	FPC	PIN	PIR	QUA	WBO	WIL
Water Management	A	A	N	N	P	O	P	O	O	O	P	P	N	N	N	N	N	N	N
Approx. Wetland Area (ha)	330	293	848	526	33	187	104	57	48	32	293	363	155	318	258	291	746	147	1030
Breeding Surveys																			
Point Counts																			
2005	---	X	X	---	---	X	---	---	---	---	---	X	X	---	---	---	---	X	---
2006	X	X	X	X	---	X	X	X	---	---	---	X	---	---	---	X	X	---	X
2007	X	X	X	X	---	X	X	X	---	---	---	X	---	---	---	X	X	---	X
Timed-area																			
2005	X	X	X	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
2006	X	X	X	X	---	X	X	X	X	X	---	X	---	---	---	X	X	---	X
2007	X	X	X	X	---	X	X	X	X	X	---	X	---	---	---	X	X	---	X
Migrant Surveys																			
Aerial Waterfowl																			
2005	X	X	X	X	X	X	X	X	X	X	X	X	---	X	X	X	X	---	X
2006	X	X	X	X	X	X	X	X	X	X	X	X	---	X	X	X	X	---	X
2007	X	X	X	X	X	X	X	X	X	X	X	X	---	X	X	X	X	---	X
Fall Ground																			
2005	X	X	X	X	X	X	---	X	X	X	---	---	---	---	---	X	X	---	---
2006	X	X	X	X	X	X	---	X	X	X	---	X	---	---	---	X	X	---	X
2007	X	X	X	X	X	X	---	X	X	X	---	X	---	---	---	X	X	---	X

Table 1 (cont'd).

	St. Clair Flats				Saginaw Bay														
	Diked		Undiked		Diked								Undiked						
	EMA	WMA	DIS	LMU	FPA	FPR	NPE	NPN	NPS	NPT	TOB	WBD	FPB	FPC	PIN	PIR	QUA	WBO	WIL
Habitat Sampling																			
2006	X	X	X	X	---	X	X	X	---	---	---	X	---	---	---	X	X	---	X
2007	X	X	X	X	---	X	X	X	---	---	---	X	---	---	---	X	X	---	X
Invertebrate Sampling																			
2006	X	X	X	X	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Water Level Monitoring																			
2005	X	X	---	---	---	X	---	---	---	---	---	X	---	---	---	---	---	---	---
2006	X	X	---	---	---	X	X	X	X	---	---	X	---	---	---	---	---	---	---
2007	X	X	---	---	---	X	X	X	X	---	---	X	---	---	---	---	---	---	---
Water Chemistry Sampling																			
2007	X	X	X	X	X	X	X	X	X	X	---	X	---	---	---	X	X	---	X

[1]Water Management Capability: A=Active, O=Opportunistic, P=Passive, and N=None. See text for further description.

Dickinson Island/Fisher and Goose Bays (DIS): Dickinson Island is located northwest of Harsens Island and almost completely consisted of emergent wetlands of various types. Marshes were also found to the immediate west and southwest along the margins of Fisher and Goose Bays. Vegetation zones were dominated by bulrushes (*Schoenoplectus acutus* and *S. pungens*), common reed, and cattail to a lesser degree. Areas of non-persistent emergent vegetation dominated by arrowhead (*Sagittaria* spp.), pickerelweed (*Pontederia cordata*), and wild rice (*Zizania* spp.) were present in Mud Lake and other protected areas. Scattered water lilies and aquatic macrophytes are present in protected sites. *Chara* spp. typically dominated the aquatic vegetation.

Little and Big Muscamoot Bays (LMU): This area occurs to the west of Harsens Island between the North and South Channels of the St. Clair River. The vegetation was similar to that of the Dickinson Island area, with zones of bulrush, common reed, cattail, non-persistent emergents, and aquatic bed wetland.

Saginaw Bay

Fifteen wetlands were visited on Saginaw Bay, of which eight were diked and seven were undiked and open to Lake Huron water level fluctuations (Figure 1).

Fish Point: Both diked and undiked wetlands were studied at Fish Point State Wildlife Area, which is in Tuscola County. We conducted surveys at the east diked unit of the refuge (FPR) all three years. Cattail and aquatic bed vegetation were the dominant wetland zones, although areas of wet meadow (sedges and grasses), common reed, and scrub-shrub (*Salix* spp. and *Cornus* spp.) vegetation were also present. White and yellow water lilies, water milfoil (*Myriophyllum* spp.), pondweeds (*Potamogeton* spp.), and

Chara spp. dominated the aquatic bed zone. Nesting islands were constructed and level ditching was conducted many decades ago to enhance waterfowl habitat. Small pockets of cottonwood (*Populus deltoides*) existed, often on old nesting islands or dredge spoils. A pump station is present at this site, although pumping was limited or impossible in recent years due to low Lake Huron levels. A second small diked wetland was investigated near Austin Road (FPA) during timed-area and fall ground surveys for migrant birds; point counts for breeding birds were not conducted due to its small size and limited emergent marsh. Vegetation consisted of aquatic bed wetland similar to FPR, cattail marsh, and wet meadow dominated by sedges, rushes, and spikerushes (*Eleocharis* spp.). Two areas of undiked wetland were surveyed: one area east of FPR near Berger Road (FPB), and a large area of fringing coastal wetland (FPC) to the southwest of FPR and FPA (Figure 1). Both undiked wetlands were dominated by emergent marshes of common reed, cattails, and bulrushes. Small pockets of wet meadow with sedges, rushes, and spikerushes were also present. We only conducted point counts at the FPB site in 2005 and the FPC site was only surveyed during aerial waterfowl surveys (Table 1).

Nayanquing Point: Four diked wetland areas were studied at Nayanquing Point State Wildlife Area (Bay County): East Marsh (NPE), North Marsh (NPN), South Refuge Unit (NPS), and Triangle Refuge Unit (NPT). The NPN, NPS, and NPT sites have water pumps that permit pumping opportunistically when Lake Huron levels allow, while NPE is a passively managed impoundment formed within a natural beach ridge with only a water control structure. All sites were dominated by cattail marsh and aquatic bed wetland consisting of water lilies and aquatic macrophytes. Small areas of wet meadow were present at the NPE and NPN sites. Areas of non-persistent emergents dominated by pickerelweed and arrowhead were present at NPN, NPS, and NPT. Small areas of common reed and hardstem bulrush were also found at NPE.

Pinconning (PIN): Undiked coastal wetland associated with the mouth of the Pinconning River (Bay County) was covered during aerial waterfowl surveys. This area was dominated by mixed emergent marsh stands of common reed, cattail, and bulrush.

Quanicassee (QUA): This site consists of undiked wetland to the northwest of the Quanicassee River mouth and is located in the Quanicassee State Wildlife Area in Tuscola and Bay Counties. The vegetation was dominated by common reed, often found in conjunction with other emergent species, such as three-square and hardstem bulrush, rushes, and cattail. Fringing zones of bulrush and cattail were typically found in deeper water.

Tobico Marsh (TOB): Tobico Marsh is an impounded wetland located in the Bay City State Recreation Area in Bay County. Historically this was a protected coastal wetland located behind a beach ridge. A small dam and control structure was installed to regulate water levels. Tobico Marsh was dominated by cattail marsh and aquatic bed wetland, with some areas of wet meadow and shrub wetland around the perimeter. This site was only visited during aerial waterfowl surveys.

Wigwam Bay: Two undiked and one diked wetland sites were surveyed in the Wigwam Bay State Wildlife Area in Arenac County. The Pine River site (PIR) encompassed undiked coastal wetlands north and south of the confluence of the Pine River and Saginaw Bay in Arenac County. Dominant vegetation consisted of bulrush (three-square and hard-stem), cattail, and wet meadow zones. Wet meadows were dominated by sedges, grasses, rushes, and spikerushes. A large diked wetland site

(WBD) is located on the north side of Saginaw and Wigwam Bays. Pump stations are not present, but water control structures regulate inflows and outflows. Emergent vegetation primarily consisted of cattail marsh and wet meadow, both of which often occurred as floating mats. Large areas of aquatic bed wetland were dominated by white and yellow water lilies and aquatic macrophytes (e.g. *Utricularia* spp. and *Potamogeton* spp.). Sporadic hard-stem bulrush and wild rice were also present, and forested and scrub-shrub wetland was found in the northwestern portion of the impoundment. Point counts were conducted at a second undiked wetland site (WBO) located east of WBD in 2005. This area is dominated by wet meadow vegetation with fringing zones of bulrush and cattail.

Wildfowl Bay (WIL): This protected undiked wetland site is located in the Wildfowl Bay State Wildlife Area in Huron County and consisted of marshes that formed behind Heisterman, Maisou, and Middle Grounds Islands. Several wetland vegetation zones were present, including bulrush and cattail marshes, common reed stands, wet meadows, and non-persistent emergent areas consisting of arrowhead, pickerelweed, and wild rice.

METHODS

Point Counts

We conducted point counts in impounded and undiked wetlands using methods similar to the *Standardized North American Marsh Bird Monitoring Protocols* (Conway 2005). Points were randomly selected from a 200 by 200 m grid overlaying the study sites so that points were at least 400 m apart. Conway (2005) suggests surveying all points on a 400 by 400 m grid covering a study site; however, that was not feasible given the size and accessibility of our study areas. Only points with standing water or saturated soils were surveyed. Due to Great Lakes water levels below the long-term average, potential survey points were within 400 m of the shoreline or other open water areas. We assumed that emergent wetland located closer to open water/aquatic bed wetland was more likely to be inundated and thus more likely to be occupied by marsh birds. Only those points with approximately 50% or more emergent vegetation were surveyed. Non-emergent cover could consist of open water/aquatic bed, scrub-shrub, or forested wetland. Potential survey points were not used if more than approximately 10% of the area within 200 m consisted of roads, dikes, buildings, upland, or wetland of a different type (e.g. undiked wetland in the case of diked points). We conducted surveys three times during the breeding season (early to mid May, mid May to early June, and early to late June); however, some points were only surveyed once or twice due to weather or other constraints. Surveys at St. Clair Flats were started approximately one week earlier than at Saginaw Bay. All birds seen or heard were counted during 10-min point counts conducted between 0.5 hour before sunrise and 10:00 AM. During the second half of the point count, we broadcasted calls of several secretive marsh birds. Calls were broadcast in the following order, as recommended by Conway (2005): Least Bittern (*Ixobrychus exilis*), Sora (*Porzana carolina*), Virginia Rail (*Rallus limicola*), King Rail (*Rallus elegans*), and American Bittern (*Botaurus lentiginosus*). We noted each minute of the survey that a waterbird was detected. The approximate distance to each marsh bird (e.g. grebes, bitterns, rails, coots, moorhens) was estimated using ocular/aural estimation and a laser rangefinder. All other birds (e.g. songbirds, waterfowl, shorebirds, terns, gulls) were noted as being in one of five distance categories: ≤18 m, >18 – 50 m, >50 – 100 m, >100 – 200 m, and >200 m.

Timed-area Surveys

We evaluated breeding waterbird use of the open water/aquatic bed zone using a timed-area approach. We identified potential areas of open water and aquatic bed wetland for survey using aerial photographs and on-site visits. Surveys were conducted during four periods, late May, mid June, mid July, and early August, which were separated by about two to three weeks. Surveys were only conducted at SCF sites in 2005, but surveys were conducted at both SCF and SAG in 2006 and 2007. Surveys were done during all four periods at both study areas in 2006, but we only conducted surveys during the first three periods at SAG sites in 2007. We randomly selected (with replacement) survey sites from the pool of potential sites for each round of surveys. Surveys were conducted in the morning between 0.5 hour before sunrise and four hours after sunrise. We waited 15 min after arrival before starting, and surveyed each area for 30 min from a stationary boat, canoe, or vehicle. We selected survey stations that afforded the best view of the area, caused the least disturbance, and offered the most concealment. We recorded the location of the survey station using GPS and estimated the area surveyed using field maps drawn with the aid of a laser rangefinder, compass, and aerial photographs. All waterfowl, waterbirds, and shorebirds seen or heard within the survey area were recorded. Birds flushed from the area upon arrival or seen only during the 15 min silent period were counted. Flying waterbirds using the area for foraging (e.g. terns) were counted. The species, number of young, estimated age class (according to Gollop and Marshall 1954, as cited in Bellrose 1980), and time when first observed was recorded for waterfowl broods.

Aerial Waterfowl Surveys

Fourteen aerial waterfowl surveys were conducted in spring (five surveys), late summer (five surveys), and early fall (four surveys) during 2005-2007 to evaluate staging and migrant waterfowl use of three St. Clair Flats and 13 Saginaw Bay study sites. Fall surveys were not attempted after duck hunting seasons began in early to mid October due to changes in waterfowl behavior and habitat use. The first survey conducted in fall 2005 was done using a MD-500 helicopter and 22 transects (12 diked, 10 open) totaling approximately 76 km (21 km diked, 55 km open) in length. Beginning in spring 2006, aerial surveys were done using a Cessna 172N fixed-wing aircraft. The fixed-wing aircraft was more cost efficient and its faster flight speed was better suited to surveying large flocks of waterfowl, which often flushed ahead of the aircraft. Sixteen transects (8 diked, 8 open) totaling 66.5 km (18.7 km diked, 47.8 km open) in total length were surveyed during subsequent surveys with fixed-wing aircraft. Methods used were similar to the standard operating procedures used for breeding surveys (USFWS/CWS 1987). Transects were flown at slow speeds of about 130 – 200 km/h (approximately 80 – 125 mph) at an altitude of approximately 30 – 45 m (about 100 – 150 ft). One observer sat on each side of the aircraft and counted all waterfowl within 200 meters for a total transect width of 400 meters. Other waterbirds that could be identified from the air (e.g. Great Blue Heron, Great Egret, American Coot) were also recorded. Transects crossing impounded wetlands were situated along the longest axis and approximately through the middle of the wetland. When only a narrow band of emergent vegetation was present along open shorelines (e.g. Saginaw Bay), transects followed the edge of the emergent vegetation.

Fall Migration Ground Surveys

We evaluated use of diked and undiked wetlands by staging and migrant shorebirds, waterbirds, and waterfowl during ground surveys conducted in late summer and early fall 2005-2007. Surveys were conducted in areas of open water/aquatic bed wetland or exposed substrate near the interface with emergent vegetation, which is the zone most likely to be used by most wetland bird species. In 2005, one or two surveys were done along four routes (two diked, two undiked) at St. Clair Flats and eight routes (five diked, three undiked) on Saginaw Bay. Three or four surveys were conducted along eight routes (four diked and four undiked) at St. Clair Flats sites and 10 routes (six diked and four undiked) at Saginaw Bay sites in 2006 and 2007. We conducted surveys between late July and mid September and surveys of a given route were spaced approximately two to three weeks apart.

Bird survey routes paralleled the open water-emergent vegetation interface in both impounded and open wetland sites. Boats or canoes were used to survey open wetlands and routes were positioned approximately 75 m from the wetland edge. All birds seen within 150 m of the emergent vegetation edge were counted. In impounded wetlands, we either traveled by foot along dikes or by boat so that routes generally paralleled the water-vegetation interface. Areas with potential habitat, as indicated by aerial photos or previous surveys, located inside of the wetland edge and not accessible by boat, were surveyed by foot as much as practicable. Routes were surveyed in the morning between sunrise and four hours after sunrise and all birds seen were recorded and the general habitat being used noted.

Habitat Sampling

To characterize the habitat present at the study sites, we collected vegetation data at three randomly selected 0.25 m^2 quadrats surrounding point count stations. Quadrats were situated randomly between one and 18 m along three compass bearings (120°, 240°, and 360°). At each quadrat we estimated percent cover of dominant vegetation types, measured the water depth, depth of organic sediments, maximum height of standing live or dead vegetation, and visual obstruction (according to Robel et al. 1970), and counted the number of live and dead shrub and tree stems >2 m tall within 2.5 m of the quadrat center (Riffle et al. 2001). Both percent cover and stem density was estimated for cattail (*Typha* spp.), bulrush (*Schoenoplectus* spp.), and common reed (*Phragmites australis*), which were the three dominant plant taxa observed. Vegetation was categorized into the following structural groups: persistent deep-water emergents, persistent shallow-water emergents, nonpersistent deep-water emergents, nonpersistent shallow-water emergents, floating-leaved and free-floating vegetation (e.g. *Nuphar* spp., *Lemna* spp.), and submersed aquatic species (e.g. *Potamogeton* spp., *Chara* spp.). Cowardin et al. (1979) defined persistent emergent species as those that normally remain standing at least until the next growing season, and nonpersistent emergents as those species that usually fall to the surface or below the water at the end of the growing season. Persistent deep-water emergents were those species with rhizomes that can survive permanent or semipermanent inundation, such as cattail and bulrush. Species that usually grow in saturated soil or very shallow water, including sedges (*Carex* spp.), rushes (*Juncus*, spp.), and grasses, were placed in the persistent shallow-water category. Although common reed can survive long-term inundation, it was considered a persistent shallow-water emergent species because it usually becomes established in moist soils or shallow water. We placed species such as arrowhead (*Sagittaria* spp.), pickerelweed (*Pontedaria cordata*), and wild rice (*Zizania* spp.) in the nonpersistent deep-water emergent category. Nonpersistent shallow-water emergents consisted of species such as spikerushes (*Eleocharis* spp.), smartweeds (*Polygonum* spp.), and beggars tick (*Bidens* spp.). We estimated percent aerial coverage for each vegetation category present within a quadrat.

Macroinvertebrates

In collaboration with Dr. Thomas Burton and a graduate student (Cole Provence) from Michigan State University, we collected invertebrates in July and August of 2006 at St. Clair Flats. Fifty-four (54) samples were collected and processed, of which 25 samples were from impounded wetlands (12 from West Marsh and 13 from East Marsh) and 29 samples from undiked wetlands (18 from Dickinson Island and 11 from Little Muscamoot Bay). We collected invertebrates at the interface of open water/aquatic bed wetland and three emergent vegetation zones: common reed, cattail, and bulrush. In diked wetlands, seven samples were collected in bulrush, nine in cattail, and nine in *Phragmites*. At undiked sites, 10 samples were collected in bulrush, nine in cattail, and 10 in *Phragmites*. Samples were collected using 500 micron mesh D-frame dip nets. Three replicate samples were collected at each site by sweeping water and emergent vegetation for one minute per replicate. Contents of the dip nets were emptied into plastic bags and preserved in 70% ethyl alcohol for future processing and identification in the laboratory. Samples were sorted and counted in the laboratory under 10x magnification to the lowest taxonomic unit (usually Family or Genus) using a variety of taxonomic keys (Merritt and Cummings 1996, Peckarsky et al. 1990, Burch and Tottenham 1980, and Wiggins 1977). Three invertebrate samples from each vegetation zone and wetland type (i.e. diked and undiked) were completely picked and sorted. Due to high organic matter and invertebrate numbers, the remaining replicates from the impounded wetlands were sieved through 4-mm and 250-micrometer sieves and subsampled by dividing into quarters using a Folsom plankton splitter. One quarter from each sample was then sorted and counted. Only 15 replicates from the open wetlands required subsampling.

Water Level Fluctuations

We monitored staff gages at a subset of diked coastal wetlands to characterize the fluctuation of water levels during spring, summer, and fall, and to compare these fluctuations with changes observed in Great Lakes water levels. In 2005, gages were read at least once per month at the EMA, WMA, FPR, and WBD sites between early May and early September. The EMA and WMA gages at St. Clair Flats were read on a weekly basis from early May through early September in 2006 and 2007. Five diked sites were monitored on at least a monthly basis at Saginaw Bay in 2006 and 2007: NPE, NPN, NPS, FPR, and WBD. We used hourly NOAA water level monitoring station data to characterize fluctuations at the open wetland sites. Two stations, Algonac, Michigan and St. Clair Shores, Michigan, were used to represent water levels in undiked wetlands at St. Clair Flats. Data from the Essexville, Michigan station located at the confluence of the Saginaw River and Saginaw Bay was used evaluate fluctuations at Saginaw Bay undiked sites. Data from staff gages and water level stations were summarized by year and week.

Water Chemistry

While conducting bird surveys in 2007, we gathered data on water temperature, dissolved oxygen (DO), pH, turbidity, alkalinity, and nitrate/ammonium levels. These data were intended only to characterize the study sites and statistical comparisons were not conducted since data collection varied by time of day and spanned the field season. We measured water temperature and DO with a YSI 55® DO meter, pH using an Oakton pH Testr 3+®, turbidity via an Oakton® T-100 turbidity meter, and alkalinity using Hach® single parameter drop titration kits. We summarized data for these parameters by study area, wetland type, site, and time period. Data were divided into early (early May – mid Jul) and late (mid July – late September) season periods. In late August and

September, we collected water samples for nutrient analysis at four sites at St. Clair Flats (two diked and two undiked) and six sites on Saginaw Bay (three diked and three undiked). We gathered three water samples from each of three vegetation zones when present: common reed, cattail, and bulrush. Samples were gathered at the vegetation-open water interface using sterilized bottles or plastic bags and were immediately placed on ice in the field. We filtered samples using 0.5 micron membrane and then froze them for later analysis. Dr. Donald Uzarski (Central Michigan University) conducted analyses for nitrite/nitrate-N and ammonium-N using procedures recommended in the *Standard Methods for the Examination of Water and Wastewater* (APHA 1992). Quality assurance/quality control procedures followed protocols recommended by the U.S. Environmental Protection Agency.

Analysis

Point Counts: Bird species were categorized as wetland dependent, wetland associated, and nonwetland species (Crowley et al. 1996, Brown and Smith 1998, see Table A-1). We compared densities (birds per ha) of all birds, wetland dependent species, wetland associated species, nonwetland species, and individual species of management concern in diked and undiked wetlands. We calculated densities using a 50-m boundary, which was the distance that appeared to be the best compromise between maximizing detection rates and minimizing the effects of decreasing density with increased distance for most species. However, we used a 100-m boundary when calculating Pied-billed Grebe (*Podilymbus podiceps*) and American Bittern densities, because density estimates and detection frequencies increased with distance. Estimates of densities and frequency of detection by distance category support the assumption that detection probabilities are similar between the two wetland types. We did not conduct analyses (e.g. distance sampling) to adjust density estimates, because population estimates were not an objective of this project, low detection rates precluded such analysis for most species of management concern, and the use of indices seemed appropriate (Johnson 2008). All avian density variables were log (natural) transformed prior to analysis.

We used a mixed model (MIXED procedure, SAS Institute 2004) to compare avian variables between impounded and undiked coastal wetlands. Mixed models are an effective means of analyzing multilevel data structures (Wagner 2006). We used a mixed model that consisted of wetland type (diked and undiked), study area (St. Clair Flats and Saginaw Bay), and survey period (early, mid, and late season) as fixed effects, and year, site (e.g. Dickinson Island), and point (i.e. point count station) as random effects. We incorporated a repeated measures component to account for multiple surveys at the same location. Using the above model, we evaluated three commonly used covariance structures: autoregressive order one (AR[1]), compound symmetric (CS), and unstructured (UN) (Littell et al. 1996, Kincaid 2005). We compared models containing the repeated measures component with a standard mixed model with no repeated measures. For each bird density variable, we selected the best-approximating model using Akaike's Information Criterion (AIC).

Timed-area Surveys: Densities (birds per ha) of waterfowl, waterbirds, and shorebirds were calculated based on the area surveyed as estimated from field maps and aerial photographs. We compared densities of three summary variables (all birds, wetland-dependent and wetland-associated birds [see Table A-2]) and species of management interest between diked and undiked coastal wetlands. Avian density variables were log (natural) transformed prior to analysis. We compared bird densities using a mixed model with wetland type, study area, and survey period (1, 2, 3, or 4) as fixed effects, and year and site as random effects. Survey areas within a given study site were considered replicates of that site.

Habitat Sampling: Several variables characterizing the vegetation composition and structure gathered during quadrat sampling were compared between diked and undiked wetlands. We also compared water depth and estimated depth of organic sediments between the wetland types. Percent variables were arcsine-square root transformed and all other variables (e.g. densities, water depth) were log (natural) transformed. We conducted analyses using a mixed model with wetland type, study area, and survey period (early, mid, and late season) as fixed effects, and year and site as random effects.

Aerial Waterfowl Surveys: We estimated waterfowl densities for each transect by dividing the number of birds observed by the total area surveyed. We compared relative densities of total waterfowl, total waterbirds, dabbling ducks, diving ducks (*Aythya* spp. and sea ducks combined), swans, teal (Blue-winged Teal [*Anas discors*] and Green-winged Teal [*Anas crecca*] combined), and several individual species of management interest between diked and undiked wetland transects. We analyzed density variables using a mixed model (MIXED procedure, SAS Institute 2004) with wetland type (diked and undiked), study area (St. Clair Flats and Saginaw Bay), and survey period (spring, late summer, and fall) as fixed effects, and year and site (e.g. Dickinson Island) as random effects.

Fall Migration Ground Surveys: We calculated densities of waterfowl, waterbirds, and shorebirds by dividing the number of birds observed by the total area surveyed. The total area of open water/aquatic bed wetland surveyed along each route was estimated with ArcView 3.2 using 2005 aerial imagery. We compared several density variables between diked and open coastal wetlands, including all birds, wetland-dependent birds, wetland-associated birds, total waterfowl, total dabbling ducks, total waterbirds (ardeids, rallids, and larids), total shorebirds, small shorebirds (*Calidris* spp.), and individual species of management interest.

We used a mixed model (MIXED procedure, SAS Institute 2004) to compare avian densities between impounded and undiked coastal wetlands, which consisted of wetland type (diked and undiked), study area (St. Clair Flats and Saginaw Bay), and survey period (1, 2, 3, and 4) as fixed effects, and year, site (e.g. Dickinson Island), and survey route as random effects. We incorporated a repeated measures component to account for multiple surveys along the same route. Using the above model, we evaluated three commonly used covariance structures: autoregressive order one (AR[1]), compound symmetric (CS), and unstructured (UN) (Littell et al. 1996, Kincaid 2005). We compared models containing the repeated measures component with a standard mixed model with no repeated measures. For each bird density variable, we selected the best-approximating model using AIC.

RESULTS

Point Counts

Average densities of all birds, wetland-associated birds, and nonwetland birds observed during point counts were similar between diked and undiked coastal wetlands, but mean density of wetland-dependent birds was higher in diked compared to undiked coastal wetlands (Table 2). Both American Bittern and Least Bittern were recorded in higher densities in diked coastal wetlands. Forster's tern (*Sterna forsteri*) was the only species observed in higher densities in undiked coastal wetlands. Specific surveys for terns were not conducted, but field observers noted when nesting colonies were seen. Forster's tern nesting colonies were only recorded in undiked wetlands dominated by bulrush at St. Clair Flats. Foraging Forster's terns were observed in diked wetlands, but no nesting colonies were observed. Black tern (*Chlidonias niger*) densities were similar between diked and open wetlands. Nesting black terns were observed in undiked coastal wetlands at St. Clair Flats in habitats similar to those used by Forster's terns. Black terns also nested in the diked WBD site on Saginaw Bay. Our analysis indicated no significant difference in Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*) densities between diked and undiked wetlands, but the species was only observed at one diked wetland (NPE) on Saginaw Bay. Similarly, we found no significant difference in King Rail densities between diked and undiked coastal wetlands, but the species was only observed in undiked wetlands at St. Clair Flats. Densities and frequencies of occurrence for all bird species observed during point counts are provided by study area and wetland type in Table A-1 (Appendix A).

Table 2. Least squares geometric means and lower and upper 95% confidence limits by wetland type for breeding bird densities (birds per ha) measured during point counts conducted at St. Clair Flats and Saginaw Bay, Michigan, coastal wetlands, 2005-2007. Bolded p-values indicate a significant difference between wetland types ($p<0.05$).

Bird Density Variable	Diked (n=294)	Undiked (n=311)	P-value
All Birds	9.95 (7.46, 13.17)	9.26 (6.95, 12.25)	0.3318
Wetland-dependent Birds	8.19 (6.23, 10.68)	7.18 (5.45, 9.38)	**0.0461**
Wetland-associated Birds	1.00 (0.55, 1.59)	1.06 (0.61, 1.64)	0.8260
Nonwetland Birds	0.23 (0.03, 0.47)	0.35 (0.14, 0.60)	0.4132
Wetland-dependent Species			
Canada Goose	0.03 (0.01, 0.04)	0.01 (0.00, 0.03)	0.3904
Mute Swan	0.01 (-0.01, 0.02)	0.01 (-0.01, 0.03)	0.5091
Wood Duck	0.02 (0.00, 0.03)	0.01 (0.00, 0.03)	0.7895
Mallard	0.02 (-0.02, 0.06)	0.05 (0.01, 0.09)	0.1286
Pied-billed Grebe	0.02 (0.00, 0.04)	0.02 (0.00, 0.05)	0.7927
American Bittern	0.06 (0.04, 0.08)	0.02 (0.01, 0.04)	**0.0012**
Least Bittern	0.04 (0.02, 0.06)	0.01 (-0.01, 0.02)	**0.0024**
King Rail	0.00 (-0.01, 0.01)	0.01 (0.00, 0.02)	0.2402
Virginia Rail	0.20 (0.14, 0.26)	0.15 (0.09, 0.21)	0.2816
Sora	0.04 (0.01, 0.07)	0.03 (0.01, 0.06)	0.6132
Common Moorhen	0.04 (0.02, 0.07)	0.02 (0.00, 0.04)	0.0864
American Coot	0.09 (0.02, 0.16)	0.10 (0.03, 0.17)	0.8550
Black Tern	0.08 (0.01, 0.15)	0.13 (0.06, 0.21)	0.2105
Forster’s Tern	0.04 (-0.04, 0.12)	0.21 (0.12, 0.30)	**0.0057**
Tree Swallow	0.21 (0.04, 0.41)	0.33 (0.15, 0.54)	0.3515
Willow Flycatcher	0.04 (0.02, 0.07)	0.02 (0.00, 0.05)	0.2605
Sedge Wren	0.01 (-0.07, 0.09)	0.05 (-0.03, 0.14)	0.4389
Marsh Wren	1.89 (1.22, 2.76)	1.31 (0.79, 1.96)	0.2024
Swamp Sparrow	1.02 (0.49, 1.72)	0.94 (0.45, 1.60)	0.7846
Red-winged Blackbird	2.69 (2.00, 3.53)	2.44 (1.81, 3.21)	0.4379
Yellow-headed Blackbird	0.09 (-0.05, 0.25)	0.00 (-0.13, 0.12)	0.2766
Wetland-associated Species			
Caspian Tern	0.01 (0.00, 0.03)	<0.01 (-0.01, 0.02)	0.3155
Eastern Kingbird	0.02 (0.00, 0.05)	0.01 (-0.01, 0.04)	0.3972
Barn Swallow	0.08 (0.00, 0.16)	0.17 (0.09, 0.25)	0.0986
Yellow Warbler	0.18 (0.07, 0.31)	0.13 (0.03, 0.25)	0.5182
Common Yellowthroat	0.43 (0.23, 0.67)	0.53 (0.31, 0.77)	0.3868
Common Grackle	0.20 (0.10, 0.31)	0.10 (0.01, 0.20)	0.0612
Nonwetland Species			
Song Sparrow	0.10 (-0.01, 0.21)	0.20 (0.09, 0.32)	0.1751

Bird species richness was similar between the two wetland types, with 57 species observed in diked wetlands and 53 species documented in undiked wetlands. Forty-four species were common to both types (Table 3). Thirteen species were unique to diked wetlands, with seven species considered wetland dependent, one wetland associated, and five nonwetland species. Nine species were unique to undiked coastal wetlands, of which five were considered wetland-dependent, one wetland-associated, and three as nonwetland species. Species unique to the two wetland types tended to those that were only observed sporadically, that use wetlands for aerial foraging, or that breed in shrub, forest, or edge habitats.

Timed-area Surveys

Densities of all birds combined, wetland-dependent birds, and wetland-associated birds were similar between diked and undiked coastal wetlands (Table 4). Canada Goose (*Branta canadensis*), Wood Duck (*Aix sponsa*), and Common Moorhen (*Gallinula chloropus*) densities were higher in diked compared to open wetlands. Densities of American coot (*Fulica americana*), Ring-billed Gull (*Larus delawarensis*), Herring Gull (*Larus argentatus*), and Forster's Tern were higher in undiked compared to diked coastal wetlands. Mallard (*Anas platyrhynchos*) densities tended to be higher in undiked coastal wetlands; however, there was no significant difference between diked and undiked wetlands (p=0.0625). Table A-2 (Appendix A) provides densities and frequencies of occurrence for all bird species observed during timed-area surveys by study area and wetland type.

Table 3. Avian species unique to diked and undiked wetlands and common to both types during breeding bird point counts conducted at St. Clair Flats and Saginaw Bay, Michigan coastal wetlands during 2005-2007.

Species	Diked	Common	Undiked
Wetland-dependent Species			
Canada Goose		X	
Mute Swan		X	
Wood Duck		X	
Mallard		X	
Blue-winged Teal	X		
Redhead			X
Pied-billed Grebe		X	
American Bittern		X	
Least Bittern		X	
Great Blue Heron	X		
Great Egret	X		
Green Heron		X	
Black-crowned Night-Heron			X
Northern Harrier			X
King Rail			X
Virginia Rail		X	
Sora		X	
Common Moorhen		X	
American Coot		X	
Spotted Sandpiper			X
Ring-billed Gull		X	
Herring Gull		X	
Black Tern		X	
Forster's Tern		X	
Alder Flycatcher	X		
Willow Flycatcher		X	
Tree Swallow		X	
Northern Rough-winged Swallow	X		
Bank Swallow	X		
Sedge Wren		X	
Marsh Wren		X	
Swamp Sparrow		X	
Red-winged Blackbird		X	
Yellow-headed Blackbird	X		

Table 3. Cont'd.

Species	Diked	Common	Undiked
Wetland-associated Species			
Killdeer			X
Caspian Tern		X	
Black-billed Cuckoo	X		
Eastern Kingbird		X	
Warbling Vireo		X	
Purple Martin		X	
Cliff Swallow		X	
Barn Swallow		X	
Gray Catbird		X	
Yellow Warbler		X	
Common Yellowthroat		X	
Common Grackle		X	
Nonwetland Species			
Ring-necked Pheasant		X	
Rock Pigeon			X
Mourning Dove		X	
Chimney Swift	X		
Northern Flicker	X		
Blue Jay		X	
Black-capped Chickadee	X		
American Robin		X	
European Starling		X	
Cedar Waxwing		X	
Yellow-rumped Warbler	X		
American Redstart			X
Scarlet Tanager		X	
Song Sparrow		X	
Northern Cardinal		X	
Rose-breasted Grosbeak		X	
Indigo Bunting			X
Brown-headed Cowbird		X	
Baltimore Oriole	X		
American Goldfinch		X	
Total Number of Species	13	44	9

Table 4. Least squares geometric means and lower and upper 95% confidence limits by wetland type for bird densities (birds per ha) measured during timed-area surveys conducted at St. Clair Flats and Saginaw Bay, Michigan, coastal wetlands, 2005-2007. Bolded p-values indicate a significant difference between wetland types (p<0.05).

Bird Density Variable	Diked (n=144)	Undiked (n=143)	P-value
All Birds	3.17 (2.27, 4.32)	2.16 (1.43, 3.11)	0.1159
Wetland-dependent Birds	3.00 (2.16, 4.08)	2.04 (1.34, 2.93)	0.1207
Wetland-associated Birds	0.14 (0.07, 0.22)	0.10 (0.03, 0.18)	0.2436
Wetland Dependent Species			
Canada Goose	0.31 (0.23, 0.40)	0.03 (-0.03, 0.10)	**<0.0001**
Mute Swan	0.15 (0.03, 0.29)	0.09 (-0.04, 0.23)	0.4863
Wood Duck	0.63 (0.39, 0.91)	0.05 (-0.12, 0.24)	**0.0002**
Mallard	0.20 (-0.03, 0.49)	0.63 (0.28, 1.07)	0.0625
Great Blue Heron	0.11 (0.03, 0.18)	0.04 (-0.03, 0.12)	0.1210
Great Egret	0.03 (-0.04, 0.09)	0.07 (0.00, 0.15)	0.3591
Black-crowned Night-Heron	0.04 (-0.04, 0.13)	<0.01 (-0.09, 0.09)	0.4736
Pied-billed Grebe	0.18 (0.03, 0.34)	0.17 (0.02, 0.35)	0.9821
Common Moorhen	0.07 (0.03, 0.11)	0.02 (-0.02, 0.06)	**0.0168**
American Coot	0.04 (-0.01, 0.10)	0.11 (0.05, 0.17)	**0.0378**
Spotted Sandpiper	0.03 (0.00, 0.06)	<0.01 (-0.03, 0.04)	0.1466
Greater Yellowlegs	0.01 (0.00, 0.02)	0.01 (0.00, 0.02)	0.9567
Lesser Yellowlegs	0.03 (-0.01, 0.08)	0.01 (-0.03, 0.06)	0.4527
Dunlin	<0.01 (-0.03, 0.02)	0.02 (0.00, 0.05)	0.1581
Ring-billed Gull	0.01 (-0.01, 0.02)	0.04 (0.03, 0.06)	**0.0025**
Herring Gull	<0.01 (-0.02, 0.03)	0.04 (0.01, 0.07)	**0.0457**
Black Tern	0.36 (0.09, 0.69)	0.18 (-0.08, 0.50)	0.3762
Forster's Tern	0.04 (-0.04, 0.13)	0.20 (0.10, 0.31)	**0.0004**
Wetland Associated Species			
Killdeer	0.04 (-0.02, 0.10)	0.01 (-0.05, 0.07)	0.2842
Caspian Tern	0.10 (0.06, 0.14)	0.09 (0.05, 0.13)	0.5782

Total species richness during timed-area surveys was 32 species for both wetland types, with 25 species common to diked and undiked wetlands (Table 5). The seven species unique to diked wetlands were considered wetland-dependent. Of the seven species unique to undiked coastal wetlands, six were considered wetland-dependent and one species wetland-associated. Bird species unique to the wetland types were only observed irregularly in low numbers.

Table 5. Avian species unique to diked and undiked wetlands and common to both types during timed-area surveys conducted at St. Clair Flats and Saginaw Bay, Michigan coastal wetlands during 2005-2007.

Species	Diked	Common	Undiked
Wetland-dependent Species			
Canada Goose		X	
Mute Swan		X	
Wood Duck		X	
Mallard		X	
Blue-winged Teal		X	
Northern Shoveler	X		
Northern Pintail			X
Green-winged Teal	X		
Canvasback	X		
Redhead			X
Scaup (species unknown)			X
Hooded Merganser			X
Pied-billed Grebe		X	
Double-crested Cormorant	X		
American Bittern		X	
Least Bittern		X	
Great Blue Heron		X	
Great Egret		X	
Green Heron		X	
Black-crowned Night-Heron	X		
Virginia Rail			X
Sora		X	
Common Moorhen		X	
American Coot		X	
Spotted Sandpiper		X	
Greater Yellowlegs		X	
Lesser Yellowlegs		X	
Least Sandpiper	X		
Dunlin			X
Wilson's Snipe	X		
Ring-billed Gull		X	
Herring Gull		X	
Black Tern		X	
Forster's Tern		X	
Belted Kingfisher		X	

Table 5. Cont'd.

Species	Diked	Common	Undiked
Wetland-associated Species			
Bald Eagle		X	
Killdeer		X	
Caspian Tern		X	
Common Tern			X
Total Number of Species	7	25	7

Aerial Waterfowl Surveys

Geometric mean densities for total waterfowl and total waterbirds were similar between diked and undiked coastal wetlands (Table 6). Wood Duck and Gadwall (*Anas strepera*) were the only species observed in higher densities in diked compared to undiked coastal wetlands. Canada Goose and American Black Duck (*Anas rubripes*) were observed in higher densities in undiked wetlands. Table A-3 (Appendix A) provides densities and frequencies of occurrence for waterfowl and waterbird variables recorded during aerial surveys by study area, wetland type, and survey period.

Fall Migration Ground Surveys

The majority of the bird density comparisons were similar between diked and undiked coastal wetland types (Table 7). Geometric mean densities of Wood Duck, Great Blue Heron (*Ardea herodias*), and Wilson's Snipe (*Gallinago delicata*) were higher in diked compared to undiked wetlands. Ring-billed Gull and Forster's Tern geometric densities were higher in undiked coastal wetlands. Densities and frequencies of occurrence for all bird species observed during fall ground surveys are provided by study area and wetland type in Table A-4 (Appendix A).

Total bird species richness was similar between diked and undiked wetlands with 53 species observed in both wetland types (Table 8). Forty-six species were common to both diked and undiked wetlands and seven species were unique to each type. The species unique to the wetland types were only observed sporadically in low numbers.

Table 6. Least squares geometric means and lower and upper 95% confidence limits by wetland type for waterfowl and waterbird densities (birds per ha) measured during aerial surveys conducted at St. Clair Flats and Saginaw Bay, Michigan, coastal wetlands, 2005-2007. Bolded p-values indicate a significant difference between wetland types ($p<0.05$).

Bird Density Variable	Diked (n=14)	Undiked (n=14)	P-value
Total Waterfowl	0.69 (0.41, 1.02)	0.84 (0.51, 1.24)	0.5034
Total Waterbirds	0.10 (0.04, 0.16)	0.08 (0.02, 0.15)	0.7066
Waterfowl Densities			
Dabbling Ducks	0.39 (0.19, 0.63)	0.47 (0.24, 0.75)	0.6173
Diving Ducks	0.14 (0.08, 0.21)	0.07 (0.00, 0.14)	0.1007
Swans	0.06 (-0.01, 0.15)	0.05 (-0.03, 0.15)	0.8457
Canada Goose	0.08 (-0.01, 0.17)	0.24 (0.14, 0.36)	**0.0114**
Wood Duck	0.03 (0.02, 0.04)	<0.01 (-0.01, 0.01)	**0.0008**
Gadwall	0.03 (0.01, 0.05)	<0.01 (-0.02, 0.02)	**0.0069**
American Wigeon	0.05 (0.00, 0.11)	<0.01 (-0.01, 0.05)	0.1237
American Black Duck	0.01 (0.00, 0.02)	0.02 (0.01, 0.04)	**0.0043**
Mallard	0.27 (0.13, 0.43)	0.42 (0.25, 0.61)	0.1420
Teal (Blue- and Green-winged combined)	0.08 (0.01, 0.16)	0.06 (-0.01, 0.14)	0.6879
Waterbird Species			
Great Blue Heron	0.02 (0.01, 0.03)	0.01 (0.00, 0.03)	0.7414
Great Egret	0.02 (-0.04, 0.08)	0.02 (-0.04, 0.09)	0.9165

Table 7. Least squares geometric means and lower and upper 95% confidence limits by wetland type for bird densities (birds per ha) measured during late summer/early fall ground surveys conducted at St. Clair Flats and Saginaw Bay, Michigan, coastal wetlands, 2005-2007. Bolded p-values indicate a significant difference between wetland types (p<0.05).

Bird Density Variable	Diked (n=86)	Undiked (n=69)	P-value
All Birds	4.39 (2.73, 6.78)	2.66 (1.40, 2.58)	0.1436
Wetland-dependent Birds	4.34 (2.72, 6.66)	2.54 (1.34, 4.36)	0.1150
Wetland-associated Birds	0.11 (0.04, 0.18)	0.10 (0.04, 0.18)	0.8096
Total Waterfowl	3.06 (1.80, 4.88)	1.70 (0.77, 3.13)	0.1285
Total Dabbling Ducks	1.20 (0.30, 2.74)	1.70 (0.48, 3.94)	0.5801
Total Waterbirds	1.13 (0.73, 1.63)	0.57 (0.23, 1.00)	0.0555
Total Shorebirds	0.40 (0.15, 0.71)	0.31 (0.04, 0.63)	0.6142
Calidris spp. Shorebirds	0.11 (0.00, 0.22)	0.02 (-0.08, 0.14)	0.2686
Wetland-dependent Species			
Canada Goose	0.09 (0.02, 0.16)	0.11 (0.03, 0.19)	0.7272
Mute Swan	0.08 (-0.02, 0.18)	0.02 (-0.08, 0.13)	0.3284
Wood Duck	1.10 (0.74, 1.54)	0.09 (-0.13, 0.35)	**<0.0001**
Gadwall	0.03 (-0.02, 0.07)	<0.01 (-0.04, 0.05)	0.5173
Mallard	0.56 (0.04, 1.36)	1.26 (0.40, 2.63)	0.2350
Blue-winged Teal	0.23 (0.08, 0.40)	0.27 (0.10, 0.46)	0.6210
Green-winged Teal	0.58 (0.27, 0.97)	0.47 (0.18, 0.83)	0.1489
Great Blue Heron	0.26 (0.17, 0.35)	0.04 (-0.04, 0.14)	**0.0006**
Great Egret	0.28 (0.15, 0.42)	0.24 (0.10, 0.39)	0.7065
Green Heron	0.08 (-0.05, 0.24)	<0.01 (-0.15, 0.16)	0.3862
Black-crowned Night-Heron	0.04 (0.01, 0.08)	0.03 (0.00, 0.07)	0.4514
Pied-billed Grebe	0.18 (0.03, 0.35)	0.01 (-0.14, 0.18)	0.1177
Common Moorhen	0.04 (0.01, 0.07)	0.03 (0.00, 0.06)	0.3923
American Coot	0.02 (0.00, 0.05)	0.03 (0.00, 0.06)	0.7091
Spotted Sandpiper	0.05 (0.01, 0.10)	0.01 (-0.04, 0.07)	0.2636
Solitary Sandpiper	0.03 (0.01, 0.06)	0.01 (-0.02, 0.04)	0.0575
Greater Yellowlegs	0.05 (0.00, 0.10)	0.09 (0.04, 0.15)	0.1637
Lesser Yellowlegs	0.09 (-0.03, 0.21)	0.09 (-0.04, 0.24)	0.9876
Least Sandpiper	0.07 (-0.01, 0.15)	0.03 (-0.06, 0.13)	0.5715
Wilson’s Snipe	0.10 (0.05, 0.14)	0.05 (0.01, 0.09)	**0.0018**
Ring-billed Gull	0.05 (-0.01, 0.11)	0.12 (0.06, 0.18)	**0.0126**
Black Tern	0.03 (0.01, 0.06)	0.03 (0.00, 0.06)	0.2330
Forster’s Tern	<0.01 (-0.01, 0.01)	0.02 (0.01, 0.03)	**<0.0001**
Wetland-associated Species			
Killdeer	0.07 (0.01, 0.13)	0.08 (0.02, 0.15)	0.7229
Caspian Tern	0.04 (0.00, 0.08)	0.03 (-0.01, 0.08)	0.6692

Table 8. Avian species unique to diked and open wetlands and common to both types during late summer/early fall ground surveys conducted at St. Clair Flats and Saginaw Bay, Michigan coastal wetlands during 2005-2007.

Species	Diked	Common	Undiked
Wetland-dependent Species			
Canada Goose		X	
Mute Swan		X	
Trumpeter Swan	X		
Wood Duck		X	
Gadwall		X	
American Wigeon		X	
American Black Duck		X	
Mallard		X	
Blue-winged Teal		X	
Northern Shoveler		X	
Northern Pintail			X
Green-winged Teal		X	
Canvasback			X
Redhead			X
Ring-necked Duck	X		
Scaup (species unknown)		X	
Bufflehead		X	
Hooded Merganser		X	
Ruddy Duck	X		
Pied-billed Grebe		X	
Double-crested Cormorant		X	
American Bittern		X	
Least Bittern		X	
Great Blue Heron		X	
Great Egret		X	
Green Heron		X	
Black-crowned Night-Heron		X	
Northern Harrier		X	
Virginia Rail		X	
Sora		X	
Common Moorhen		X	
American Coot		X	
Sandhill Crane		X	
Semipalmated Plover		X	
Spotted Sandpiper		X	
Solitary Sandpiper		X	

Table 8. Cont'd.

Species	Diked	Common	Undiked
Wetland-dependent Species			
Greater Yellowlegs		X	
Lesser Yellowlegs		X	
Semipalmated Sandpiper		X	
Least Sandpiper		X	
Baird's Sandpiper			X
Pectoral Sandpiper		X	
Dunlin	X		
Stilt Sandpiper		X	
Short-billed Dowitcher		X	
Wilson's Snipe		X	
American Woodcock	X		
Red-necked Phalarope	X		
Bonaparte's Gull			X
Ring-billed Gull		X	
Herring Gull		X	
Black Tern		X	
Forster's Tern		X	
Belted Kingfisher		X	
Wetland-associated Species			
Bald Eagle		X	
Merlin	X		
Black-bellied Plover			X
Killdeer		X	
Caspian Tern		X	
Common Tern			X
Total Number of Species	7	46	7

Habitat Sampling

Hydrologic and biogeochemical changes that occur as a result of coastal wetland isolation appear to have caused changes in vegetation and physical parameters measured during habitat sampling in diked and undiked coastal wetlands (Table 9). Mean percent cover of open water/aquatic bed wetland, floating vegetation, persistent deep-water vegetation, and cattail was higher in diked wetlands than in undiked coastal wetlands. Average percent cover of persistent shallow-water vegetation, non-persistent shallow-water vegetation, bulrush, common reed, surface litter, and exposed sediments were higher in undiked wetlands compared to diked sites. Although significant differences were observed between diked and undiked wetlands in percent cover of non-persistent shallow-water emergents and exposed sediments, mean estimates for both wetland types were low. Percent cover of emergent vegetation and submersed vegetation was similar between wetland types. Mean density of cattail stems was higher in diked compared to undiked wetlands, while densities of bulrush and common reed were higher in undiked wetlands. Mean depths of water and organic sediment were higher in diked compared to undiked coastal wetlands.

Table 9. Least squares geometric means and standard errors for vegetation variables measured during quadrat sampling conducted at St. Clair Flats and Saginaw Bay, Michigan, coastal wetlands, 2006-2007. Bolded p-values indicate a significant difference between wetland types (p<0.05).

Vegetation Variable	Diked (n=771)	Undiked (n=750)	P-value
Percent Cover			
Emergent Vegetation	23.9 (15.2, 34.0)	25.7 (16.3, 36.4)	0.7578
Open Water/Aquatic Bed	73.8 (61.6, 84.5)	40.0 (26.9, 53.9)	**0.0003**
Submersed Vegetation	1.1 (0.2, 2.6)	0.2 (0.0, 1.1)	0.1393
Floating Vegetation	1.9 (0.7, 3.7)	<0.1 (0.2, 0.5)	**0.0020**
Persistent Deep-water	16.9 (9.9, 25.3)	6.3 (2.1, 12.7)	**0.0258**
Persistent Shallow-water	1.0 (0.0, 3.8)	8.0 (3.4, 14.3)	**0.0033**
Non-persistent Deep-water	<0.1(<0.1, <0.1)	<0.1(<0.1, 0.1)	0.0601
Non-persistent Shallow-water	0.1 (<0.1, 0.4)	0.8 (0.4, 1.3)	**0.0005**
Typha	16.3 (9.7, 24.3)	1.8 (0.1, 5.7)	**0.0001**
Schoenoplectus	<0.1 (<0.1, 0.2)	1.8 (1.0, 2.8)	**<0.0001**
Phragmites australis	0.2 (0.1, 1.7)	3.4 (1.0, 7.2)	**0.0227**
Surface Litter	13.0 (6.5, 21.2)	31.0 (20.9, 42.2)	**0.0038**
Exposed Sediments	<0.1 (<0.1, 0.1)	0.3 (0.1, 0.6)	**0.0171**
Stem Density			
Typha[1]	11.78 (6.76, 20.06)	1.58 (0.52, 3.38)	**<0.0001**
Schoenoplectus[1]	0.10 (-0.19, 0.49)	2.88 (1.80, 4.37)	**<0.0001**
Phragmites australis[1]	0.46 (-0.14, 1.48)	2.80 (1.16, 5.67)	**0.0134**
Trees and Shrubs[2]	0.24 (0.08, 0.42)	0.04 (-0.10, 0.20)	0.0837
Vegetation Height (m)	1.55 (1.22, 1.92)	1.44 (1.11, 1.82)	0.6628
Visual Obstruction (m)	1.17 (0.85, 1.56)	0.81 (0.52, 1.16)	0.1271
Water Depth (m)	0.30 (0.22, 0.39)	0.09 (0.02, 0.17)	**0.0002**
Organic Sediment Depth (m)	0.40 (0.30, 0.50)	0.24 (0.15, 0.34)	**0.0069**

[1] No. stems per 0.25 m^2 quadrat.

[2] No. stems >2 m tall per 20 m^2 (within 2.5 m radius of quadrat center).

Macroinvertebrates

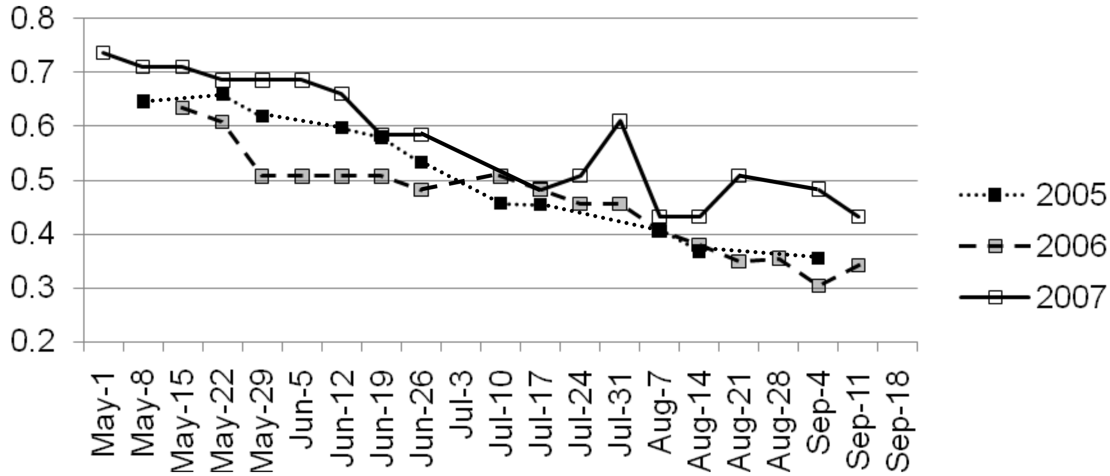
The following is a brief summary of the results of macroinvertebrate sampling conducted at St. Clair Flats and presented in Provence (2008), a study conducted in coordination with our research. Mean abundance (total number of invertebrates per sample) was significantly higher in diked compared to undiked sites (p=0.03), with mean abundance nearly seven times higher in diked wetlands. Average taxa richness was significantly higher in diked compared to undiked wetlands (p=0.05), but mean Shannon diversity and Simpson evenness indices were similar between wetland types. The higher abundance and taxa richness in diked compared to open, undiked marshes was consistent across vegetation zones. Sorensen Similarity Index indicated a 77% similarity between the invertebrate communities of diked and undiked wetlands. There was no significant difference in the invertebrate community among the three vegetation zones sampled (cattail, bulrush, and common reed) or between study sites within each wetland type. A combined total of 144 invertebrate taxa were collected in diked and open wetlands. A total of 121 taxa were collected in diked marshes, 113 taxa in undiked wetlands, and 90 taxa were common to both wetland types. Sorensen Index values for pair-wise comparisons of the invertebrate communities in all combinations of the three vegetation zones and wetland types ranged from 68-82%, indicating that invertebrate composition was similar overall.

Approximately 80% of the difference in total mean invertebrate abundance between diked and undiked wetlands was accounted for by five taxa: amphipods (Amphipoda), segmented worms (Naididae), *Caenis* mayflies, snails (Gastropoda), and non-biting midges (Chironomidae). Mean abundances of eleven invertebrate taxa were higher in diked compared to undiked coastal wetlands. The most common amphipod in diked wetlands was *Hyallela azteca*, and the average number of all amphipods per sample was significantly higher in diked (1093 per sample) compared to undiked (31 per sample) wetlands (p=0.02). While *Gammarus* was the dominant amphipod taxa in undiked wetlands, it was not observed in diked samples. Mean total snail (Gastropoda) abundance was significantly higher in diked (607 per sample) compared to undiked (67 per sample) wetlands (p=0.03). Average abundance of water mites (*Hydracarina*) in diked wetlands was 109 per sample, which was significantly higher than the mean of eight per sample observed in undiked wetlands (p=0.01). Significantly more dragonflies and damselflies (Odonata) were collected per sample in diked (168 per sample) compared to open (18 per sample) wetlands (p=0.02). Average Odonata taxa richness was also higher in diked compared to undiked wetlands (p=0.02). Members of the pygmy backswimmer family (Pleidae) of true bugs (Hemiptera) were collected in higher abundance in diked compared to undiked wetlands (p=0.05), with means of 48 per sample in diked and three per sample in undiked sites. The mean total number of Lepidopterans per sample was higher in diked (21 per sample) compared to undiked (two per sample) wetlands (p=0.05). Average abundance of aquatic beetles (Coleoptera) was significantly higher in diked compared to undiked wetlands (p=0.02), with a mean of 53 per sample in diked and 10 per sample in undiked sites. Mean total number of flies (Diptera) was nearly six times higher in diked (366 per sample) compared to undiked (66 per sample) wetlands (p=0.03), which included three subfamilies of midges that were observed in significantly higher numbers in diked wetlands (*Chironomini* [p=0.02], *Tanypodinae* [p=0.02], and *Tanytarsini* [p=0.04]).

A summary of invertebrate composition by functional feeding group indicated that gatherer-collectors made up about 60% of the invertebrates collected in both diked and undiked coastal wetlands, while predators made up approximately 20% and scrapers about 10% of the total. Composition was similar by wetland type, with gatherer-collectors accounting for 49 to 70% of the invertebrates collected in diked vegetation zones and 52 to 62% of the invertebrates collected in undiked vegetation zones. Scrapers made up a greater percentage of the total than predators in diked cattail and common reed zones, but predators were more common than scrapers in all other zones of both wetland types.

Water Level Fluctuations

Staff gage monitoring at diked SCF sites indicated highest water levels in spring and declining levels throughout much the growing season (Figure 2). Levels consistently declined at EMA throughout the monitoring period, with lowest levels in August or September. At WMA, lowest water levels were in July or August, with increasing levels occurring in the late summer in response to higher precipitation and/or pumping to increase water levels for fall waterfowl hunting. Results from the Algonac and St. Clair Shores gaging stations were similar to the diked wetlands in 2005 and 2007 (Figure 3). Highest water elevations of the period examined occurred in spring. Similar to the diked wetlands, water levels declined throughout the monitoring period and were lowest in September. Water levels in 2006 were lower in spring, increased during the spring and early summer to a peak in late July, and then declined in the late summer. This pattern is similar to the annual cycle typically observed in Great Lakes water levels. Lake St. Clair water levels are usually lowest in late winter, increase during spring and early summer, peak in July, and then decrease during late summer and fall (Figure 4).



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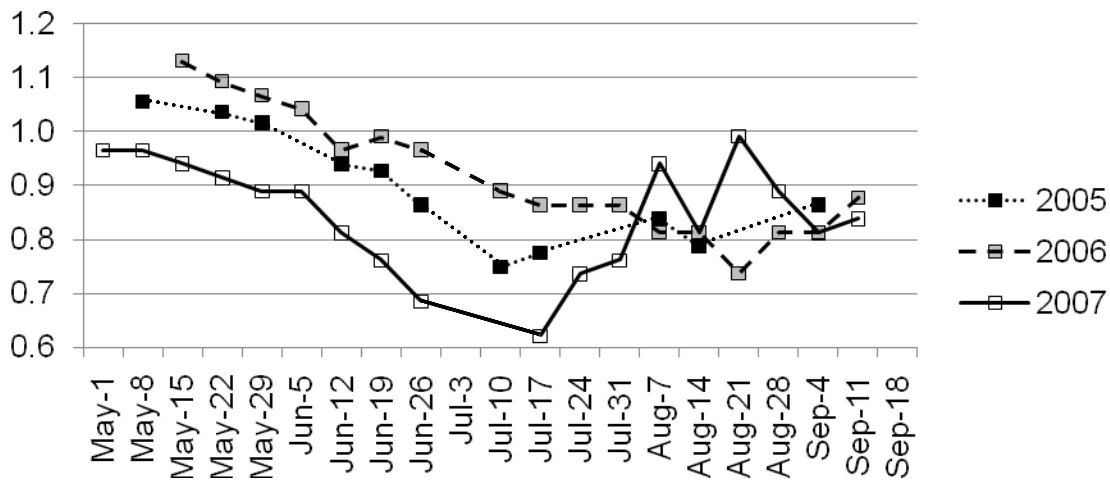

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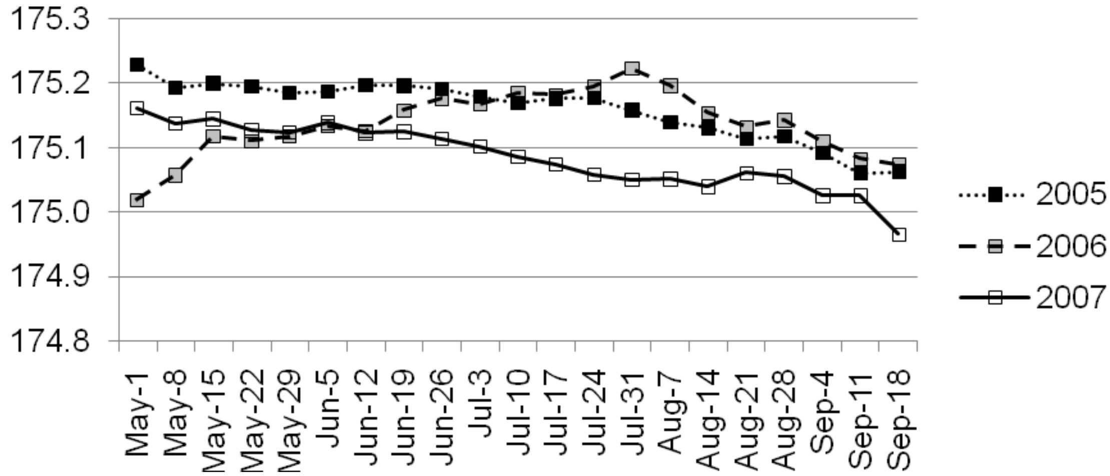
Figure 2. Water level fluctuations by week and year during late spring and summer at diked sites on St. Clair Flats, Michigan 2005-2007: A) East Marsh and B) West Marsh. The y-axis is in meters and references selected heights on staff gages, rather than true water elevation (i.e. meters above sea level) of the study sites.



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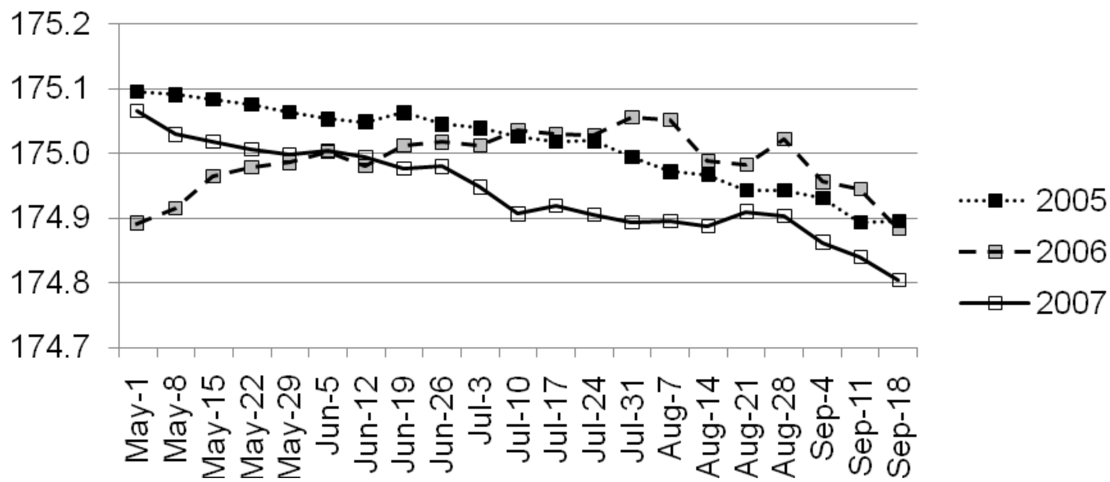

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Figure 3. Water level fluctuations by week of year during late spring and summer at undiked NOAA water gage locations on St. Clair Flats, Michigan 2005-2007: A) Algonac and B) St. Clair Shores. The y-axis represents true water elevations in meters above sea level for the St. Clair River (A. Algonac gage) and Lake St. Clair (B. St. Clair Shores gage).

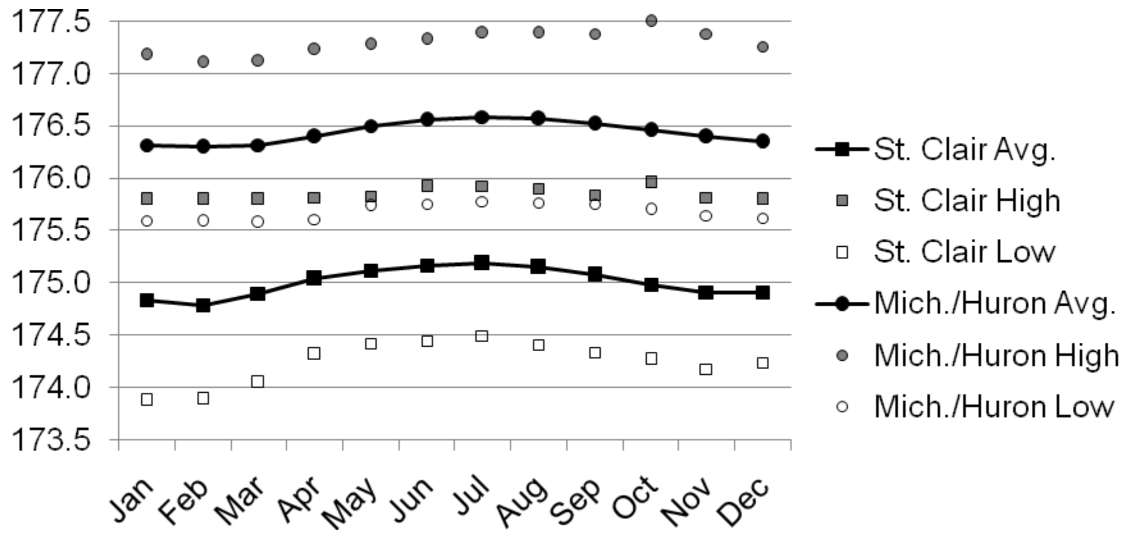
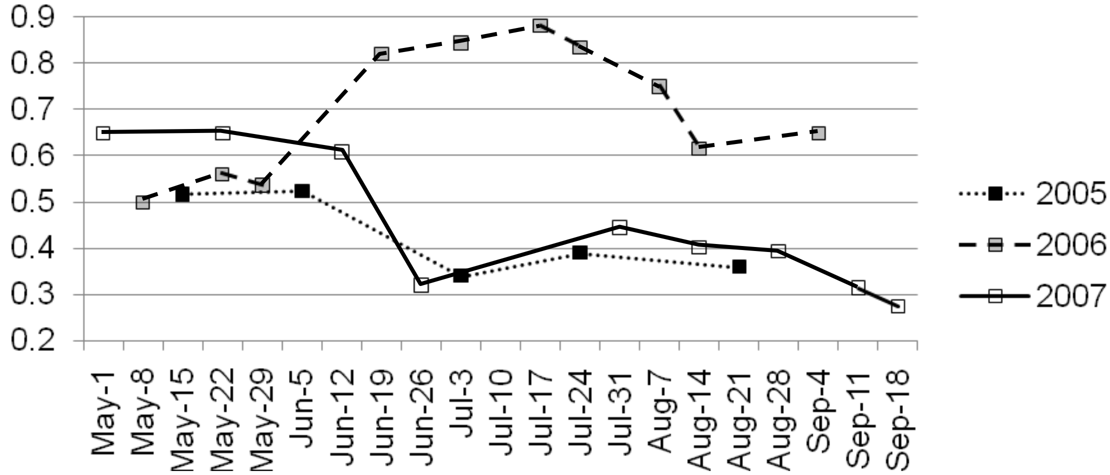


Figure 4. Long-term (1918-2007) average water levels in meters above sea level for spring and summer months on Lake St. Clair and Lakes Michigan and Huron. Error bars indicate record high and low water levels for each month. Data obtained from the U.S. Army Corps of Engineers website (www.lre.usace.army.mil/greatlakes/hh/greatlakes waterlevels/historicdata/greatlakeshydrographs/).

Water level fluctuations at diked SAG sites were similar to diked wetlands at SCF. Levels were usually highest in the spring and declined throughout the monitoring period (Figure 5). Exceptions occurred at those sites with water pumping stations. At FPR in 2006, water levels increased in spring and early summer to a peak in July due to water pumping, and then decreased during late summer after pumping stopped. Water level increases observed at NPN and NPS in August and September were due to pumping in preparation for the fall waterfowl hunting seasons. Elevations recorded in 2005 and 2006 at the Essexville station indicated increasing water levels in spring and early summer to peaks in July or August, and then decreasing water levels thereafter (Figure 6). In 2007, water levels were generally stable from about early May through mid July and then decreased in the late summer. Water level patterns observed at the Essexville station during the study were consistent with long-term averages (Figure 4).

Figure 5. Water level fluctuations by week of year during late spring and summer at diked sites on Saginaw Bay, Michigan 2005-2007: A) Fish Point Refuge (FPR), B) Nayanquing Point (NPE, NPN, and NPS), and C) Wigwam Bay (WBD). The y-axis is in meters and references selected heights on staff gages, rather than true water elevation (i.e. meters above sea level) of the study sites.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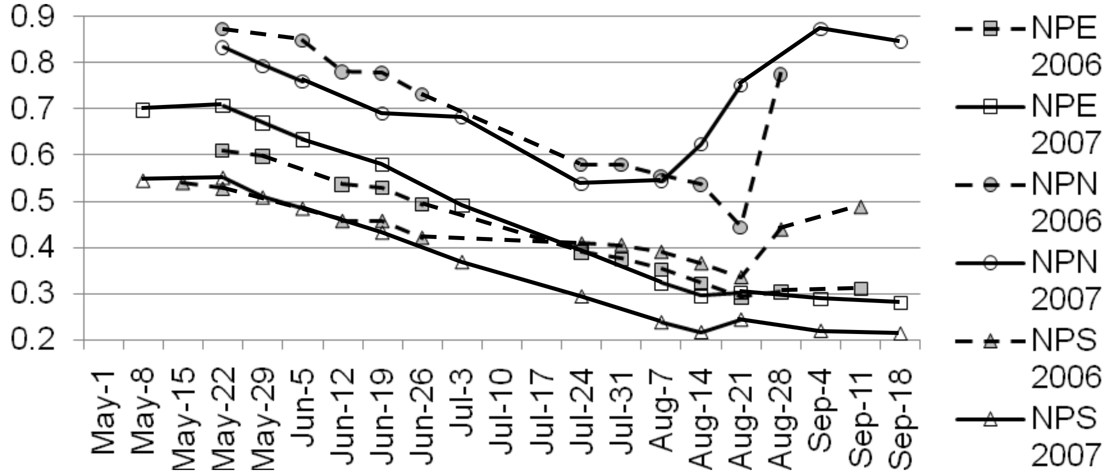
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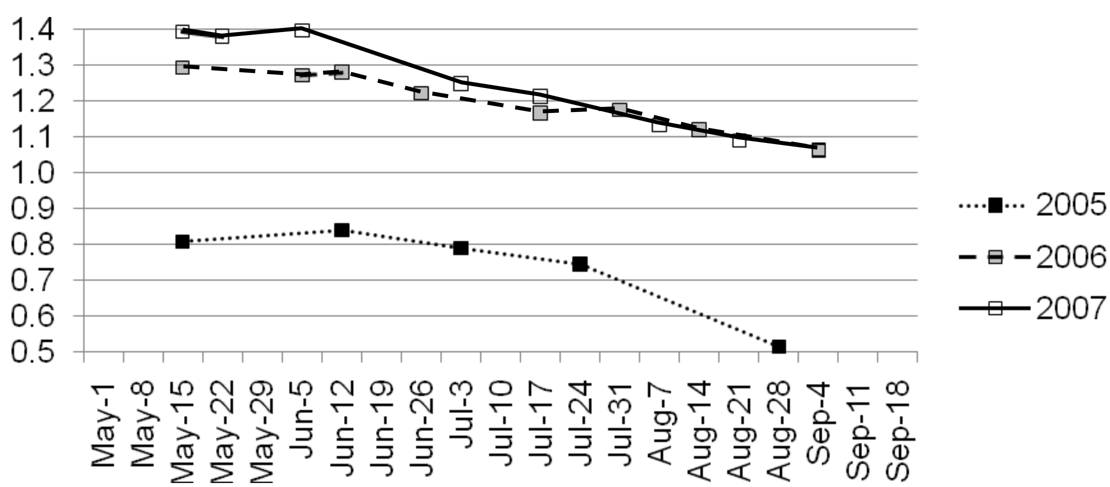
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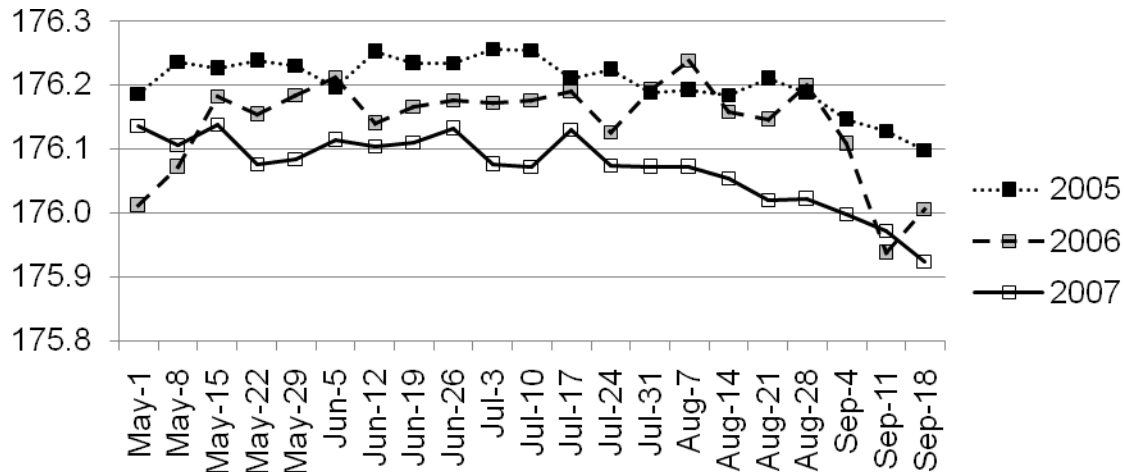

Figure 6. Water level fluctuations by week of year during late spring and summer at undiked Essexville NOAA water gage on Saginaw Bay, Michigan 2005-2007. The y-axis represents true water elevation in meters above sea level for Saginaw Bay, Lake Huron.

Water Chemistry

Diked wetlands tended to have lower dissolved oxygen (DO) levels and pH compared to undiked wetlands, regardless of sample period and study area (Table 10). Mean water temperatures were similar between diked and undiked wetlands. Diked St. Clair Flats sites consistently had higher alkalinity compared to the undiked sites; however, alkalinity varied within and between wetland types at Saginaw Bay. Turbidity was lower in diked compared to undiked wetlands at St. Clair Flats, but varied by site at Saginaw Bay wetlands with overall means being similar. Nitrate levels in diked wetlands appeared to be lower compared to undiked wetlands (Table 10). Average ammonium levels were slightly higher in undiked compared to diked sites at the St. Clair Flats, but appeared similar between the wetland types on Saginaw Bay.

Table 10. Means ± SE by wetland type, study area, site, and period for water chemistry parameters measured during sampling conducted at Saginaw Bay and St. Clair Flats, Michigan in 2007. Data are partitioned into early (early May – mid Jul) and late (mid July – late September) periods and the number of samples are in parentheses.

Area, Site, and Type	Period	Dissolved Oxygen (mg/L)	Water Temp (°C)	pH	Alkalinity (mg/L)	Turbidity (ntu)	Nitrate (mg/L)	Ammonium (mg/L)
SCF – Diked								
EMA	Early	3.35±0.29 (41)	19.4±0.7 (42)	7.32±0.05 (42)	163±7 (41)	2.0±0.3 (41)	---	---
	Late	4.82±0.54 (13)	23.7±0.4 (13)	7.45±0.08 (13)	197±6 (13)	0.8±0.1 (13)	0.013±0.004 (6)	0.033±0.003 (9)
WMA	Early	2.60±0.33 (31)	20.6±0.8 (32)	7.54±0.06 (32)	251±10 (32)	3.6±0.8 (31)	---	---
	Late	4.44±0.71 (12)	22.0±0.8 (12)	7.02±0.39 (12)	202±14 (12)	1.3±0.2 (12)	0.012±0.003 (9)	0.026±0.004 (9)
Overall	Early	3.01±0.22 (73)	19.9±0.5 (73)	7.41±0.04 (74)	202±8 (73)	2.7±0.4 (72)	---	---
	Late	4.64±0.43 (25)	22.8±0.5 (25)	7.24±0.19 (25)	199±7 (25)	1.0±0.1 (25)	0.012±0.002 (15)	0.029±0.002 (18)
SCF – Undiked								
DIS	Early	4.93±0.49 (39)	18.7±0.7 (39)	7.62±0.09 (39)	139±5 (39)	9.5±1.8 (38)	---	---
	Late	8.59±0.72 (13)	24.4±0.7 (13)	8.23±0.12 (13)	131±5 (13)	3.0±0.7 (13)	0.099±0.034 (9)	0.045±0.007 (9)
LMU	Early	4.85±0.46 (42)	18.1±0.6 (42)	7.73±0.09 (42)	138±4 (41)	8.0±1.9 (42)	---	---
	Late	8.84±0.54 (13)	21.7±0.9 (13)	8.29±0.09 (13)	123±2 (13)	4.2±1.0 (13)	0.122±0.036 (9)	0.047±0.010 (8)
Overall	Early	4.89±0.33 (81)	18.4±0.5 (81)	7.68±0.06 (81)	80±3 (80)	8.7±1.3 (80)	---	---
	Late	8.72±0.44 (26)	23.1±0.6 (26)	8.26±0.07 (26)	127±3 (26)	3.6±0.6 (26)	0.111±0.024 (18)	0.046±0.006 (17)
SAG - Diked								
FPR	Early	8.36±1.39 (17)	19.3±1.5 (17)	8.73±0.45 (20)	195±11 (16)	---	---	---
	Late	11.64±0.70 (22)	24.4±0.6 (24)	9.20±0.07 (24)	177±6 (24)	12.3±1.4 (24)	0.062±0.024 (6)	0.011±0.005 (6)
FPA	Late	7.27±0.56 (19)	20.5±0.8 (19)	7.74±0.10 (19)	165±7 (19)	3.5±0.6 (19)	0.028±0.008 (9)	0.035±0.003 (9)
NPE	Early	3.02±0.44 (13)	21.4±0.6 (13)	7.40±0.20 (9)	169±9 (9)	---	---	---
	Late	3.28±0.89 (4)	18.5±0.3 (4)	7.20±0.09 (4)	230±19 (4)	4.3±1.6 (4)	0.103±0.092 (5)	0.041±0.004 (5)
NPN	Early	1.28±0.31 (10)	19.2±1.1 (10)	7.20±0.14 (10)	148±15 (5)	---	---	---
	Late	5.91±0.54 (15)	22.9±0.4 (15)	7.75±0.09 (15)	133±5 (15)	9.1±2.1 (15)	0.021±0.007 (2)	0.042±0.006 (2)

Table 10. Cont'd.

Area, Site, and Type	Period	Dissolved Oxygen	Water Temp	pH	Alkalinity	Turbidity	Nitrate	Ammonium
SAG – Diked, Cont'd.								
NPS	Early	5.68±1.43 (4)	20.9±0.5 (4)	8.21±0.19 (4)	195±10 (4)	---	---	---
	Late	3.93±0.98 (9)	20.3±0.9 (9)	7.38±0.15 (9)	244±12 (9)	2.3±0.5 (9)	---	---
WBD	Early	3.35±0.35 (36)	18.6±0.7 (36)	7.36±0.28 (30)	75±5 (29)	---	---	---
	Late	3.56±0.39 (24)	19.7±0.8 (24)	7.13±0.08 (24)	101±3 (24)	2.0±0.4 (24)	0.018±0.004 (9)	0.039±0.005 (8)
Overall	Early	4.29±0.43 (82)	19.4±0.5 (82)	7.78±0.18 (65)	135±8 (75)	---	---	---
	Late	6.63±0.41 (93)	21.6±0.4 (95)	7.90±0.09 (95)	157±5 (95)	6.1±0.7 (95)	0.043±0.015 (31)	0.039±0.002 (30)
SAG – Undiked								
PIR	Early	10.05±1.01 (9)	21.7±1.2 (9)	7.68±0.61(9)	143±8 (13)	---	---	---
	Late	9.89±0.35 (19)	23.9±0.4 (19)	8.58±0.06 (18)	140±4 (18)	9.2±1.5 (19)	0.106±0.051 (6)	0.038±0.007 (6)
QUA	Early	11.09±1.12 (12)	23.3±1.4 (13)	8.50±0.15 (13)	229±26 (9)	---	---	---
	Late	9.74±0.53 (23)	21.3±1.0 (23)	8.31±0.10 (23)	146±8 (23)	6.8±0.7 (23)	0.127±0.051 (6)	0.043±0.007 (6)
WIL	Early	8.09±0.62 (29)	20.7±0.8 (30)	8.47±0.20 (25)	171±11 (26)	---	---	---
	Late	10.09±0.68 (24)	24.2±0.5 (24)	8.51±0.09 (24)	140±7 (24)	5.8±1.2 (24)	0.028±0.006 (8)	0.043±0.004 (9)
Overall	Early	9.62±0.51 (50)	21.5±0.6 (52)	8.33±0.16 (47)	174±9 (48)	---	---	---
	Late	9.91±0.32 (66)	23.1±0.4 (66)	8.46±0.05 (65)	142±4 (65)	7.1±0.7 (66)	0.081±0.023 (20)	0.042±0.003 (21)

DISCUSSION

Wildlife managers in the Great Lakes region built dikes around certain wetlands to improve their ability to manipulate water levels to enhance conditions for wetland birds. This study aimed to evaluate bird use of diked wetlands through comparisons with wetlands open to Great Lakes water level fluctuations, and to examine bird use in the context of habitat conditions. We found higher densities of some wetland-dependent breeding bird species in diked compared to undiked coastal wetlands, while others were observed in lower densities. Most of the breeding bird density variables were not significantly different between wetland types. Total wetland-dependent bird densities were higher in diked coastal wetlands during point counts, but densities observed during timed-area surveys were similar. Galloway et al. (2006) observed higher abundance of several groups of birds in diked wetlands, including marsh-nesting obligates, marsh-nesting generalists, and area-sensitive marsh-nesting obligates in pooled comparisons of diked and undiked coastal wetlands of the southern Great Lakes. We observed similar total species richness between diked and open wetlands during both point counts and timed-area surveys. Approximately two-thirds of the species observed during breeding surveys were common to both wetland types, and unique species consisted primarily of species normally seen in low numbers, such as nonbreeding species or late migrants, or those that use adjacent habitats, such as forests, shrub lands, or grasslands. Galloway et al. (2006) found higher cumulative species richness in diked compared to open wetlands for several of the marsh bird groups they compared, and only aerial forager species richness was higher in undiked wetlands. Although Galloway et al. (2006) observed significantly higher bird abundance and species richness for several bird groups in overall comparisons of diked and undiked sites, they noted that few significant differences in wetland bird communities were observed in paired comparisons of nearby diked and undiked sites. Differences in the results of the current study and Galloway et al. (2006) could be due to variation in management and hydrologic regimes, human disturbance levels, invasive species impacts, and surrounding landscape. Galloway et al. (2006) also only sampled during one field season, which may not have accounted for long-term variation in bird use and habitat conditions.

Most of the breeding species observed in higher densities in diked compared to undiked coastal wetlands use deep-water marshes for some part of their life cycle. Canada Geese and Wood Ducks were observed in higher densities in diked wetlands during timed-area surveys. Higher water levels in the diked wetlands likely provided attractive brood rearing habitat for both species proximal to nesting sites. Canada Geese regularly nest on dikes and were observed feeding on both the dikes and in nearby row-crop fields. Most of the diked wetlands had Wood Duck nest boxes, while the undiked wetlands did not. Wood Ducks may have been attracted to dense cover provided by emergent and floating-leaved plants of the diked wetlands, and the greater abundance of aquatic invertebrates, which are an important food source for nesting females and broods (Drobney and Fredrickson 1979). Densities of American and Least Bittern were higher in diked coastal wetlands. Least Bitterns tend to use deeper water marshes when compared to American Bittern (Weller 1961, Weller and Spatcher 1965), and Bogner and Baldassarre (2002) suggested vegetation type and cover ratios (emergent:open water) may be more important factors to Least Bitterns populations than marsh size. American

Bitterns in Maine appeared to prefer impounded and beaver-created wetlands over wetlands of glacial origin (Gibbs et al. 1992). Higher water levels and percent open water in the diked wetlands may have increased interspersion of emergent vegetation and open water, which would be attractive to these species. Dikes surrounding the isolated coastal wetlands may have provided nesting bitterns protection from wave action and seiches. Higher water levels in the diked compared to undiked wetlands may have created a more stable environment for the invertebrates, amphibians, and small fish that bitterns use for food. Although densities of Common Moorhen were similar between diked and undiked wetlands during point count surveys, densities were higher in diked wetlands during timed-area surveys. Common Moorhens typically breed in permanently flooded deep-water marshes consisting of tall emergent vegetation interspersed with open areas containing floating-leaved and submersed vegetation or mudflats (Bannor and Kiviat 2002). American Coot, Ring-billed Gull, Herring Gull, and Forster's Tern were the only breeding species observed in higher densities in undiked compared to diked wetlands. American Coot densities in diked and undiked wetland were similar during point counts; however, densities during timed-area surveys were higher in undiked coastal wetlands. Weller and Fredrickson (1974) suggested that American Coots pioneer new habitats quickly, while Common Moorhens tend to move into sites several years after reflooding. Fish are an important component of the diets of Ring-billed Gull, Herring Gull, and Forster's Tern (see Ryder 1993, Pierotti and Good 1994, McNicholl et al. 2001). Studies conducted in Lake Erie coastal wetlands indicated differences in the fish using diked and undiked wetlands (Johnson et al. 1997, Markham et al. 1997). A key variable not measured in this study was fish abundance and composition of diked and undiked wetlands. It would be useful to know the relative abundance of forage fish to understand the effects coastal wetland isolation on these bird species. Foraging in diked wetlands may have been more difficult for these species due to greater coverage of floating-leaved vegetation. Forster's Terns were only observed nesting in undiked wetlands where dead bulrush stems from the previous growing season collected, which provided a substrate for their floating nests. Bulrush percent coverage and stem density were significantly lower in diked compared to undiked wetlands.

No studies evaluating migrant bird use of diked and undiked coastal wetlands were found for the Great Lakes region. We observed few differences in migrant waterfowl densities between diked and undiked coastal wetlands during aerial and early fall ground surveys. Brasher et al. (2007) found that duck foraging resources were abundant during fall in both actively (water-level control) and passively (no water-level control) managed wetlands in Ohio. Similarity of waterfowl use of diked and undiked wetlands could indicate that minimum food resources are available in both wetland types, regardless of habitat conditions. Canada Goose densities were significantly higher in open wetlands during aerial surveys, while fall ground surveys revealed similar densities in diked and undiked wetlands. This discrepancy is may be due to seasonal changes in Canada Goose densities and habitat use, high variation of densities during migration, and the low number of aerial surveys conducted. Large concentrations of Canada Geese were observed on open Saginaw Bay wetlands during spring aerial surveys. Canada Geese probably used these wetlands as roosting sites and flew to other locations (e.g. agricultural lands) to forage, so the primary determinant of habitat selection may be secure roosting areas. Wood Duck densities were higher in diked compared to undiked wetlands during both aerial and early fall ground surveys. We observed the same pattern of Wood Duck densities during the breeding season, and higher use could be related to cover provided by dense floating-leaved vegetation. There was a likely trend for higher Mallard densities in undiked compared to diked wetlands during both breeding and migration surveys. Fredrickson and Taylor (1982) indicated that preferred foraging depths for Mallards in seasonally flooded impoundments was approximately 11-16 cm, so the shallow water depths observed in the undiked wetlands could provide better foraging habitat. Wilcox (1995) suggested that shorebirds may lose habitat provided by continually changing Great Lakes water levels when coastal wetlands are isolated through diking. Our surveys indicated fall migration shorebird use of diked and undiked wetlands on St. Clair Flats and Saginaw Bay was similar. Wilson's Snipe was the only shorebird species observed in higher densities in diked compared to undiked wetlands, which may have been due to organic soils and high invertebrate abundance. No shorebird species were observed in higher densities in undiked compared to diked coastal wetlands. Although water depths were higher in diked compared to undiked wetlands, water levels were usually lowest in late summer, which provided pockets of mudflats and shallow water at a time when fall shorebird migration typically peaks. Conversely, Lake St. Clair and Huron water levels are usually highest in late summer. In some cases, pumping to increase water levels in diked wetlands in preparation for fall waterfowl hunting reduced available habitat for migrant shorebirds. Alterations to water management schedules could enhance habitat for migrant shorebirds at a time when available shorebird habitat in coastal wetlands could be limited.

Hydrologic isolation of the diked wetlands has caused changes to physical, chemical, and vegetation characteristics when compared to undiked sites. Average water depth and depth of organic sediment was significantly higher in diked compared to undiked wetlands. Herrick and Wolf (2005) found that the soils of diked wetlands had higher percent organic matter when compared to undiked wetlands. They also observed higher total N, available P, and available K in the soils of diked compared to undiked wetlands. Our limited testing for nitrate and ammonium in water samples are not directly comparable to the study by Herrick and Wolf (2005) due to differing methods and timing of sample collection, but our results indicated higher levels of both compounds in undiked compared to diked wetlands. Robb (1989) found no significant difference in nitrate and ammonia levels in water of diked and undiked wetlands. We found that the diked sites tended to be more acidic and less turbid compared to undiked wetlands, which is consistent with other studies (Herrick and Wolf 2005, Robb 1989). We observed higher percent cover of open water, floating vegetation, persistent deep-water emergents, and cattails, and higher mean cattail density in diked compared to undiked wetlands, and these differences were likely due to higher, more stable water levels in the diked areas. Percent cover and density of bulrush and common reed were higher in undiked compared to diked wetlands. In vegetation comparisons between diked and undiked wetlands, Herrick and Wolf (2005) similarly found higher cattail cover in diked wetlands and higher common reed cover in open wetlands. Lower mean percent cover and stem density of common reed in diked compared to undiked wetlands may be due to higher water levels and common reed management (e.g. herbicide application, burning) that occurred in some diked areas.

Several studies have suggested that wetland plant species are distributed along gradients of disturbance, fertility, and organic matter content based on competitive abilities (e.g. Wilson and Keddy 1986, Gaudet and Keddy 1988, 1995, Day et al. 1988, Moore et al. 1989), with species such as cattails outcompeting other species in areas with high fertility and low disturbance (Wisheu and Keddy 1990). Diked wetlands may experience less disturbance due to stabilized water levels and higher fertility due to high organic content of soils and trapped nutrients, which could lead to dominance by cattail. Herrick et al. (2007) suggested that diked coastal wetlands serve as traps for organic matter and nutrients.

We found no significant difference in percent cover of submersed plants between the wetland types; however, sampling was focused in emergent marsh where point counts were conducted. Sampling of submersed vegetation within the open water/aquatic bed zone may have produced different results. Prince (1985) observed that bird species richness and nesting density were negatively related to percent open water during surveys of diked and undiked wetlands, and that the lack of submersed vegetation limited breeding bird use in some wetlands.

Mean total invertebrate abundance and taxa richness were significantly higher in diked compared to undiked coastal wetlands of the St. Clair Flats (Provence 2008). This effect was consistent for the bulrush, cattail, and common reed plant zones with diked wetlands supporting a several fold increase in numbers of invertebrates compared to undiked wetlands for each of these plant zones in pairwise comparisons between diked and undiked marshes. We suspect that the seven-fold increase overall in invertebrate numbers in diked marshes compared to undiked marshes reflected the fact that we sampled the edge of each of these three plants zones near the interface with aquatic bed wetland and dredged channels in diked marshes, which were dominated by submersed aquatic vegetation (SAV), and open water areas in undiked wetlands. High SAV abundance is often associated with high invertebrate numbers and particularly with high amphipod densities (Anteau and Afton 2008). The observed displacement of *Gammarus* spp. in undiked marshes by much higher numbers of *Hyallela azteca* in diked marshes may have been a function of differences in SAV between diked and undiked wetlands related to consistent levels of flooding in diked compared to undiked marshes, which would have been subjected to much greater variation in water levels and exposure to waves and storm surges. McLaughlin and Harris (1990) observed a greater number of taxa and higher total biomass of emerging aquatic insects in a diked compared to an undiked wetland; however, total abundance was similar between the two types. Because McLaughlin and Harris (1990) only sampled emerging insects, they excluded taxa such as segmented worms (Naididae) and amphipods (Amphipoda), which dominated the invertebrate community in our study (see Provence 2008). There were no significant differences in the invertebrate communities of the three vegetation zones sampled in diked or undiked marshes. Thus, major differences in abundance between diked and undiked wetlands appeared to be the result of diking rather than being related to differences in plant zones, since results were consistent for each of the three plant zones sampled. Other studies of Great Lakes coastal marshes have indicated that vegetation type is an important factor structuring macroinvertebrate communities (Cardinale et al. 1998, Burton et al. 2002, 2004, Merritt et al. 2002, Stricker et al. 2001). This inconsistency is likely due to edge effects caused by our sample design. We sampled at the emergent vegetation-open water interface where many wetland bird species tend to feed and where invertebrates from submergent and emergent plant zones were likely to be present. Previous research has also indicated that invertebrate abundance is higher in areas with sparse emergent vegetation (Voigts 1976, McLaughlin and Harris 1990, De Szalay and Cassidy 2001). Swanson et al. (1974, 1979) highlighted the importance of aquatic invertebrates as food for waterfowl during the breeding season, and invertebrates make up an important component of the diets of many other wetland bird species. Several taxa known to be important to breeding wetlands birds were more abundant in the diked wetlands than in undiked wetlands, including amphipods, segmented worms, mayflies (*Caenis*), snails (Gastropoda), and midges (Chironomidae). Our study suggests that the diked wetlands at St. Clair Flats provide enhanced food resources for some bird species, especially those that tend to feed in the interface between submersed and emergent aquatic vegetation (e.g. dabbling ducks). Interspersion between plant stems tends to be greater here than in the interior of emergent plant zones. Thus, we caution that our findings should not be extrapolated to the interior of emergent plant zones where mixing of invertebrates from emergent and submergent plant zones is not likely to occur.

Research Needs

Our study occurred during a period of low Great Lakes water levels. Bird use of diked and undiked coastal wetlands could be different during normal to high water levels, and more research is needed during other parts of the Great Lakes water level cycle to investigate if patterns of bird use change under different hydrologic conditions. Long term studies are needed to understand changes in wetlands that occur over 5-20 years.

Additional analyses (e.g. multivariate) using the data set gathered in this study may elucidate possible relationships between bird use and wetland conditions, which could facilitate management decisions. Research is needed to understand the effects that structural differences (e.g. water depths, floating vegetation mats, interspersion) in the habitats of diked and undiked wetlands may have on bird species. More study is needed to determine if the pattern of higher invertebrate abundance in diked compared to undiked wetlands that we observed at St. Clair Flats applies to wetlands in other parts of the Great Lakes, and to examine if wetland bird density and diversity is linked to food abundance. We need to develop management guidelines that maximize wildlife benefits in diked wetlands in the context of changing coastal wetland conditions associated with climate change and invasive species expansion, or for specific species of concern (e.g. species of greatest conservation need). Diked wetlands provide opportunities to conduct experimental studies that test the success of water level management regimes for selected management goals (e.g. enhanced migrant waterfowl or shorebird use, diverse vegetation communities). Fish and amphibian populations are also likely affected by the isolation of coastal wetlands, and the effects on their populations and the secondary effects on bird populations are not understood.

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APPENDIX A

BIRD DATA TABLES BY WETLAND TYPE AND STUDY AREA

Table A-1. Mean densities (birds/ha), standard error, and frequency of occurrence (in parentheses) by study area and wetland type for bird species observed during breeding bird point counts conducted at St. Clair Flats and Saginaw Bay, Michigan coastal wetlands during 2005-2007. Frequency of occurrence is the proportion of point counts that the species was observed.

	St. Clair Flats		Saginaw Bay	
Species	Diked	Open	Diked	Open
Wetland-dependent Species				
Canada Goose	0.07±0.04 (0.02)	0.04±0.02 (0.02)	0.04±0.02 (0.02)	0.01±0.01 (0.01)
Mute Swan	0.01±0.01 (0.01)	0.06±0.03 (0.03)	---	---
Wood Duck	0.02±0.01 (0.01)	0.03±0.02 (0.02)	0.02±0.01 (0.01)	0.03±0.02 (0.01)
Mallard	0.05±0.03 (0.03)	0.17±0.06 (0.07)	0.01±0.01 (0.01)	0.07±0.03 (0.04)
Blue-winged Teal	---	---	0.02±0.02 (0.01)	---
Redhead	---	0.01±0.01 (0.01)	---	---
Pied-billed Grebe	0.02±0.01 (0.06)	0.06±0.01 (0.12)	0.02±0.01 (0.05)	---
American Bittern	0.10±0.01 (0.27)	0.03±0.01 (0.07)	0.04±0.01 (0.12)	0.02±0.01 (0.05)
Least Bittern	0.06±0.03 (0.05)	---	0.08±0.03 (0.06)	0.01±0.01 (0.01)
Great Blue Heron	---	---	0.02±0.02 (0.01)	---
Great Egret	---	---	0.03±0.02 (0.01)	---
Green Heron	0.01±0.01 (0.01)	---	---	0.01±0.01 (0.01)
Black-crowned Night-Heron	---	---	---	0.01±0.01 (0.01)
Northern Harrier	---	0.01±0.01 (0.01)	---	---
King Rail	---	0.04±0.02 (0.02)	---	---
Virginia Rail	0.36±0.07 (0.19)	0.22±0.05 (0.13)	0.35±0.07 (0.19)	0.33±0.08 (0.17)
Sora	0.07±0.03 (0.05)	0.06±0.02 (0.05)	0.07±0.03 (0.05)	0.05±0.02 (0.03)
Common Moorhen	0.07±0.03 (0.04)	0.08±0.03 (0.04)	0.05±0.02 (0.03)	0.02±0.02 (0.01)
American Coot	0.16±0.05 (0.10)	0.27±0.05 (0.15)	0.11±0.04 (0.06)	0.12±0.06 (0.04)
Spotted Sandpiper	---	---	---	0.02±0.01 (0.01)

Table A-1. Cont'd.

Species	St. Clair Flats Diked	St. Clair Flats Open	Saginaw Bay Diked	Saginaw Bay Open
Ring-billed Gull	---	0.01±0.01 (0.01)	0.01±0.01 (0.01)	0.02±0.01 (0.01)
Herring Gull	---	---	0.01±0.01 (0.01)	0.01±0.01 (0.01)
Black Tern	0.13±0.04 (0.08)	0.72±0.15 (0.20)	0.34±0.19 (0.05)	---
Forster's Tern	0.10±0.03 (0.07)	0.94±0.19 (0.27)	0.02±0.01 (0.01)	0.09±0.04 (0.04)
Alder Flycatcher	0.02±0.02 (0.01)	---	---	---
Willow Flycatcher	0.02±0.02 (0.01)	---	0.12±0.04 (0.07)	0.07±0.02 (0.05)
Tree Swallow	0.37±0.07 (0.22)	0.47±0.08 (0.23)	0.41±0.07 (0.24)	0.61±0.11 (0.23)
Northern Rough-winged Swallow	0.02±0.01 (0.01)	---	---	---
Bank Swallow	---	---	0.01±0.01 (0.01)	---
Sedge Wren	---	---	0.04±0.02 (0.02)	0.10±0.04 (0.07)
Marsh Wren	3.32±0.22 (0.74)	2.60±0.21 (0.68)	2.18±0.17 (0.66)	1.81±0.18 (0.59)
Swamp Sparrow	1.31±0.12 (0.54)	1.16±0.12 (0.47)	1.94±0.12 (0.77)	1.90±0.13 (0.71)
Red-winged Blackbird	4.46±0.19 (0.99)	4.30±0.21 (0.94)	2.56±0.15 (0.82)	2.39±0.19 (0.76)
Yellow-headed Blackbird	---	---	0.23±0.07 (0.09)	---
Wetland-associated Species				
Killdeer	---	0.02±0.02 (0.01)	---	0.03±0.02 (0.02)
Caspian Tern	---	0.01±0.01 (0.01)	0.05±0.02 (0.03)	0.01±0.01 (0.01)
Black-billed Cuckoo	---	---	0.02±0.02 (0.01)	---
Eastern Kingbird	---	0.01±0.01 (0.01)	0.08±0.03 (0.05)	0.03±0.02 (0.01)
Warbling Vireo	---	---	0.02±0.01 (0.01)	0.02±0.01 (0.01)
Purple Martin	0.08±0.03 (0.05)	0.06±0.03 (0.03)	---	0.05±0.03 (0.02)
Cliff Swallow	0.02±0.02 (0.01)	---	0.02±0.01 (0.01)	0.02±0.01 (0.01)
Barn Swallow	0.16±0.04 (0.10)	0.23±0.05 (0.13)	0.10±0.04 (0.06)	0.31±0.06 (0.18)

Table A-1. Cont'd.

Species	St. Clair Flats		Saginaw Bay	
	Diked	Open	Diked	Open
Wetland-associated Species				
Gray Catbird	---	---	0.06±0.02 (0.05)	0.06±0.03 (0.03)
Yellow Warbler	0.03±0.02 (0.03)	0.12±0.03 (0.07)	0.54±0.08 (0.29)	0.39±0.08 (0.18)
Common Yellowthroat	0.55±0.08 (0.30)	1.04±0.11 (0.44)	0.81±0.08 (0.46)	0.68±0.08 (0.41)
Common Grackle	0.43±0.09 (0.16)	0.29±0.08 (0.12)	0.64±0.16 (0.17)	0.07±0.03 (0.04)
Nonwetland Species				
Ring-necked Pheasant	0.02±0.01 (0.01)	0.01±0.01 (0.01)	---	0.01±0.01 (0.01)
Rock Pigeon	---	0.06±0.06 (0.01)	---	---
Mourning Dove	0.02±0.01 (0.01)	0.03±0.02 (0.02)	0.01±0.01 (0.01)	0.03±0.02 (0.02)
Chimney Swift	0.02±0.02 (0.01)	---	---	---
Northern Flicker	---	---	0.01±0.01 (0.01)	---
Blue Jay	---	0.01±0.01 (0.01)	0.05±0.05 (0.01)	---
Black-capped Chickadee	---	---	0.01±0.01 (0.01)	---
American Robin	---	0.01±0.01 (0.01)	0.02±0.01 (0.01)	0.04±0.02 (0.02)
European Starling	0.08±0.04 (0.03)	0.07±0.04 (0.02)	---	---
Cedar Waxwing	---	---	0.02±0.01 (0.01)	0.06±0.03 (0.02)
Yellow-rumped Warbler	---	---	0.02±0.02 (0.01)	---
American Redstart	---	---	---	0.01±0.01 (0.01)
Scarlet Tanager	---	---	0.01±0.01 (0.01)	0.01±0.01 (0.01)
Song Sparrow	0.01±0.01 (0.01)	0.26±0.05 (0.17)	0.22±0.05 (0.14)	0.34±0.06 (0.21)
Northern Cardinal	0.01±0.01 (0.01)	---	0.01±0.01 (0.01)	0.02±0.02 (0.01)
Rose-breasted Grosbeak	---	---	0.01±0.01 (0.01)	0.02±0.02 (0.01)
Indigo Bunting	---	---	---	0.01±0.01 (0.01)

Table A-1. Cont'd.

Species	St. Clair Flats		Saginaw Bay	
	Diked	Open	Diked	Open
Brown-headed Cowbird	0.02±0.02 (0.01)	---	0.07±0.03 (0.06)	0.09±0.04 (0.05)
Baltimore Oriole	---	---	0.01±0.01 (0.01)	---
American Goldfinch	0.02±0.01 (0.01)	0.05±0.02 (0.04)	0.11±0.04 (0.07)	0.11±0.05 (0.05)

Table A-2. Mean densities (birds/ha), standard error, and frequency of occurrence (in parentheses) by study area and wetland type for bird species observed during timed-area surveys conducted at St. Clair Flats and Saginaw Bay, Michigan coastal wetlands during 2005-2007. Frequency of occurrence is the proportion of open water areas that the species was observed.

	St. Clair Flats		Saginaw Bay	
Species	Diked (n=88)	Open (n=92)	Diked (n=56)	Open (n=51)
Wetland-dependent Species				
Canada Goose	0.69±0.19 (0.27)	0.03±0.01 (0.09)	0.54±0.16 (0.29)	0.10±0.08 (0.08)
Mute Swan	0.11±0.08 (0.06)	0.23±0.05 (0.45)	0.25±0.08 (0.27)	0.04±0.02 (0.12)
Wood Duck	1.03±0.16 (0.51)	0.06±0.02 (0.11)	1.21±0.40 (0.45)	0.06±0.04 (0.12)
Mallard	0.46±0.31 (0.17)	0.51±0.08 (0.61)	1.43±1.09 (0.34)	2.67±1.48 (0.69)
Blue-winged Teal	<0.01±<0.01 (0.01)	<0.01±<0.01 (0.01)	0.05±0.05 (0.02)	<0.01±<0.01 (0.02)
Northern Shoveler	---	---	<0.01±<0.01 (0.02)	---
Northern Pintail	---	---	---	<0.01±<0.01 (0.02)
Green-winged Teal	0.01±0.01 (0.01)	---	---	---
Canvasback	---	---	<0.01±<0.01 (0.02)	---
Redhead	---	0.07±0.03 (0.12)	---	---
Scaup (species unknown)	---	0.01±0.01 (0.01)	---	---
Hooded Merganser	---	<0.01±<0.01 (0.01)	---	---
Pied-billed Grebe	0.10±0.04 (0.18)	0.37±0.06 (0.62)	0.24±0.06 (0.41)	0.11±0.07 (0.16)
Double-crested Cormorant	---	---	0.10±0.04 (0.13)	---
American Bittern	0.05±0.04 (0.05)	0.06±0.02 (0.11)	0.01±0.01 (0.02)	---
Least Bittern	0.03±0.01 (0.06)	---	0.02±0.01 (0.07)	<0.01±<0.01 (0.04)
Great Blue Heron	0.10±0.03 (0.20)	0.04±0.01 (0.21)	0.12±0.04 (0.23)	0.03±0.01 (0.14)
Great Egret	---	0.01±0.01 (0.03)	0.10±0.05 (0.13)	0.16±0.04 (0.35)
Green Heron	---	---	0.02±0.02 (0.04)	0.01±0.01 (0.02)
Black-crowned Night-Heron	<0.01±<0.01 (0.01)	---	0.09±0.05 (0.07)	---

Table A-2. Cont'd.

Species	St. Clair Flats		Saginaw Bay	
	Diked (n=88)	Open (n=92)	Diked (n=56)	Open (n=51)
Virginia Rail	---	<0.01±<0.01 (0.02)	---	0.05±0.03 (0.10)
Sora	0.02±0.02 (0.02)	---	---	0.04±0.04 (0.04)
Common Moorhen	0.17±0.06 (0.15)	0.03±0.01 (0.15)	0.05±0.02 (0.16)	0.02±0.01 (0.08)
American Coot	0.09±0.04 (0.09)	0.32±0.10 (0.37)	0.04±0.02 (0.09)	0.07±0.07 (0.02)
Spotted Sandpiper	0.11±0.10 (0.03)	<0.01±<0.01 (0.01)	0.01±0.01 (0.02)	---
Greater Yellowlegs	0.02±0.02 (0.02)	0.02±0.01 (0.03)	---	---
Lesser Yellowlegs	0.13±0.10 (0.03)	0.03±0.03 (0.01)	---	---
Least Sandpiper	0.01±0.01 (0.02)	---	---	---
Dunlin	---	0.10±0.10 (0.02)	---	0.03±0.03 (0.02)
Wilson's Snipe	0.01±0.01 (0.01)	---	---	---
Ring-billed Gull	<0.01±<0.01 (0.02)	0.02±0.01 (0.05)	0.01±0.01 (0.05)	0.11±0.04 (0.22)
Herring Gull	---	<0.01±<0.01 (0.02)	0.02±0.01 (0.05)	0.09±0.03 (0.31)
Black Tern	1.20±0.35 (0.32)	0.48±0.10 (0.58)	0.80±0.28 (0.36)	0.12±0.06 (0.14)
Forster's Tern	0.19±0.05 (0.34)	0.47±0.09 (0.64)	0.01±<0.01 (0.04)	0.17±0.05 (0.35)
Belted Kingfisher	---	---	0.01±0.01 (0.05)	<0.01±<0.01 (0.02)
Wetland-associated Species				
Bald Eagle	---	---	0.01±0.01 (0.02)	<0.01±<0.01 (0.04)
Killdeer	0.24±0.21 (0.02)	---	---	<0.01±<0.01 (0.02)
Caspian Tern	<0.01±<0.01 (0.01)	0.03±0.01 (0.10)	0.22±0.04 (0.50)	0.17±0.03 (0.51)
Common Tern	---	<0.01±<0.01 (0.01)	---	---

Table A-3. Mean densities (birds/ha), standard errors, and frequencies (in parentheses) by study area, wetland type, and survey period for several waterfowl and waterbird species observed during aerial surveys conducted at St. Clair Flats and Saginaw Bay, Michigan coastal wetlands during 2005-2007. Frequencies are the proportions of transects with the species present.

Species		St. Clair Flats		Saginaw Bay	
		Diked	Open	Diked	Open
Total Waterfowl:	Spring (n=5)	0.68±0.07 (1.00)	1.19±0.25 (1.00)	2.08±0.25 (1.00)	3.22±0.42 (1.00)
	Summer (n=5)	0.07±0.04 (0.90)	0.52±0.05 (1.00)	0.80±0.29 (1.00)	0.69±0.15 (1.00)
	Fall (n=4)	0.07±0.03 (0.88)	0.61±0.11 (1.00)	2.62±0.77 (0.86)	1.22±0.24 (1.00)
Total Waterbirds:	Spring (n=5)	0.02±<0.01 (0.90)	0.03±0.01 (0.44)	0.16±0.08 (0.40)	0.02±0.02 (0.33)
	Summer (n=5)	0.05±0.02 (0.80)	0.07±0.04 (0.90)	0.18±0.05 (0.93)	0.17±0.05 (1.00)
	Fall (n=4)	0.02±0.01 (0.88)	0.10±0.05 (0.86)	0.22±0.05 (0.82)	0.27±0.12 (0.93)
Dabbling Ducks:	Spring (n=5)	0.23±0.06 (1.00)	0.57±0.23 (1.00)	0.80±0.19 (1.00)	1.01±0.15 (1.00)
	Summer (n=5)	0.05±0.04 (0.60)	0.36±0.03 (1.00)	0.65±0.29 (0.79)	0.63±0.15 (1.00)
	Fall (n=4)	0.05±0.03 (0.75)	0.37±0.11 (1.00)	2.09±0.69 (0.75)	1.02±0.23 (1.00)
Diving Ducks:	Spring (n=5)	0.29±0.06 (1.00)	0.37±0.08 (1.00)	0.77±0.16 (0.93)	0.32±0.10 (0.93)
	Summer (n=5)	---	---	---	<0.01±<0.01 (0.03)
	Fall (n=4)	---	<0.01±<0.01 (0.14)	0.04±0.02 (0.18)	<0.01±<0.01 (0.04)
Swans:	Spring (n=5)	0.03±0.01 (0.70)	0.16±0.05 (1.00)	0.12±0.03 (0.83)	0.22±0.11 (0.47)
	Summer (n=5)	<0.01±<0.01 (0.10)	0.15±0.05 (0.70)	0.09±0.02 (0.50)	---
	Fall (n=4)	0.01±0.01 (0.13)	0.23±0.07 (1.00)	0.08±0.03 (0.43)	<0.01±<0.01 (0.04)
Canada Goose:	Spring (n=5)	0.12±0.02 (1.00)	0.09±0.02 (1.00)	0.39±0.05 (1.00)	1.69±0.30 (0.97)
	Summer (n=5)	---	<0.01±<0.01 (0.10)	0.01±<0.01 (0.07)	0.05±0.02 (0.23)
	Fall (n=4)	---	<0.01±<0.01 (0.14)	0.33±0.21 (0.29)	0.19±0.07 (0.41)
Wood Duck:	Spring (n=5)	0.01±0.01 (0.10)	0.01±0.01 (0.22)	0.01±0.01 (0.13)	<0.01±<0.01 (0.03)
	Summer (n=5)	0.02±<0.01 (0.70)	<0.01±<0.01 (0.20)	0.06±0.02 (0.64)	0.01±<0.01 (0.33)
	Fall (n=4)	0.02±0.01 (0.50)	<0.01±<0.01 (0.14)	0.07±0.03 (0.43)	0.01±<0.01 (0.26)

Table A-3. Cont'd.

Species		St. Clair Flats		Saginaw Bay	
		Diked	Open	Diked	Open
Gadwall:	Spring (n=5)	<0.01±<0.01 (0.10)	<0.01±<0.01 (0.11)	0.06±0.02 (0.33)	<0.01±<0.01 (0.20)
	Summer (n=5)	---	---	---	<0.01±<0.01 (0.03)
	Fall (n=4)	---	---	0.09±0.04 (0.21)	---
Am. Wigeon:	Spring (n=5)	0.01±<0.01 (0.30)	---	0.05±0.04 (0.17)	0.01±<0.01 (0.30)
	Summer (n=5)	---	<0.01±<0.01 (0.10)	---	<0.01±<0.01 (0.10)
	Fall (n=4)	---	---	0.31±0.13 (0.25)	0.01±<0.01 (0.30)
Am. Black Duck:	Spring (n=5)	0.02±0.01 (0.40)	0.07±0.02 (0.89)	0.01±0.01 (0.13)	0.05±0.01 (0.73)
	Summer (n=5)	---	<0.01±<0.01 (0.10)	<0.01±<0.01 (0.04)	<0.01±<0.01 (0.37)
	Fall (n=4)	<0.01±<0.01 (0.25)	<0.01±<0.01 (0.14)	0.01±<0.01 (0.14)	0.02±0.01 (0.59)
Mallard:	Spring (n=5)	0.19±0.05 (1.00)	0.48±0.22 (1.00)	0.56±0.12 (1.00)	0.73±0.11 (1.00)
	Summer (n=5)	0.02±0.01 (0.60)	0.32±0.03 (1.00)	0.45±0.27 (0.68)	0.51±0.14 (1.00)
	Fall (n=4)	0.04±0.03 (0.63)	0.37±0.11 (1.00)	1.37±0.58 (0.75)	0.85±0.20 (1.00)
Teal:	Spring (n=5)	0.01±0.01 (0.30)	<0.01±<0.01 (0.11)	0.11±0.06 (0.40)	0.22±0.06 (0.83)
	Summer (n=5)	0.03±0.03 (0.20)	0.04±0.02 (0.50)	0.19±0.09 (0.50)	0.11±0.03 (0.70)
	Fall (n=4)	<0.01±<0.01 (0.13)	---	0.31±0.18 (0.39)	0.14±0.07 (0.48)
Great Blue Heron:	Spring (n=5)	---	---	---	<0.01±<0.01 (0.07)
	Summer (n=5)	0.02±0.01 (0.70)	0.01±<0.01 (0.70)	0.03±0.01 (0.82)	0.02±<0.01 (0.90)
	Fall (n=4)	0.01±<0.01 (0.75)	0.03±0.01 (0.86)	0.04±0.01 (0.71)	0.03±<0.01 (0.81)
Great Egret:	Spring (n=5)	---	<0.01±<0.01 (0.11)	---	0.10±0.02 (1.00)
	Summer (n=5)	0.02±0.02 (0.40)	<0.01±<0.01 (0.13)	0.12±0.04 (0.61)	<0.01±<0.01 (0.10)
	Fall (n=4)	0.01±<0.01 (0.25)	0.02±0.02 (0.43)	0.08±0.03 (0.36)	0.09±0.02 (0.74)

Table A-4. Mean densities (birds/ha), standard error, and frequency of occurrence (in parentheses) by study area and wetland type for bird species observed during late summer/early fall ground surveys conducted at St. Clair Flats and Saginaw Bay, Michigan coastal wetlands during 2005-2007. Frequency of occurrence is the proportion of surveys that the species was observed.

	St. Clair Flats		Saginaw Bay	
Species	Diked (n=36)	Open (n=36)	Diked (n=50)	Open (n=33)
Wetland-dependent Species				
Canada Goose	0.03±0.02 (0.17)	0.01±<0.01 (0.21)	0.20±0.08 (0.28)	0.19±0.10 (0.33)
Mute Swan	0.03±0.01 (0.14)	0.06±0.01 (0.75)	0.18±0.04 (0.38)	<0.01±<0.01 (0.06)
Trumpeter Swan	---	---	<0.01±<0.01 (0.04)	---
Wood Duck	1.48±0.20 (1.00)	0.04±0.01 (0.69)	1.30±0.14 (0.92)	0.09±0.02 (0.79)
Gadwall	---	---	0.08±0.07 (0.10)	<0.01±<0.01 (0.06)
American Wigeon	---	<0.01±<0.01 (0.03)	0.02±0.01 (0.08)	0.01±0.01 (0.03)
American Black Duck	<0.01±<0.01 (0.06)	<0.01±<0.01 (0.22)	0.01±0.01 (0.08)	0.01±<0.01 (0.39)
Mallard	0.64±0.14 (0.92)	0.94±0.15 (1.00)	2.01±0.69 (0.74)	3.51±0.83 (1.00)
Blue-winged Teal	0.04±0.02 (0.28)	0.03±0.01 (0.33)	0.18±0.05 (0.36)	2.15±0.89 (0.76)
Northern Shoveler	<0.01±<0.01 (0.03)	<0.01±<0.01 (0.03)	0.02±0.01 (0.08)	---
Northern Pintail	---	<0.01±<0.01 (0.06)	---	<0.01±<0.01 (0.03)
Green-winged Teal	0.28±0.14 (0.28)	0.05±0.04 (0.19)	0.94±0.31 (0.42)	1.21±0.72 (0.76)
Canvasback	---	<0.01±<0.01 (0.03)	---	---
Redhead	---	<0.01±<0.01 (0.06)	---	<0.01±<0.01 (0.03)
Ring-necked Duck	---	---	0.01±<0.01 (0.12)	---
Scaup (species unknown)	<0.01±<0.01 (0.03)	---	---	<0.01±<0.01 (0.03)
Bufflehead	---	<0.01±<0.01 (0.03)	<0.01±<0.01 (0.02)	---
Hooded Merganser	---	---	0.03±0.01 (0.16)	0.01±<0.01 (0.24)
Ruddy Duck	---	---	<0.01±<0.01 (0.02)	---
Pied-billed Grebe	0.02±0.01 (0.19)	0.03±0.01 (0.75)	0.32±0.04 (0.80)	0.04±0.02 (0.45)

Table A-4. Cont'd.

Species	St. Clair Flats Diked (n=36)	St. Clair Flats Open (n=36)	Saginaw Bay Diked (n=50)	Saginaw Bay Open (n=33)
Wetland-dependent Species				
Double-crested Cormorant	0.01±<0.01 (0.08)	<0.01±<0.01 (0.08)	0.06±0.01 (0.36)	0.03±0.02 (0.24)
American Bittern	0.01±<0.01 (0.39)	0.01±<0.01 (0.39)	0.03±0.02 (0.16)	0.01±<0.01 (0.51)
Least Bittern	0.03±0.01 (0.33)	<0.01±<0.01 (0.06)	0.02±0.01 (0.16)	<0.01±<0.01 (0.03)
Great Blue Heron	0.26±0.02 (1.00)	0.03±<0.01 (0.92)	0.32±0.04 (0.88)	0.06±0.01 (0.97)
Great Egret	0.09±0.02 (0.44)	0.01±<0.01 (0.33)	0.93±0.26 (0.58)	0.54±0.14 (0.88)
Green Heron	0.01±<0.01 (0.17)	---	0.16±0.05 (0.36)	<0.01±<0.01 (0.03)
Black-crowned Night-Heron	0.06±0.02 (0.58)	<0.01±<0.01 (0.08)	0.13±0.06 (0.28)	<0.01±<0.01 (0.06)
Northern Harrier	0.01±<0.01 (0.22)	<0.01±<0.01 (0.22)	0.01±<0.01 (0.16)	0.01±<0.01 (0.42)
Virginia Rail	0.01±<0.01 (0.11)	---	0.01±<0.01 (0.06)	<0.01±<0.01 (0.09)
Sora	0.01±0.01 (0.17)	<0.01±<0.01 (0.06)	0.01±<0.01 (0.08)	<0.01±<0.01 (0.09)
Common Moorhen	0.06±0.02 (0.44)	0.02±<0.01 (0.36)	0.09±0.03 (0.26)	---
American Coot	0.01±<0.01 (0.14)	0.06±0.02 (0.64)	0.04±0.02 (0.18)	<0.01±<0.01 (0.09)
Sandhill Crane	<0.01±<0.01 (0.06)	<0.01±<0.01 (0.03)	0.01±0.01 (0.02)	<0.01±<0.01 (0.03)
Semipalmated Plover	0.01±0.01 (0.17)	---	0.04±0.02 (0.16)	<0.01±<0.01 (0.03)
Spotted Sandpiper	0.02±0.01 (0.42)	<0.01±<0.01 (0.03)	0.10±0.03 (0.44)	0.01±<0.01 (0.27)
Solitary Sandpiper	0.02±0.01 (0.25)	---	0.07±0.03 (0.22)	<0.01±<0.01 (0.12)
Greater Yellowlegs	0.02±0.01 (0.25)	0.01±<0.01 (0.39)	0.26±0.09 (0.32)	0.11±0.03 (0.70)
Lesser Yellowlegs	0.03±0.01 (0.25)	0.01±<0.01 (0.28)	0.20±0.06 (0.26)	0.26±0.08 (0.67)
Semipalmated Sandpiper	0.02±0.01 (0.11)	---	0.04±0.02 (0.12)	0.01±<0.01 (0.15)
Least Sandpiper	0.06±0.03 (0.31)	<0.01±<0.01 (0.08)	0.14±0.06 (0.20)	0.04±0.01 (0.30)
Baird's Sandpiper	---	---	---	<0.01±<0.01 (0.06)
Pectoral Sandpiper	<0.01±<0.01 (0.11)	---	0.01±<0.01 (0.06)	<0.01±<0.01 (0.12)
Dunlin	---	---	<0.01±<0.01 (0.02)	---

Table A-4. Cont'd.

Species	St. Clair Flats		Saginaw Bay	
	Diked (n=36)	Open (n=36)	Diked (n=50)	Open (n=33)
Wetland-dependent Species				
Stilt Sandpiper	---	---	0.02±0.01 (0.06)	<0.01±<0.01 (0.06)
Short-billed Dowitcher	---	---	0.02±0.01 (0.08)	<0.01±<0.01 (0.09)
Wilson's Snipe	0.12±0.03 (0.58)	<0.01±<0.01 (0.03)	0.22±0.08 (0.44)	0.02±0.01 (0.45)
American Woodcock	---	---	<0.01±<0.01 (0.02)	---
Red-necked Phalarope	---	---	0.01±<0.01 (0.06)	---
Bonaparte's Gull	---	---	---	<0.01±<0.01 (0.06)
Ring-billed Gull	<0.01±<0.01 (0.06)	0.03±0.01 (0.61)	0.08±0.02 (0.36)	0.29±0.09 (0.85)
Herring Gull	---	<0.01±<0.01 (0.11)	<0.01±<0.01 (0.04)	0.04±0.01 (0.64)
Black Tern	0.09±0.06 (0.14)	0.03±0.01 (0.31)	0.03±0.01 (0.24)	<0.01±<0.01 (0.03)
Forster's Tern	<0.01±<0.01 (0.03)	0.01±<0.01 (0.19)	<0.01±<0.01 (0.02)	0.04±0.01 (0.42)
Belted Kingfisher	<0.01±<0.01 (0.06)	<0.01±<0.01 (0.03)	0.04±0.01 (0.46)	<0.01±<0.01 (0.27)
Wetland-associated Species				
Bald Eagle	---	---	<0.01±<0.01 (0.06)	<0.01±<0.01 (0.12)
Merlin	---	---	<0.01±<0.01 (0.04)	---
Black-bellied Plover	---	---	---	<0.01±<0.01 (0.06)
Killdeer	0.07±0.02 (0.47)	<0.01±<0.01 (0.08)	0.17±0.05 (0.32)	0.17±0.06 (0.61)
Caspian Tern	0.02±0.01 (0.42)	0.02±<0.01 (0.61)	0.08±0.03 (0.40)	0.04±0.01 (0.76)
Common Tern	---	<0.01±<0.01 (0.03)	---	<0.01±<0.01 (0.09)