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BIRD USE OF DIKED AND UNDIKED COASTAL WETLANDS
IN MICHIGAN

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BIRD USE OF DIKED AND UNDIKED COASTAL WETLANDS IN MICHIGAN

By

Michael Joseph Monfils

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ABSTRACT

BIRD USE OF DIKED AND UNDIKED COASTAL WETLANDS IN MICHIGAN

By

Michael Joseph Monfils

Some Great Lakes coastal wetlands were diked to permit water level manipulations and management for waterfowl and other wetland wildlife during periods of low lake levels. Diking of coastal wetlands can alter biogeochemical cycling, flood storage, sediment movements, plant diversity, and fish and wildlife habitat. I evaluated breeding and migrant bird use during 2005-2007 at 10 diked and nine undiked sites within two coastal wetland complexes in Michigan: Saginaw Bay of Lake Huron and St. Clair River delta on Lake St. Clair. My goal was to test the hypothesis that diked coastal wetlands support greater densities and diversities of wetland birds compared to undiked sites. Breeding bird surveys consisted of 10-min point counts at random locations in emergent marsh and 30-min timed-area surveys of randomly selected areas of open water/aquatic bed wetland. Aerial surveys were done using fixed-wing aircraft or helicopter during early fall, spring, and late summer to compare migrant waterfowl use of diked and undiked wetlands. Fall ground surveys were conducted to compare migrant waterfowl, shorebird, and waterbird use of diked and undiked sites. I measured vegetation and physical characteristics during the breeding season in emergent marsh near point count stations, and along open water-emergent marsh interfaces surveyed during migrant bird ground surveys.

Vegetation and physical variable sampling revealed that diked sites were dominated by cattail, had greater water depths and percent cover of open water and floating plants, and more organic soils compared to undiked wetlands, while undiked sites had shallower water depths, greater percent cover and density of common reed and bulrush, and more inorganic soils than diked wetlands. Bird use was largely similar between the wetland types during breeding and migration periods. Bird species richness was comparable between diked and undiked sites and similarity indices indicated high similarity in bird communities during the breeding season and early fall migration. Wood Ducks were observed in greater densities in diked and Forster's Tern and Ring-billed Gull in undiked wetlands during breeding and migration surveys. Breeding surveys indicated that diked wetlands benefited Canada Goose, American and Least Bitterns, and Common Moorhen, while Mallard, American Coot, and Herring Gull appeared more abundant at undiked sites. Although shorebird use was similar between wetland types, linear densities (birds/km edge) of Mallards and dabbling ducks were greater in undiked than diked wetlands during early fall. Water level manipulations, such as reduced water depths and periodic complete drawdowns, could increase use of diked wetlands by breeding wetland birds and migrant dabbling ducks and shorebirds. Given an uncertain future for Great Lakes coastal wetlands due to climate change and invasive species, diked wetlands may provide opportunities to maintain and improve habitat for priority wetland birds. Experimental studies are needed to identify water level management strategies that increase use by priority bird species and maximize overall wetland functioning.

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PREFACE

This dissertation is divided into four chapters. Chapter 1 provides an introduction to the issue of Great Lakes coastal wetland diking, including potential impacts to wetland functioning and benefits of wetland management, and detailed descriptions of the study areas. Chapter 1 also includes a description of the overall study design, summary of water level fluctuation and water chemistry data, and discussion of possible effects of diking on coastal wetlands. Readers interested in the primary results of my research are referred to Chapters 2 and 3, which were written as independent chapters to facilitate publication. I evaluate breeding bird use of diked and undiked coastal wetlands in Chapter 2, while in Chapter 3, I compare migrant bird use of diked and undiked wetlands. In Chapter 4, I provide a brief summary of the implications of my research with regard to the management of diked wetlands for birds, including differences in bird use of diked and undiked wetlands, management recommendations, and research needs.

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CHAPTER 1

INTRODUCTION AND STUDY AREA DESCRIPTIONS

INTRODUCTION

Great Lakes coastal wetlands provide vital breeding, migration, and wintering habitat for an array of birds. Approximately three million swans, geese, and ducks travel along migration corridors that cross the Great Lakes region (Great Lakes Basin Commission 1975, 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. Eighty bird species used coastal wetlands of Lake Huron as breeding habitat (Prince and Flegel 1995).

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, Weller and Fredrickson 1974, Kaminski and Prince 1981a, b, Murkin et al. 1982) or shallow-water marshes dominated by moist-soil vegetation to attract migrant birds (Fredrickson and Taylor 1982). Hemi-marshes are marshes with approximately equal proportions of emergent vegetation and open water produced by natural water level fluctuations and mammal herbivory. 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 during periods of high water levels (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) documented increased amounts of invasive species in standing vegetation and seed banks of diked compared to undiked wetlands in Saginaw Bay, Michigan and Green Bay, Wisconsin, 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 greater 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 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, meaning seeds are held in place by dikes due to reduced water exchange with the lakes. In comparisons between vegetation in diked and undiked Lake Erie coastal wetlands during a high water year, Thiet (2002) found greater 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 diking on animal communities. McLaughlin and Harris (1990) compared aquatic insect emergence in one diked and one undiked wetland on Green Bay, Wisconsin and recorded more insect taxa and greater total insect biomass emergence from 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 increased sediment organic matter from outer to inner marsh and between littoral and adjacent inland marshes. Some invertebrates were more common on gradient ends, 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 inland from Lake Huron. Although species richness was similar between coastal and inland cattail marshes, bird densities in marshes located far offshore were lower than most 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 greater 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.

Ecological studies of the effects of coastal wetland isolation from natural, highly variable water level fluctuations 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 wetlands in Michigan to gain insights into the effects of wetland diking on avian communities. I tested the hypothesis that coastal impoundments with managed water levels provide enhanced habitat for wetland birds compared to undiked wetlands. I view this research as one of many comparisons needed over the long-term to better understand how diked and undiked wetlands function during the full cycle of Great Lakes water levels.

STUDY DESIGN

My objectives for this project were to 1) compare indices of bird abundance and diversity between diked and undiked coastal wetlands, 2) gather information on the vegetation structure and composition of diked and undiked wetlands and investigate potential relationships with bird abundance and diversity, and 3) characterize the physical and chemical environment of diked and undiked wetlands. Indices of bird use, vegetation, and physical and chemical attributes were compared between diked and undiked wetlands to investigate the potential effects of diking on Great Lakes coastal wetlands and test the hypothesis that impounded coastal wetlands provide improved habitat for wetland birds compared to undiked wetlands. A study of invertebrate abundance and composition was undertaken by another investigator through detailed comparisons of diked and undiked wetlands at the St. Clair Flats (see Provence 2008).

I focused my research in two of Michigan's most important coastal wetland complexes, the St. Clair River delta, also known as the St. Clair Flats (SCF), and Saginaw Bay (SAG). The St. Clair Flats is a 17,500 ha wetland complex in the U.S. and Canada where the St. Clair River flows into Lake St. Clair. About one-third of the St. Clair Flats is diked and approximately one-third is in U.S. territory (Bookhout et al. 1989). 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). The St. Clair Flats and Saginaw Bay are two of the four major coastal wetland complexes identified by Krieger et al. (1992) in their call for more research in Great Lakes coastal wetlands. I selected these wetland complexes for several reasons: 1) they are two of Michigan's largest and most intact wetland complexes, 2) rare and declining waterbird species of management importance use these complexes for breeding, 3) their importance as migratory stop-overs for waterfowl, waterbirds, and shorebirds, and 4) the presence of both managed diked wetlands and unmanaged undiked wetlands.

I classified diked wetland sites 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, so water was only pumped into the diked wetlands when conditions allowed. Passive water level management occurred at sites with dikes and water control structures, but without water pumping capabilities. Water levels in these wetlands were independent of Great Lakes levels; however, pumping was not an option and water inputs came from precipitation or through control structures. I selected sites to ensure that diked wetlands were sampled in all three water level management categories; however, I was not able to make comparisons among the three management regimes due to the low number of sites within each category.

Several bird surveys were used to produce indices of bird abundance, species richness, and diversity. Indices, rather than total population estimates, were used, because total population estimates are expected to vary based on size of the study sites and are less important than relative differences in use by species of management importance. I assumed densities (birds/ha of wetland or birds/km of edge) and other indices would vary based on species' food preferences and differences in vegetation and physical aspects of the study sites, so differences in bird communities between diked and undiked wetlands should have been evident in the indices if they existed. Both breeding and migrant bird surveys were conducted at 19 study sites (Table 1). I measured vegetation composition and structure at sites where bird surveys were conducted to evaluate possible relationships between habitat conditions and bird use. Provence (2008) sampled the invertebrate community at diked and open wetlands of the St. Clair Flats. Staff gages were installed and monitored at several diked wetlands to compare their water level fluctuations with undiked wetlands, since water level changes can affect use by breeding and migrant birds. I used data from National Oceanic and Atmospheric Administration (NOAA) water level stations on Lake St. Clair/St. Clair River and Saginaw Bay to characterize water level fluctuations at the undiked sites. Basic water chemistry parameters and nutrient levels were collected in 2007 to describe conditions at the study sites, since other researchers observed differences in water and soil chemistry of diked compared to undiked coastal wetlands (Robb 1989, Herrick and Wolf 2005).

Table 1. Study sites surveyed and research activities conducted at St. Clair Flats and Saginaw Bay, Michigan during 2005-2007. An "X" indicates that a specific research activity was conducted at the site[1]. Approximate areas and water management capability[2] 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	WBU	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	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
2006	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
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	WBU	WIL
Vegetation 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]Study site abbreviations: EMA=East Marsh; WMA=West Marsh; DIS=Dickinson Island/Fisher and Goose Bays; LMU=Little and Big Muscamoot Bays; FPA=Fish Pt. Austin Rd.; FPR=Fish Pt. Refuge; NPE=Nayanquing Pt. East Marsh; NPN=Nayanquing Pt. North Marsh; NPS=Nayanquing Pt. South Refuge Unit; NPT=Nayanquing Pt. Triangle Unit; TOB=Tobico Marsh; WBD=Wigwam Bay Diked Unit; FPB=Fish Pt. Berger Rd.; FPC=Fish Pt. Coastal; PIN=Pinconning; QUA=Quanicassee; WBU=Wigwam Bay Undiked; and WIL=Wildfowl Bay. See text for further description.

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

STUDY AREA DESCRIPTIONS

St. Clair Flats

I investigated four sites (two diked and two undiked) at St. Clair Flats. Both diked wetlands occur on Harsens Island, while undiked wetland sites were 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 within the St. Clair Flats State Wildlife Area.

Harsens Island: I studied two diked wetlands at St. Clair Flats: West Marsh (WMA) and East Marsh (EMA) (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 over with emergent vegetation, most remain today. These impounded wetlands had similar vegetation communities and 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.).

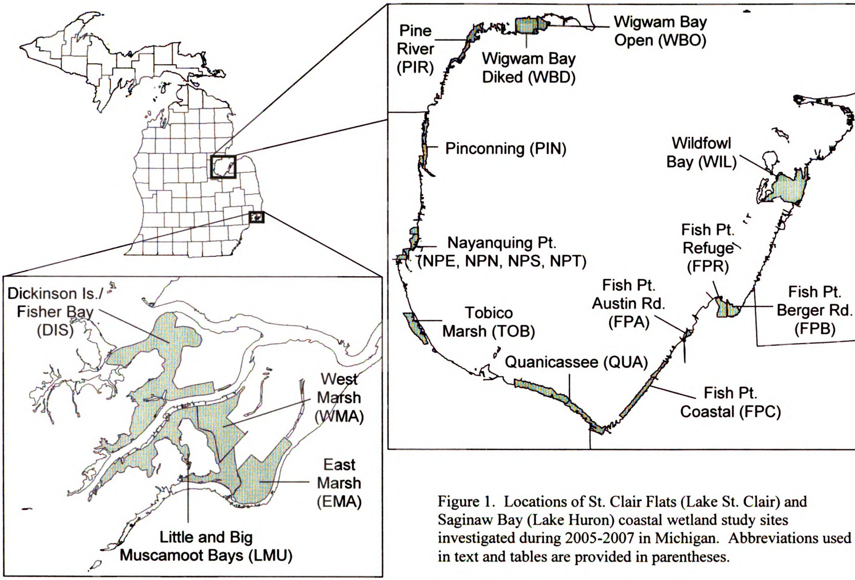


Figure 1. Locations of St. Clair Flats (Lake St. Clair) and Saginaw Bay (Lake Huron) coastal wetland study sites investigated during 2005-2007 in Michigan. Abbreviations used in text and tables are provided in parentheses.

Dickinson Island/Fisher and Goose Bays (DIS): Dickinson Island is located northwest of Harsens Island and was dominated by emergent wetlands. Marshes were also found to the immediate west and southwest along the margins of Fisher and Goose Bays. Emergent marshes 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, stoneworts, and aquatic macrophytes were present in aquatic bed zones of protected sites. *Chara* spp. typically dominated the aquatic bed vegetation.

Little and Big Muscamoot Bays (LMU): Little and Big Muscamoot Bays are found 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 studied on Saginaw Bay, of which eight were diked and seven were undiked and open to Lake Huron water level fluctuations (Figure 1).

Fish Point: I studied both diked and undiked wetlands at Fish Point State Wildlife Area, which is in Tuscola County. I 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. Waterfowl 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 only occurred in 2006 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 was similar to FPR and consisted of aquatic bed wetland, cattail marsh, and wet meadow dominated by sedges, rushes, and spikerushes (*Eleocharis* spp.). Two areas of undiked wetland were surveyed: one 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. I only conducted point counts at the FPB site in 2005 and the FPC site was only used for 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 inside of a natural beach ridge with a small dike and 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. I only conducted point counts at NPE and NPN, because of the limited amount of emergent marsh at NPS and small size of NPT. I conducted timed-area and fall ground surveys at all sites except NPE, which had limited open water/aquatic bed habitat.

Pinconning (PIN): I surveyed undiked coastal wetland associated with the mouth of the Pinconning River (Bay County) 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 occurred 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. I only visited this site during aerial waterfowl surveys.

Wigwam Bay: I surveyed two undiked and one diked wetland sites 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 on 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 sedge 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 (WBU) located east of WBD in 2005. This area is dominated by wet meadow vegetation with fringing zones of bulrush and cattail.

Wildfowl Bay (WIL): I investigated protected undiked wetlands in the Wildfowl Bay State Wildlife Area in Huron County. These wetlands 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

Water Level Fluctuations

I monitored staff gages at a subset of diked coastal wetlands to characterize the fluctuation of water levels during spring and summer 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. I monitored gages at least monthly at two St. Clair Flats sites (EMA, WMA) and five Saginaw Bay sites (NPE, NPN, NPS, FPR, WBD) from early May through early September in 2006 and 2007. I used hourly NOAA water level monitoring station data to characterize fluctuations at the open wetland sites. Data from two stations, Algonac, Michigan and St. Clair Shores, Michigan, were used to represent water levels in undiked wetlands at St. Clair Flats. The Essexville, Michigan station located at the confluence of the Saginaw River and Saginaw Bay was used to evaluate fluctuations at Saginaw Bay undiked sites. I averaged water level data from NOAA stations by year and week to allow comparisons with diked sites.

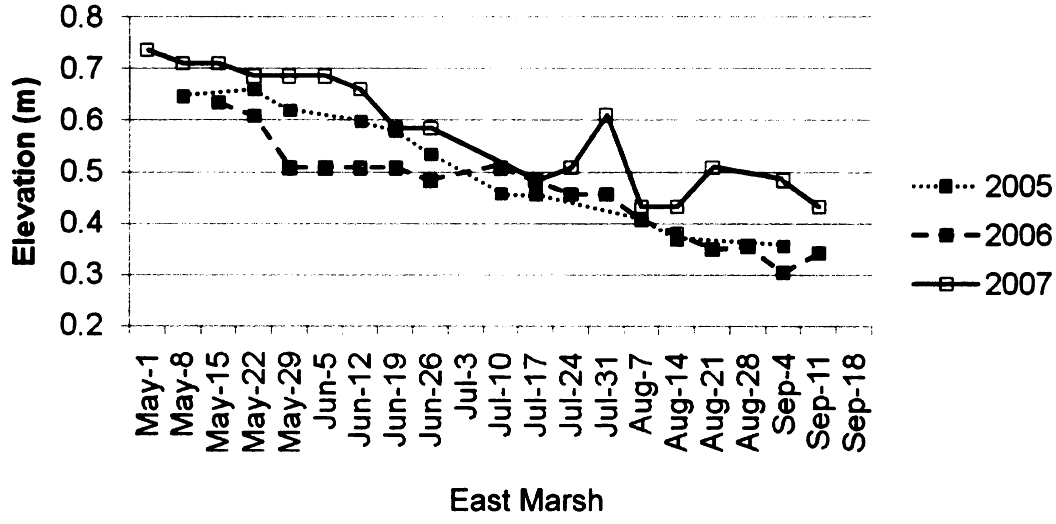
Water Chemistry

While conducting bird surveys in 2007, I gathered data on the following water parameters: temperature, dissolved oxygen (DO), pH, turbidity, alkalinity, and nutrient levels (nitrate-N, ammonium-N, and soluble reactive phosphorus [SRP]). I only intended to use the water chemistry data to characterize the study sites. Data collection varied by time of day and season and was not intensive enough to permit statistical comparisons between the wetland types. I 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. I summarized data for these parameters by study area, wetland type, site, and time period (early [May – mid July] and late [mid July – late September] season). In late August and September, I 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). I gathered three water samples from each of three vegetation zones (common reed, cattail, and bulrush), when present, at the vegetation-open water interface using sterilized bottles or plastic bags. Water samples were immediately placed on ice in the field. I filtered samples using 0.5 micron membrane and then froze them for later analysis. Dr. Donald Uzarski (Central Michigan University) conducted analyses for nitrate-N, ammonium-N, and SRP using procedures recommended in the *Standard Methods for the Examination of Water and Wastewater* (American Public Health Association 1992). Quality assurance/quality control procedures followed protocols recommended by the U.S. Environmental Protection Agency.

RESULTS

Water Level Fluctuations

Staff gage monitoring at diked St. Clair Flats sites indicated highest water levels in spring and declining levels throughout much of 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 precipitation and/or pumping to increase water levels for fall waterfowl hunting. Results from the Algonac and St. Clair Shores gaging stations were consistent with those of the SCF diked wetlands in 2005 and 2007 (Figure 3). Similar to the diked wetlands, water elevations during the monitoring period were highest in spring, declined throughout the spring and summer, and were lowest in September. The overall drop in water levels in the undiked gages in 2005 and 2007 was lower compared to the diked wetlands. Water levels observed in the undiked gages 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 (Figure 4). 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.



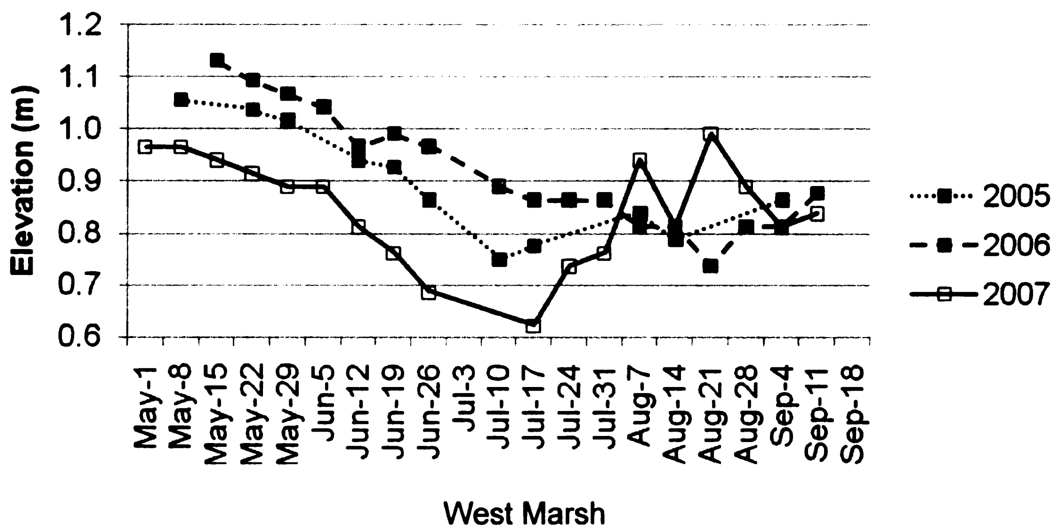


Figure 2. Water level fluctuations by week and year during late spring and summer at the East Marsh and West Marsh diked sites at St. Clair Flats, Michigan 2005-2007. The y-axis references selected heights on staff gages, rather than true water elevation (i.e. meters above sea level) of the study sites.

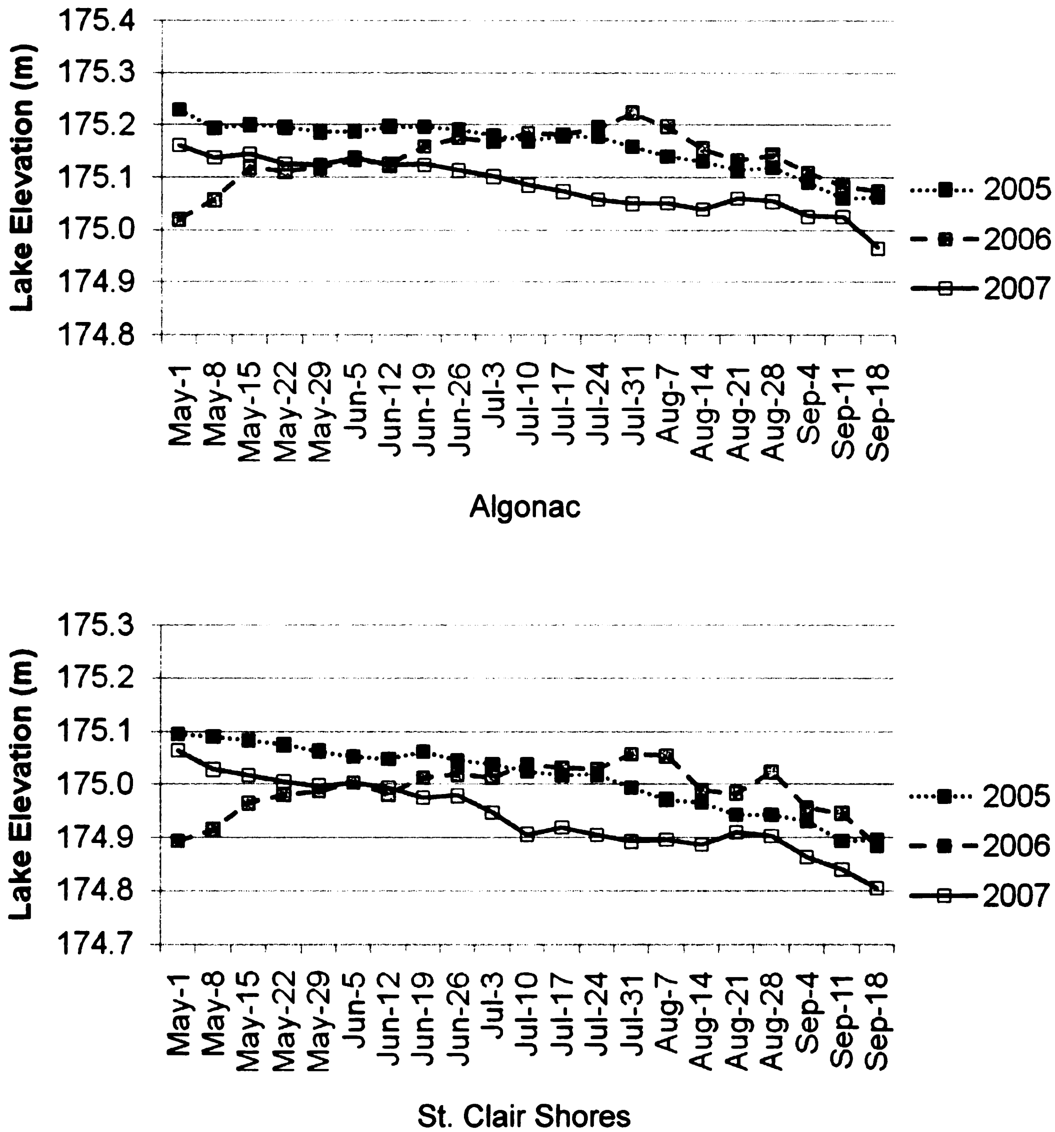
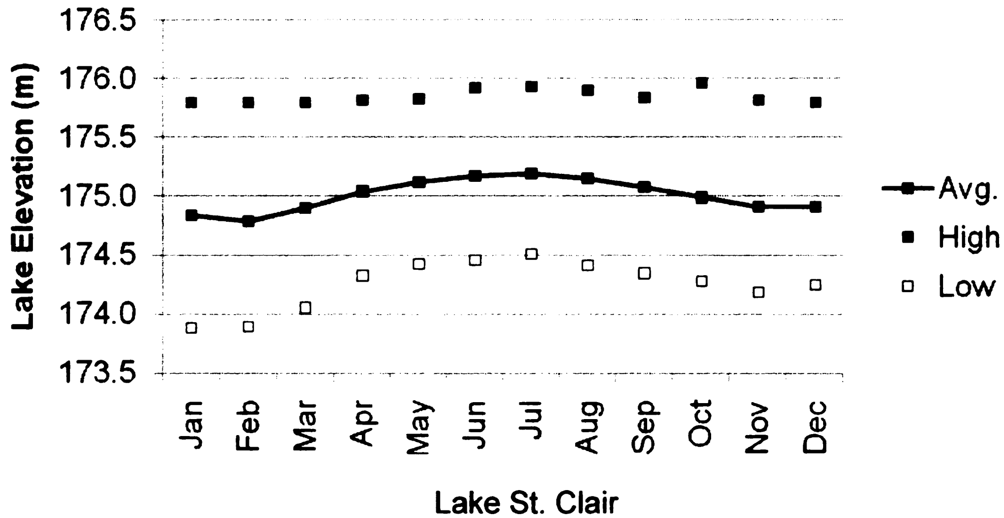


Figure 3. Water level fluctuations by week of year during late spring and summer at undiked Algonac and St. Clair Shores NOAA water gage locations near St. Clair Flats, Michigan 2005-2007. The y-axis represents true water elevations above sea level for the St. Clair River (Algonac gage) and Lake St.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



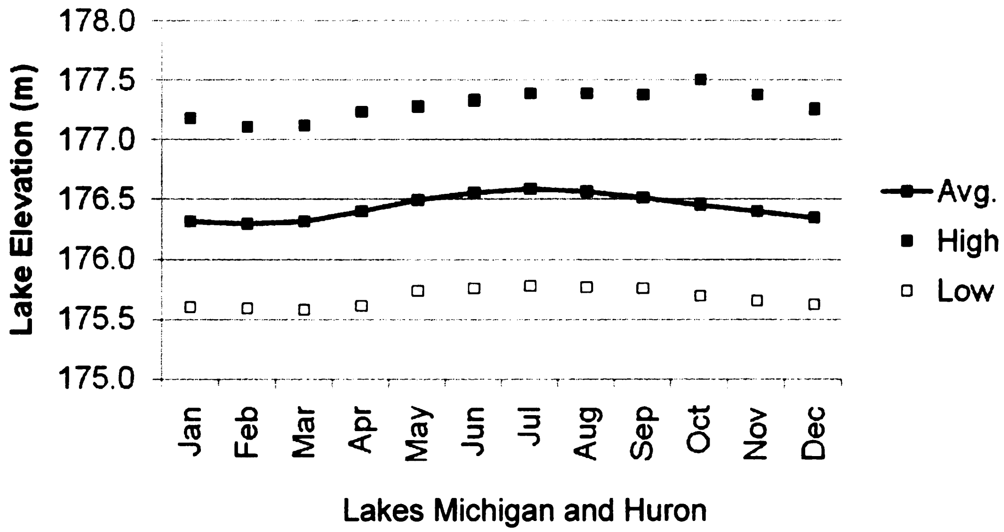
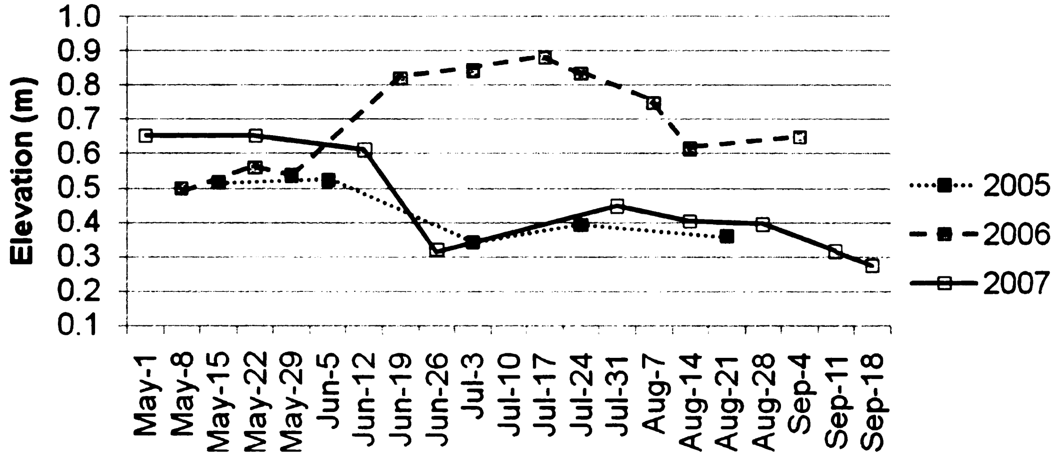


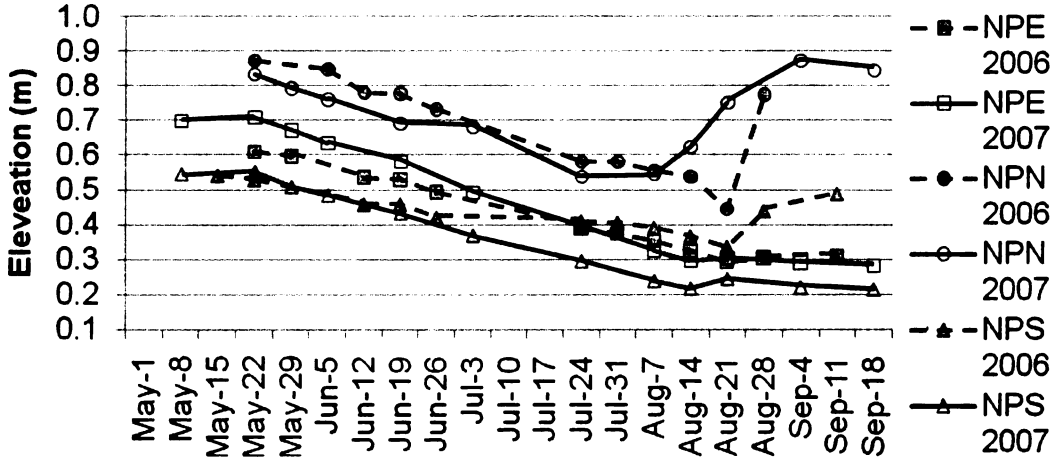
Figure 4. Long-term (1918-2007) average water levels in meters above sea level for Lake St. Clair and Lakes Michigan and Huron by month. Error bars indicate record high and low water levels for each month. Data obtained from the U.S. Army Corps of Engineers website (www.lre.usace.army.mil/greatlakes/hh/greatlakeswaterlevels/historicdata/greatlakeshydrographs/).

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 at NPN and NPS in August and September were due to pumping in preparation for the fall waterfowl hunting seasons. Water 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 generally consistent with long-term averages (Figure 4).

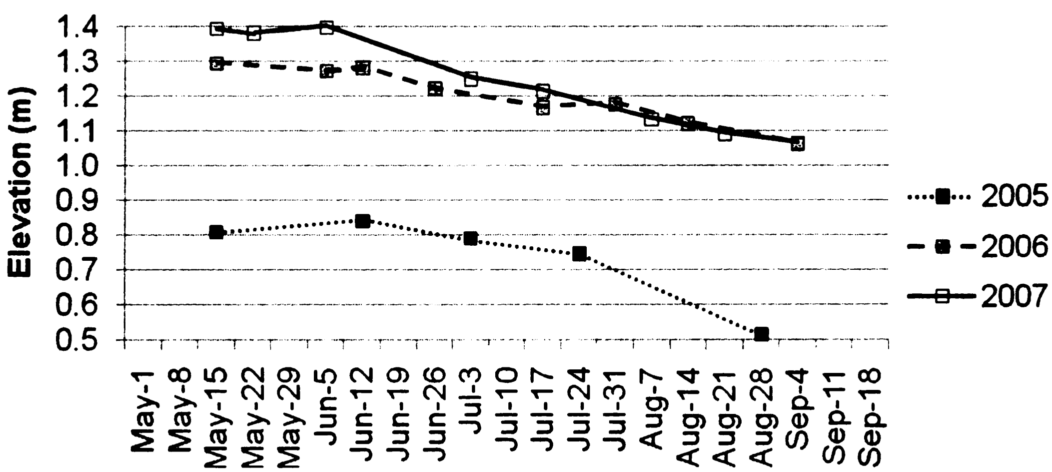
Figure 5. Water level fluctuations by week of year during late spring and summer at diked sites on Saginaw Bay, Michigan 2005-2007: Fish Point Refuge (FPR), Nayanquing Point (NPE, NPN, and NPS), and Wigwam Bay (WBD). The y-axis references selected heights on staff gages, rather than true water elevation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



Fish Point Refuge



Nayanquing Point (East, North, and South Units)



Wigwam Bay

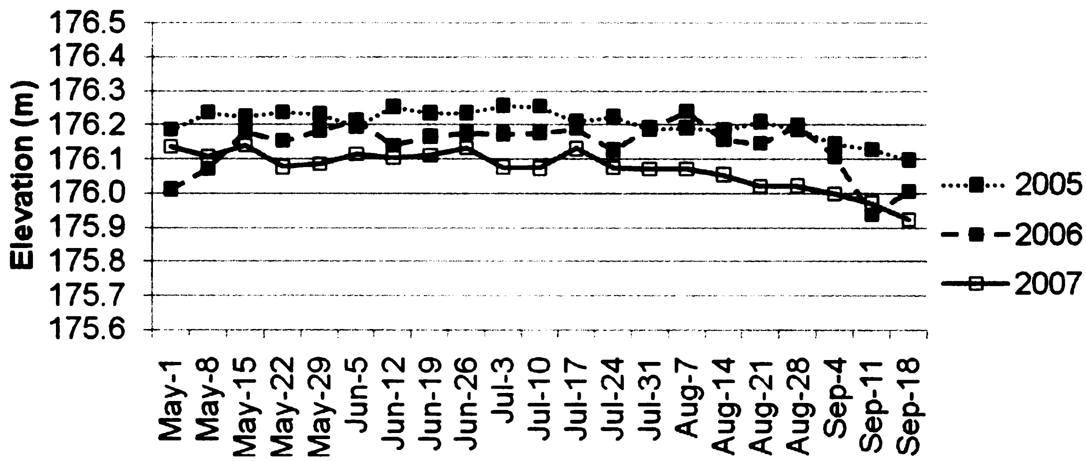


Figure 6. Water level fluctuations by week of year during late spring and summer at open Essexville NOAA water gage on Saginaw Bay, Michigan 2005-2007. The y-axis represents true water elevation in meters above sea level for Saginaw Bay, Lake Huron.

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 2). Mean water temperatures were similar between diked and undiked wetlands. Diked St. Clair Flats sites consistently had greater 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. Within each of the study areas, nitrate-N levels in diked wetlands tended to be lower than undiked wetlands (Table 3). Average ammonium-N levels were slightly greater in undiked than diked sites at the St. Clair Flats, but appeared similar between the wetland types on Saginaw Bay. Mean SRP levels were low and similar among wetland types, study areas, and sites (Table 3).

Table 2. Means ± SE by wetland type, study area, site, and period for water chemistry parameters measured during sampling conducted at St. Clair Flats and Saginaw Bay, Michigan in 2007. Data are partitioned into early (early May – mid Jul) and late (mid July – late September) periods and sample size is in parentheses.

Area, Site[1], and Wetland Type	Period	Dissolved Oxygen (mg/L)	Water Temp (°C)	pH	Alkalinity (mg/L)	Turbidity (ntu)
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)
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)
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)
SCF – Open						
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)
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)
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)
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)
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)
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)
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)

Table 2. Cont'd.

Area, Site, and Wetland Type	Period	Dissolved Oxygen (mg/L)	Water Temp (°C)	pH	Alkalinity (mg/L)	Turbidity (ntu)
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)
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)
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)
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)
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)
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)
Total						
Diked	Early	3.69±0.25 (155)	19.7±0.36 (155)	7.60±0.09 (149)	170±6 (138)	2.7±0.4 (72)
	Late	6.21±0.35 (118)	21.8±0.32 (120)	7.76±0.09 (120)	166±5 (120)	5.1±0.6 (120)
Undiked	Early	6.52±0.34 (131)	19.6±0.39 (133)	7.92±0.08 (128)	152±4 (128)	8.7±1.3 (80)
	Late	9.57±0.27 (92)	23.1±0.36 (92)	8.40±0.04 (91)	138±3 (91)	6.1±0.5 (92)

[1]Study site abbreviations: EMA=East Marsh; WMA=West Marsh; DIS=Dickinson Island/Fisher and Goose Bays; LMU=Little and Big Muscamoot Bays; FPA=Fish Pt. Austin Rd.; FPR=Fish Pt. Refuge; NPE=Nayanquing Pt. East Marsh; NPN=Nayanquing Pt. North Marsh; NPS=Nayanquing Pt. South Refuge Unit; NPT=Nayanquing Pt. Triangle Unit; TOB=Tobico Marsh; WBD=Wigwam Bay Diked Unit; FPB=Fish Pt. Berger Rd.; FPC=Fish Pt. Coastal; PIN=Pinconning; QUA=Quanicassee; WBU=Wigwam Bay Undiked; and WIL=Wildfowl Bay. See text for further description.

Table 3. Means (mg/L) ± SE by wetland type, study area, and site for nitrate-N, ammonium-N, and soluble reactive phosphorous (SRP) in water samples collected at St. Clair Flats and Saginaw Bay, Michigan in late summer 2007. The number of samples for each parameter is listed in parentheses.

Study Area, Site, and Wetland Type	Nitrate-N (mg/L)	Ammonium-N (mg/L)	SRP (mg/L)
SCF – Diked			
EMA	0.013±0.004 (6)	0.033±0.003 (9)	0.001±<0.0001 (8)
WMA	0.012±0.003 (9)	0.026±0.004 (9)	0.003±0.0015 (10)
Overall	0.012±0.002 (15)	0.029±0.002 (18)	0.002±0.0008 (18)
SCF – Undiked			
DIS	0.099±0.034 (9)	0.045±0.007 (9)	0.002±0.0005 (9)
LMU	0.122±0.036 (9)	0.047±0.010 (8)	0.001±<0.0001 (9)
Overall	0.111±0.024 (18)	0.046±0.006 (17)	0.001±0.0003 (18)
SAG – Diked			
FPR	0.062±0.024 (6)	0.011±0.005 (6)	0.003±0.0004 (7)
FPA	0.028±0.008 (9)	0.035±0.003 (9)	0.002±0.0004 (9)
NPE	0.103±0.092 (5)	0.041±0.004 (5)	0.003±0.0012 (4)
NPN	0.021±0.007 (2)	0.042±0.006 (2)	0.002±0.0005 (3)
WBD	0.018±0.004 (9)	0.039±0.005 (8)	0.002±0.0003 (8)
Overall	0.043±0.015 (31)	0.039±0.002 (30)	0.002±0.0002 (31)
SAG – Undiked			
PIR	0.106±0.051 (6)	0.038±0.007 (6)	0.002±0.0005 (6)
QUA	0.127±0.051 (6)	0.043±0.007 (6)	0.002±0.0003 (5)
WIL	0.028±0.006 (8)	0.043±0.004 (9)	0.003±0.0010 (8)
Overall	0.081±0.023 (20)	0.042±0.003 (21)	0.002±0.0004 (19)
Total – Diked	0.033±0.011 (46)	0.035±0.002 (48)	0.002±0.0003 (49)
Total – Undiked	0.095±0.016 (38)	0.044±0.003 (38)	0.002±0.0003 (37)

DISCUSSION

Water levels of the undiked wetlands, as indicated by NOAA monitoring stations, were below long-term mean elevations for both Lake St. Clair and Saginaw Bay during all three years of the study. Below average water depths of the undiked wetlands likely influenced bird use, so comparisons with the diked wetlands must be viewed within the context of a period of low Great Lakes water levels. Investigations such as my study need to be conducted during the full range of water levels to gain a full understanding of the value of diked and undiked wetlands to birds. The water level changes I observed in Lake St. Clair during the breeding seasons of 2005 and 2007 were not consistent with the pattern observed over the long term, with lake levels declining throughout the spring and summer. This pattern is similar to that documented in the diked wetlands. Water level changes recorded in Lake St. Clair during 2006 were similar to long-term averages, with levels increasing in the spring and early summer to a peak in July and then decreasing in late summer and fall. The seasonal changes I observed in the elevation of Saginaw Bay wetlands were similar to those observed over the long-term. Isolation from the adjacent lakes altered the hydroperiod of diked wetlands when compared to undiked wetlands. Highest water levels in diked wetlands occurred in the spring, while peak water levels in undiked systems are usually in mid to late summer. Water level changes in diked wetlands were also more pronounced than the gradual changes that occurred in undiked systems. For example, even when both wetland types exhibited drawdowns, water levels tended to drop faster and at a greater depth in the diked wetlands. Conversely, water levels often increased substantially (e.g., ~0.25-0.40 m) in diked wetlands over a short time (e.g., ~2-4 weeks) when pumping occurred.

Both long- and short-term (i.e., seiche) Great Lakes water level fluctuations can influence biogeochemical cycling in coastal marshes (Burton 1985). Although modifications to the hydrology of the diked wetlands undoubtedly altered biogeochemical cycling, more intensive water chemistry sampling than conducted in this study is needed to understand these changes. My results indicated higher levels of nitrate-N in undiked compared to diked wetlands. Higher nitrate-N levels in undiked compared to isolated wetlands would be expected as increased DO levels and sediment exposure of undiked wetlands could increase organic matter decomposition and nitrification (Burton 1985). Runoff from agricultural lands containing excess fertilizer could have contributed to nitrate-N levels in undiked wetlands. Anaerobic conditions created by higher water levels in the diked wetlands probably lead to increased denitrification, thus reducing nitrate-N levels. Ammonium-N appeared to be slightly higher in undiked compared to diked wetlands at St. Clair Flats, but was similar between diked and undiked wetlands on Saginaw Bay. Robb (1989) found no significant difference in nitrate-N and ammonia-N levels in water of diked and undiked wetlands. I found similar levels of SRP in diked and undiked wetlands, while Robb (1989) recorded higher levels of orthophosphate in diked wetlands and higher total phosphate in undiked sites during comparisons of diked and undiked coastal wetlands on Lake Erie. Herrick and Wolf (2005) observed higher total N, available P, and available K in the soils of diked compared to undiked wetlands. My limited testing for nitrate-N and ammonium-N in water samples is not directly comparable to the study by Herrick and Wolf (2005), due to differing methods and timing of sample collection. The nitrate-N levels I observed were lower than averages recorded by Uzarski et al. (2005) in cattail (*Typha* spp.) and aquatic bed zones across a range of Great Lakes coastal wetlands, but similar to values they observed in bulrush (*Schoenoplectus* spp.) marshes. My nitrate values were also lower than those of Robb (1989) in diked and undiked Lake Erie wetlands. I observed ammonium-N levels of about 0.03-0.04 mg/L, which are similar to values recorded by Robb (1989) and slightly lower than the mean observed by Uzarski et al. (2005) in aquatic bed wetlands. The SRP levels I observed were much lower than those reported by others in Great Lakes coastal wetlands (Robb 1989, Uzarski et al. 2005), which may be due to differences in sampling methodologies and timing of collections, or the small sample size used in my study. I found that the diked sites tended to be more acidic and less turbid compared to undiked wetlands, which is consistent with other studies (Robb 1989, Herrick and Wolf 2005). The mean pH readings that I observed in undiked wetlands that were similar to the undiked wetlands sampled by Uzarski et al. (2005), while the average pH values I recorded in diked wetlands tended to be lower. My mean turbidity values tended to be lower than averages reported by Uzarski et al. (2005), regardless of study area or wetland type.

More study is needed to better understand the hydrology, water chemistry, and nutrient cycling of diked compared to undiked wetlands. Intensive water chemistry testing across the range of diked and undiked coastal wetlands and through a normal range of water level fluctuations is needed to learn how hydrological isolation affects wetland functioning. Wide variation in the functioning of diked wetlands is likely, due to differing hydrology of the sites. For example, diked wetlands with only passive (i.e., no pumps) or opportunistic (i.e., can only pump with higher Great Lakes levels) tend to have shallower water depths and more pronounced summer drawdowns compared to sites with active water pumping regimes. A better understanding of the biogeochemical cycling of diked wetlands may permit the development of water level management guidelines that optimize wetland functioning, while maintaining the capability to manage for wildlife.

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CHAPTER 2

BREEDING BIRD USE OF DIKED AND UNDIKED COASTAL WETLANDS IN MICHIGAN

INTRODUCTION

Great Lakes coastal wetlands provide vital breeding, migration, and wintering habitat for an array of birds. 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. Eighty bird species used coastal wetlands of Lake Huron as breeding habitat (Prince and Flegel 1995).

Impoundments control structures have long been used by wildlife managers to enhance wetlands for wildlife (Kadlec 1962), especially breeding and migrating waterfowl. When the goal is to maximize breeding bird use, wildlife biologists often manage for hemi-marshes. Hemi-marshes are marshes with approximately equal proportions of emergent vegetation and open water produced by natural water level fluctuations and mammal herbivory. Several authors have found that hemi-marshes typically attract greater densities and diversities of wetland birds compared to marshes with more or less emergent vegetation (Weller and Spatcher 1965, Weller and

Fredrickson 1974, Kaminski and Prince 1981a, b, Murkin et al. 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) documented increased amounts of invasive species in standing vegetation and seed banks of diked compared to undiked wetlands in Saginaw Bay, Michigan and Green Bay, Wisconsin, 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 greater 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 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 between vegetation in diked and undiked Lake Erie coastal wetlands during a high water year, Thiet (2002) found greater 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 diking on animal communities. McLaughlin and Harris (1990) compared aquatic insect emergence in one diked and one undiked wetland on Green Bay, and recorded more insect taxa and greater total insect biomass emergence from the diked wetland. Burton et al. (2002) noted that both plant-community composition and exposure to wave action were important determinants of invertebrate diversity and biomass in Great Lakes marshes. Invertebrates were distributed along gradients of decreased mixing of pelagic water and increased 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 inland from Lake Huron. Although species richness was similar between coastal and inland cattail marshes, bird densities in marshes located far offshore were lower than most 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 greater abundance and species richness for several groups of birds in diked wetlands, but indicated that long-term research is needed to account for long-term variation in bird and vegetation communities associated with Great Lakes water level cycles and management activities.

Ecological studies of the effects of coastal wetland isolation from natural, highly variable water level fluctuations 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 breeding bird use, vegetation composition and structure, and physical and chemical attributes of several diked and undiked wetlands in Michigan to gain insights into the effects of wetland diking on avian communities. I tested the hypothesis that coastal impoundments with managed water levels provide enhanced conditions for breeding wetland birds compared to undiked wetlands. This research is one of many comparisons needed over the long-term to better understand how diked and undiked wetlands function during the full cycle of Great Lakes water levels.

METHODS

To assess bird communities of diked and undiked coastal wetlands, I compared several indices of breeding bird use at sites in two study areas: St. Clair Flats, Lake St. Clair and Saginaw Bay, Lake Huron (Figure 1 – detailed descriptions found in Chapter 1). These study areas are two of Michigan's largest remaining coastal wetland complexes (Bookhout et al. 1989, Krieger et al. 1992). Sixteen study sites were sampled during breeding bird surveys 2005-2007: four sites at St. Clair Flats (two diked, two open), and 12 sites at Saginaw Bay (six diked, five undiked). Undiked study sites at St. Clair Flats were located at two general areas: 1) Dickinson Island and nearby marshes on Fisher and Goose Bays, and 2) Little and Big Muscamoot Bays. All of the St. Clair Flats study sites were located in St. Clair Flats State Wildlife Area (SWA). I examined the following diked wetlands on Saginaw Bay: two sites at Fish Point SWA (East Refuge Unit [FPR], Austin Road [FPA]), four sites at Nayanquing Point SWA (East Marsh [NPE], North Marsh [NPN], South Refuge Unit [NPS], and Triangle Unit [NPT]), and one site at Wigwam Bay SWA (WIG). Undiked sites on Saginaw Bay were located at Wildfowl Bay SWA (WIL), Fish Point SWA near Berger Road (FPB), Quanicassee SWA west of the mouth of the Quanicassee River (QUA), Wigwam Bay SWA (PIR) north and south of the Pine River, and at Wigwam Bay SWA (WBO) in wetlands east of the diked unit.

Two survey techniques were used to investigate breeding bird use of coastal wetlands: 1) point counts to assess bird use of emergent vegetation and 2) timed-area surveys to evaluate bird use of the open water/aquatic bed zone. Randomly selected points were surveyed three times at 13 sites (six diked, seven undiked) within the two study areas (Figure 7). Open water areas were randomly selected for timed-area surveys during four periods from 14 sites (nine diked, five undiked) at the two study areas (Figure 8).

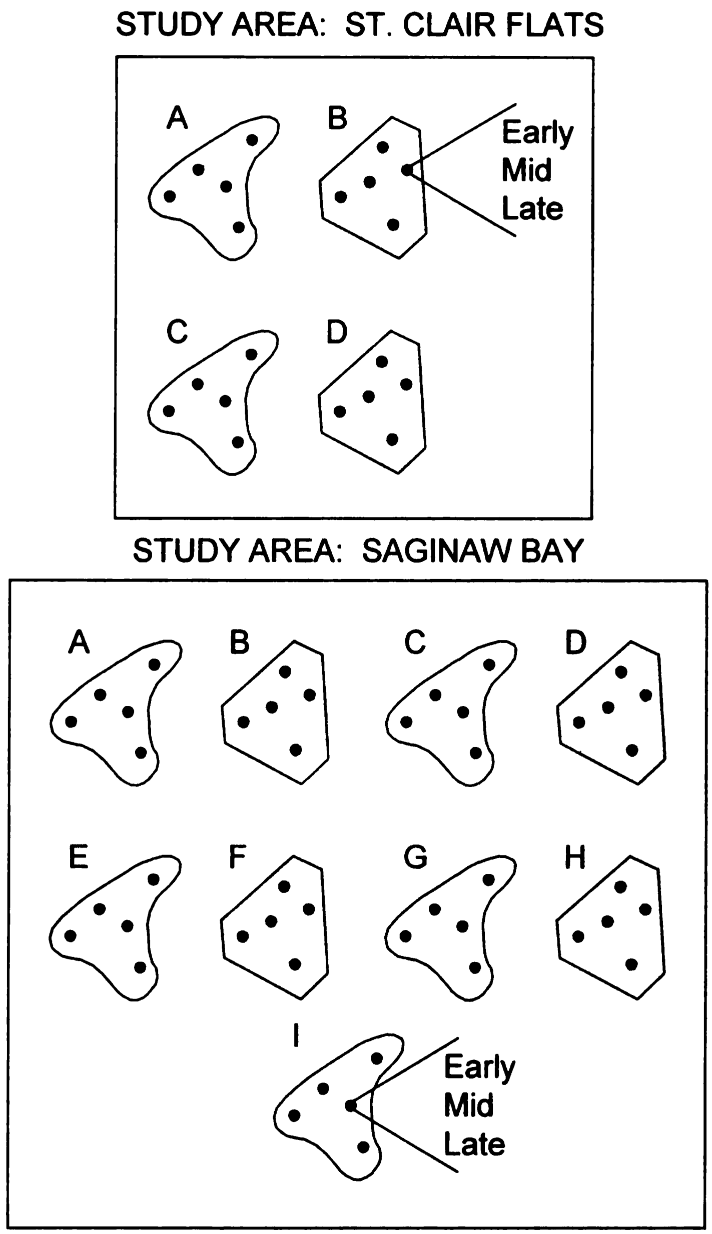

Figure 7. Illustration of study design used for breeding bird point counts conducted in Great Lakes coastal wetlands in Michigan (St. Clair Flats and Saginaw Bay), 2005-2007. Independent study sites (lettered polygons) were sampled within each study area, with approximately half of the points occurring in each of two wetland types (diked – shaded, undiked – not shaded). Points (black dots) were situated randomly within each study site, and three surveys (early, mid, and late season) were conducted at each point.

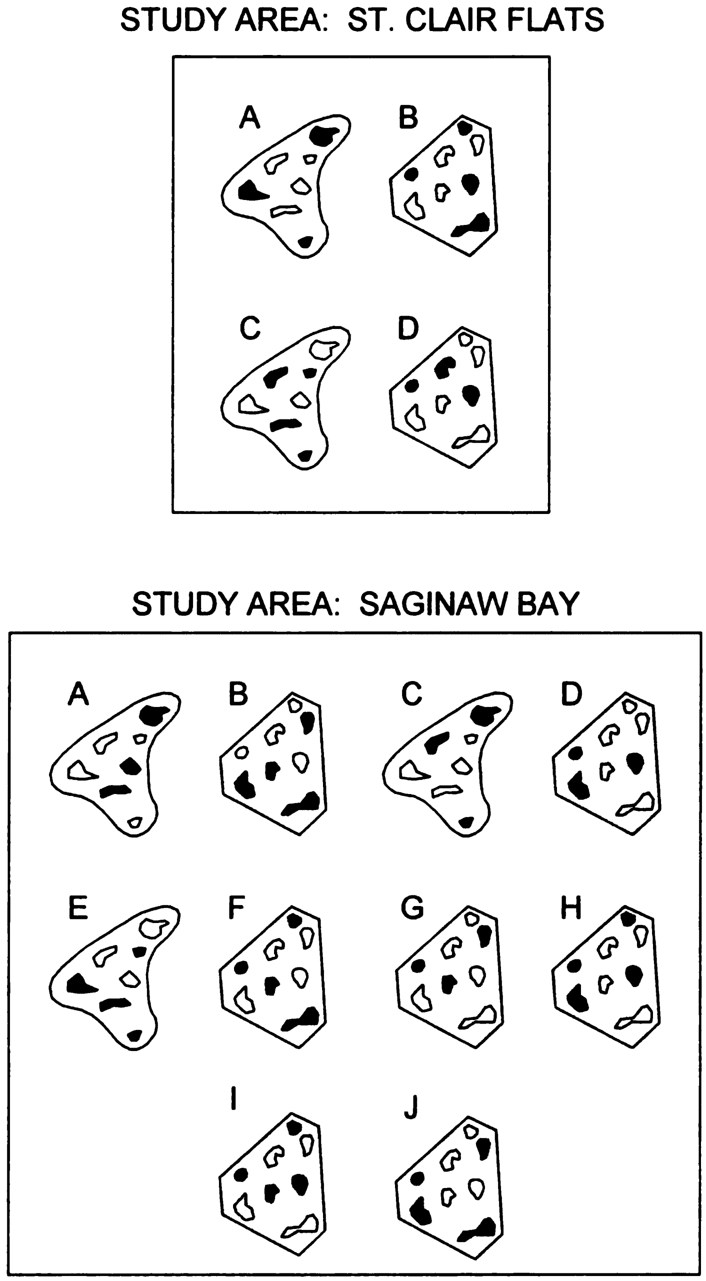

Figure 8. Illustration of study design used for timed-area surveys for breeding birds conducted in Great Lakes coastal wetlands in Michigan (St. Clair Flats and Saginaw Bay), 2005-2007. Independent study sites (lettered polygons) were sampled within each study area, with approximately half of the open water areas occurring in each of two wetland types (diked – shaded, undiked – not shaded). Open water areas (polygons) were randomly selected (shaded polygons) within each study site. During each of four survey periods, a new set of open water areas were randomly selected.

Point Counts

I conducted point counts in emergent marshes of impounded and undiked wetlands using methods similar to the *Standardized North American Marsh Bird Monitoring Protocols* (Conway 2005). Potential survey points were identified using ArcView 3.2, aerial photographs, and 200 by 200 m grids overlaying the study sites. Because Great Lakes water levels were below the long-term average every year of the study, I positioned potential survey points within 400 m of the shoreline or other open water areas. I assumed that emergent wetland located closer to open water/aquatic bed wetland was more likely to be inundated and occupied by marsh birds. Potential survey points had greater than or equal to 50% emergent vegetation within 200 m. Non-emergent cover consisted of open water/aquatic bed, scrub-shrub, or forested wetland. Potential survey points were not used if greater than 10% of the total area within 200 m of the point consisted of roads, dikes, buildings, upland, or wetland of a different type (e.g., undiked wetland in the case of diked points). 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. I surveyed randomly selected points that were at least 400 m apart and had standing water or saturated soils 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. Each survey was separated by at least seven days. Surveys at St. Clair Flats were started approximately one week earlier than at Saginaw Bay. I counted all birds seen or heard during 10-min surveys conducted between 0.5 hour before sunrise and 10:00 AM. During the second half of the point count, I broadcasted calls of several secretive marsh birds 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*). I 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

I evaluated breeding bird use of the open water/aquatic bed zone using a timed-area approach. Potential open water/aquatic bed survey areas were identified using aerial photographs and on-site visits. Surveys were conducted during four periods, late-May, mid-June, mid-July, and early-August, separated by two to three weeks. I only conducted surveys at St. Clair Flats sites in 2005, but surveyed sites at both St. Clair Flats and Saginaw Bay in 2006 and 2007. Surveys were done during all four periods at both study areas in 2006, but I only conducted surveys during the first three periods at Saginaw Bay sites in 2007. I 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. I waited 15 min after arrival before starting each survey, and surveyed each area for 30 min from a stationary boat, canoe, or vehicle. I selected survey stations that afforded the best view of the area, caused the least disturbance, and offered the most concealment. I recorded the location of the survey station using GPS and estimated the size of the survey area 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 counted. Birds flushed from the area upon arrival or seen only during the 15 min silent period were also counted. Flying waterbirds using the area for foraging (e.g., terns) were counted. I recorded the time of each observation and noted if I thought a bird or group of birds was observed previously during the survey, but excluded suspected repeat observations from analyses. The species, number of young, and estimated age class (according to Gollop and Marshall 1954, as cited in Bellrose 1980) were recorded for waterfowl broods.

Vegetation and Physical Variable Sampling

To characterize the habitat present at the study sites, I 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 I 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). I estimated the depth of organic sediments by pushing a 1.2-m wooden stick (2-cm diameter, graduated in centimeters) to the bottom of the organic layer and measuring the depth of the sediments minus the water depth. 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.

I categorized the vegetation into the following structural groups: persistent deep-water emergents, persistent shallow-water emergents, non-persistent deep-water emergents, non-persistent 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, such as cattail, bulrushes, and sedges (*Carex* spp.), and non-persistent 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 consisted of 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, rushes (*Juncus*, spp.), and grasses, were placed in the persistent shallow-water category. Although common reed can survive inundation, I considered it a persistent shallow-water emergent species because it often establishes in moist soils or shallow water, tends to occur near the wetland-upland interface, and its growth and survival is inhibited by long-term flooding with deep water (Roman et al. 1984, Tucker 1990, Marks et al. 1994). Species such as arrowhead (*Sagittaria* spp.), pickerelweed (*Pontedaria cordata*), and wild rice (*Zizania* spp.) were included in the non-persistent deep-water emergent category. Non-persistent shallow-water emergents consisted of species such as spikerushes (*Eleocharis* spp.), smartweeds (*Polygonum* spp.), and beggars tick (*Bidens* spp.). I estimated percent areal coverage for each vegetation category present within a quadrat.

Analysis

Point Counts: I categorized bird species as wetland dependent, wetland associated, and non-wetland species (Crowley et al. 1996, Brown and Smith 1998). A list of bird species assigned to each category, as well as common and scientific names, is provided in Appendix A (Table A-1). Nomenclature follows the American Ornithologists' Union (AOU) *Check-list of North American Birds* (AOU 1998) and subsequent supplements. I compared densities (birds per ha) of all birds, wetland dependent species, wetland associated species, non-wetland species, and individual species of management concern between diked and undiked wetlands 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 (see Appendix B, Tables B-1, B-2). However, I used a 100-m boundary when calculating Pied-billed Grebe (*Podilymbus podiceps*) and American Bittern densities, since density estimates and detection frequencies increased with distance. Observed density and frequency of detection estimates by distance category support my assumption that detection probabilities were similar between the two wetland types (Tables B-1, B-2). I 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 of species of management concern, and the use of indices is appropriate in many situations (Johnson 2008). Before analysis, I log (natural) transformed all avian density variables.

I 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 et al. 2006). I 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. A repeated measures component was used to account for multiple surveys at the same location.

Using the above model, I evaluated three commonly used covariance structures: autoregressive order one (AR[1]), compound symmetric (CS), and unstructured (UN) (Littell et al. 1996, Kincaid 2005). I compared models containing the repeated measures component with a standard mixed model with no repeated measures. For each bird density variable, I selected the best-approximating model using Akaike's Information Criterion (AIC). Of the three structures evaluated, UN covariance appeared to function best for the majority of the variables analyzed based on AIC values (Table B-3). Models containing the UN covariance structure were the best-approximating models in 17 of the 32 variables tested. I used the AR(1) structure in seven of the 32 best-approximating models, while only two of the best-approximating models included the CS structure. Standard mixed models lacking the repeated measures component appeared best of those examined for six of the variables. In all bird variable comparisons except Mallard (*Anas platyrhynchos*) density, model selection did not alter decisions regarding rejection of null hypotheses that bird densities were similar between diked and undiked wetlands (Table B-3). The models I evaluated produced similar least squares mean estimates for the bird density variables. Some analyses produced G matrices that were not positive definite when one of the covariance parameter estimates equaled zero. In those cases, I set the lower boundary for the covariance parameters with zero estimates at a small value close to zero using the PARMS statement (SAS Institute 2004), which allowed the G matrices to be positive definite. Two values (0.0000001 and 0.00001) were used as the lower bound for covariance parameters with zero estimates in initial models. The new models achieved positive definite G matrices, but did not alter the original decisions regarding null hypotheses or parameter estimates (Table B-4). Values used for the lower bound of covariance parameter estimates (i.e., 0.0000001 or 0.00001) changed p-values and AIC estimates slightly, but not selection of the best-approximating models or decisions regarding null hypotheses.

I used three similarity indices (Jaccard, Sorensen, and Morisita) to examine the level of similarity between the bird communities of diked and undiked wetlands. The Jaccard and Sorensen indices are calculated using species presence-absence data, while the Morisita index also incorporates species abundance. I calculated similarity indices between diked and undiked wetlands for all study areas and sites combined.

I conducted correspondence analysis (CA) to evaluate possible relationships in breeding bird abundance of the emergent zone observed at diked and undiked study sites. Correspondence analysis is often used in ecological analyses of species data at different sampling sites (Legendre and Legendre 1998). I used the following 11 categories of bird species/groups in the CA: waterfowl, Pied-billed Grebes, bitterns, herons, rails, American Coots (*Fulica americana*) and Common Moorhens (*Gallinula chloropus*), gulls and terns, aerial-foraging songbirds (e.g., swallows), wetland-dependent songbirds (e.g., Swamp Sparrow [*Melospiza georgiana*]), wetland-associated songbirds (e.g., Common Yellowthroat [*Geothlypis trichas*]), and non-wetland birds (Mourning Dove [*Zenaida* *macroura*]). Bird abundance (no. observed per point) was averaged by site and year prior to analysis. I only interpreted the first two dimensions and the solution was not rotated.

Timed-area Surveys: I calculated two indices of abundance for breeding birds using open water/aquatic bed zones at diked and undiked sites: areal bird density (birds per ha) and linear bird density (birds per km). Areal bird densities were estimated by dividing the number of birds observed by the total area of open water/aquatic bed wetland surveyed at each site. Linear bird densities were calculated by dividing the total number of birds observed by the total amount of edge (interface of emergent vegetation and open water) surveyed at each area. I analyzed both density indices, because linear density may be an appropriate measure of bird abundance. Wetland birds often focus feeding, nesting, and rearing activities at the interface of emergent vegetation and open water, and the boundary used to delineate survey areas along open shorelines was sometimes arbitrary. I examined the relationship between the two density measures using Pearson product-moment correlation (CORR procedure, SAS Institute 2004), and used the chi-square test (FREQ procedure, SAS Institute 2004) to compare the frequencies of species with higher densities in diked and undiked wetlands between the two density calculations. The total area of wetland and length of edge surveyed at each site was estimated using ArcView 3.2 with 2005 color aerial imagery and on-site maps. I compared several density variables between diked and open coastal wetlands, including all birds, wetland-dependent birds, wetland-associated birds, and individual species of management interest. I log (natural) transformed avian density variables prior to analysis.

To compare avian densities between diked and undiked wetlands, I used a mixed model with wetland type (diked and undiked), study area (St. Clair Flats and Saginaw Bay), and survey period (1, 2, 3, or 4) as fixed effects, and year and site as random effects. Open water areas surveyed within a given location were considered replicates of that site. When analysis of an avian density variable resulted in a G matrix that was not positive definite, I set the lower bound for covariance parameter(s) that equaled zero using the same procedure described above for the point count data. Setting the lower bound for random variables did not alter parameter estimates.

I calculated the same three similarity indices used for the point count data to compare bird species composition of diked and undiked wetlands in the open water/aquatic bed zone. When calculating the Morisita index, I used areal bird density (birds per ha surveyed) as the measure of abundance to account for differences in the size of the survey areas.

I conducted correspondence analysis (CA) to evaluate potential relationships in breeding bird abundance observed in the open water zone at diked and undiked study sites. The following 11 categories of bird species/groups were used in the CA: dabbling ducks, diving ducks, geese and swans, Wood Ducks (*Aix sponsa*), Pied-billed Grebes, bitterns, herons, rails, American Coots and Common Moorhens, shorebirds, and gulls and terns. Areal densities were used as an index of bird abundance to account for differences in the size of survey areas. I averaged densities by site and year prior to analysis. I only interpreted the first two dimensions and the solution was not rotated.

Vegetation and Physical Variable Sampling: I compared several variables characterizing the vegetation composition and structure of diked and undiked wetlands using data gathered during quadrat sampling at point-count stations. I 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 depths) were log (natural) transformed. I 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.

To evaluate the variation in vegetation structure and composition and physical variables among diked and undiked coastal wetlands, I conducted principal components analysis (PCA) on vegetation and physical variables gathered during quadrat sampling. I used SAS (PRINCOMP procedure, SAS Institute 2004) to conduct the PCA. Habitat data for the three surveys was averaged by point and year prior to analysis. The following variables were excluded from the PCA because they were highly correlated ($r \geq 0.70$) with similar variables: visual obstruction, cattail density, bulrush density, and common reed density. I also did not include percent cover of exposed substrate, non-persistent deep-water emergents, and shrubs/trees, or shrub/tree density, due to low frequencies of occurrence (less than 10% of total quadrats). This resulted in a total of 14 vegetation and physical variables being used for the PCA. Percent variables were arcsine-square root transformed prior to analysis. Correlation coefficients were used to form the cross-products matrix and the ordination axes were not rotated. When evaluating the importance of the principal component loadings, I only considered loadings greater than 0.20 or less than -0.20, which is an approach similar to interpreting correlation coefficient significance at a 0.01 alpha level and sample size between 100 and 200 (Hair et al. 1987, McGarigal et al. 2000).

RESULTS

Point Counts

Average densities of all birds, wetland-associated birds, and non-wetland birds observed during point counts were similar between diked and undiked wetlands, but mean density of wetland-dependent birds was greater in diked compared to undiked wetlands (p=0.0461, Table 4). American Bittern and Least Bittern mean densities were greater in diked than undiked wetlands (p=0.0012 and p=0.0024, respectively). Forster's Tern (*Sterna forsteri*) was the only species observed in greater densities in undiked coastal wetlands (p=0.0057). Specific surveys were not conducted for nesting terns, but field observers noted when nesting colonies were seen. Forster's Tern nests were only found 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. I provide densities and frequencies of occurrence for all bird species observed during point counts in Table B-5 (Appendix B).

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 5). Thirteen species were unique to diked wetlands, with seven species considered wetland dependent, one wetland associated, and five non-wetland species. Nine species were unique to undiked coastal wetlands, of which five were considered wetland-dependent, one wetland-associated, and three as non-wetland species. Species unique to the two wetland types tended to be those that were only observed sporadically, use wetlands for aerial foraging, or breed in shrub,

Table 4. Least squares geometric means and lower and upper 95% confidence limits (CL) 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 ($p<0.05$).

	Diked (n=294)			Undiked (n=311)			
Bird Density Variable	Mean	Lower CL	Upper CL	Mean	Lower CL	Upper CL	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
Non-wetland 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
Non-wetland Species							
Song Sparrow	0.10	-0.01	0.21	0.20	0.09	0.32	0.1751

Table 5. 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 5. 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	
Non-wetland 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

forest, or edge habitats. I calculated a Jaccard index value of 0.66 and Sorensen index of 0.80 between diked and undiked wetlands, indicating high similarity in species composition between the wetland types. Morisita similarity index between diked and undiked wetlands was 0.98, which indicates high similarity in species composition and abundance.

The first dimension of the correspondence analysis explained 31.3% of the variation in bird abundance during point counts and the second dimension 25.6% of the variation. Correspondence analysis did not reveal distinct groupings of bird use at diked and undiked sites (Figure 9). Gulls/terns, Pied-billed Grebe, and coots/moorhens had positive dimension 1 coordinates and non-wetland birds and herons had negative values (Table 6). Bird groups that use large open water areas or wetland edges appeared to be associated with positive dimension 2 coordinates, such as gulls/terns, aerial-foraging songbirds, and non-wetland birds, while species more typical of emergent marshes, such as bitterns, herons, coots/moorhens, and rails, tended to have negative coordinates (Table 6). Diked and undiked sites at St. Clair Flats seemed to be separated along the second dimension, indicating that bitterns and coots/moorhens were more abundant in diked compared to undiked wetlands, and undiked wetlands tended to have greater numbers of terns/gulls, Pied-billed Grebes, and waterfowl compared to diked sites. Diked and undiked Saginaw Bay sites were not separated along either dimension.

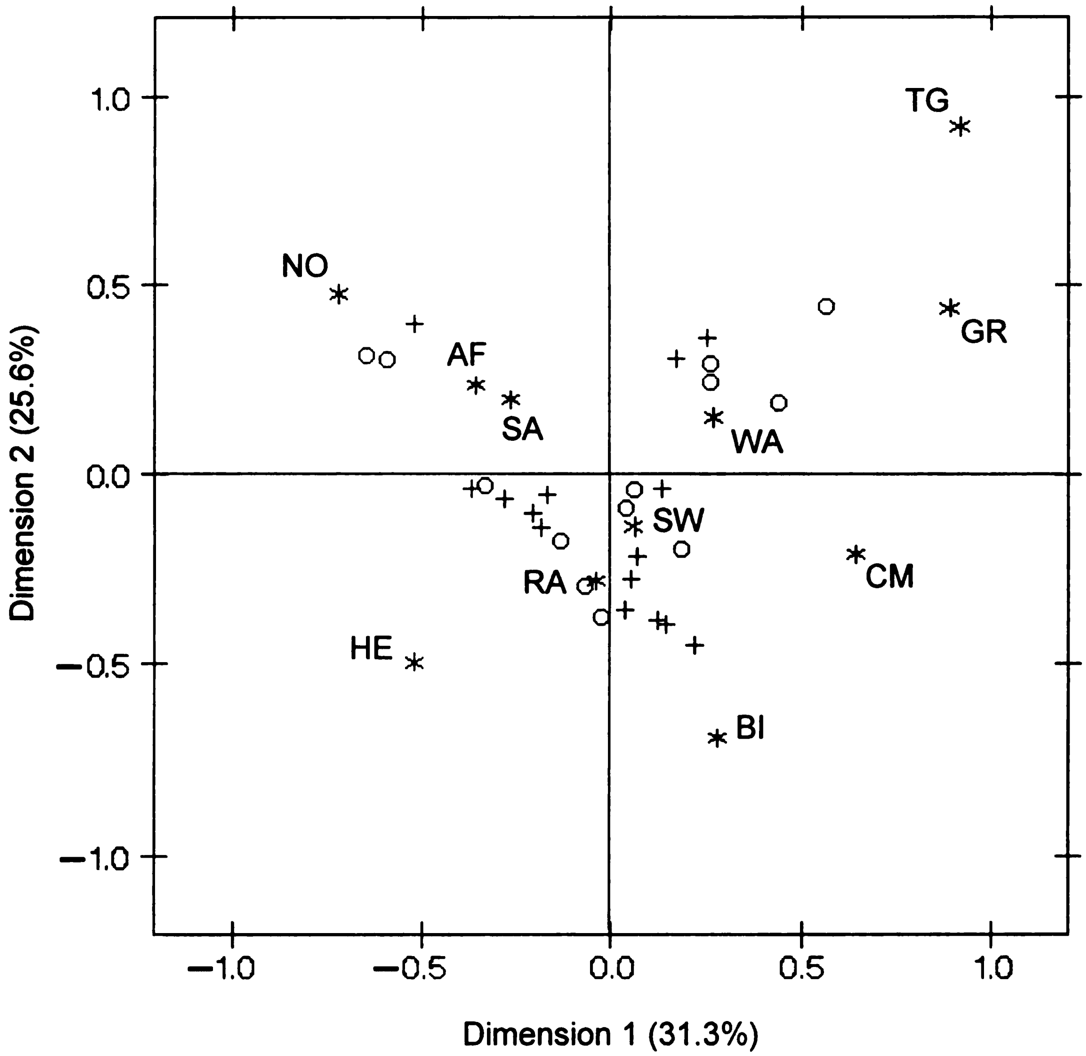

Figure 9. Biplot of site and bird group coordinates for dimensions 1 and 2 from correspondence analysis conducted using point count data collected at St. Clair Flats (SCF) and Saginaw Bay (SAG), Michigan, coastal wetlands, 2005-2007. Site coordinates are coded by wetland type ("+" diked; "o" undiked). Bird group coordinates are coded with an "*" and labeled as follows: AF = aerial-foraging songbirds, BI = bitterns, CM = American Coots and Common Moorhens, GR = Pied-billed Grebes, HE = herons, NO = non-wetland birds, RA = rails, SA = wetland-associated songbirds, SW = wetland-dependent songbirds, TG = terns and gulls, and WA = waterfowl.

Table 6. First and second dimension coordinates for birds species/groups from correspondence analysis conducted on data from 605 breeding bird point counts (294 diked and 311 undiked) at St. Clair Flats and Saginaw Bay, Michigan, coastal wetlands, 2005-2007.

Bird Species/Group	Dimension 1	Dimension 2
Waterfowl (WA)	0.2682	0.1519
Pied-billed Grebe (GR)	0.8915	0.4398
Bitterns (BI)	0.2813	-0.6925
Herons (HE)	-0.5228	-0.4930
Rails (RA)	-0.0384	-0.2811
American Coots/Common Moorhens (CM)	0.6442	-0.2082
Gulls/Terns (GT)	0.9188	0.9214
Aerial-foraging Songbirds (AF)	-0.3587	0.2352
Wetland-dependent Songbirds (SW)	0.0603	-0.1353
Wetland-associated Songbirds (SA)	-0.2674	0.1975
Non-wetland Birds (NO)	-0.7244	0.4769

Timed-area Surveys

Mean areal densities of all birds, wetland-dependent birds, and wetland-associated birds were similar between diked and undiked coastal wetlands (Table 7). Average Canada Goose (*Branta canadensis*), Wood Duck (*Aix sponsa*), and Common Moorhen (*Gallinula chloropus*) areal densities were greater in diked compared to undiked wetlands ($p<0.0001$, $p=0.0002$, and $p=0.0168$, respectively). Mean areal densities of American Coot (*Fulica americana*), Ring-billed Gull (*Larus delawarensis*), Herring Gull (*Larus argentatus*), and Forster's Tern were greater in undiked than diked wetlands ($p=0.0378$, $p=0.0025$, $p=0.0457$, and $p=0.0004$, respectively). Table B-6 (Appendix B) provides areal densities and frequencies of occurrence for all bird species observed during timed-area surveys by study area and wetland type.

Table 7. Least squares geometric means and lower and upper 95% confidence limits (CL) by wetland type for areal bird densities (birds per ha open water) 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 ($p<0.05$).

	Diked (n=144)			Undiked (n=143)			
Bird Density Variable	Mean	Lower CL	Upper CL	Mean	Lower CL	Upper CL	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-cr. 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

Average linear (birds per km of edge surveyed) and areal (birds per ha surveyed) densities for species observed during timed-area surveys were correlated ($r=0.998$, $p<0.0001$), and a chi-square test revealed no difference between linear and areal densities ($p=0.3581$) in the number of species with greatest densities in diked and undiked wetlands. I found greater mean linear densities of all birds combined ($p=0.0171$) and wetland-dependent birds ($p=0.0241$) in undiked compared to diked wetlands (Table 8), while areal densities for these variables were similar between the two wetland types. Average wetland-associated bird linear densities were similar between the wetland types ($p=0.4016$), which is consistent with results of areal density analysis. Similar to the results of areal density analyses, Canada Goose and Wood Duck linear densities were greater in diked wetlands ($p<0.0001$). I observed greater mean Mallard linear densities in undiked than diked wetlands ($p=0.0001$). Mean linear densities of Ring-billed Gull, Herring Gull, and Forster's Tern were greater in undiked compared to diked wetlands ($p=0.0027$, $p=0.0278$, and $p=<0.0001$, respectively), which is the same pattern observed in the areal density analysis.

Total species richness during timed-area surveys was 32 species for both wetland types, with 25 species common to diked and undiked wetlands (Table 9). 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 observed irregularly in low numbers. Jaccard and Sorensen similarity index values for diked and undiked wetlands were 0.64 and 0.73, respectively, which indicates high similarity in species composition between the wetland types. I calculated a Morisita index value of

Table 8. Least squares geometric means and lower and upper 95% confidence limits (CL) by wetland type for linear bird densities (birds per km of edge) 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).

	Diked (n=144)			Undiked (n=143)			
Bird Density Variable	Mean	Lower CL	Upper CL	Mean	Lower CL	Upper CL	P-value
All Birds	7.02	5.55	8.82	9.92	7.87	12.44	**0.0171**
Wetland-dependent Birds	6.65	5.27	8.33	9.26	7.36	11.58	**0.0241**
Wetland-associated Birds	0.29	0.17	0.43	0.37	0.24	0.52	0.4016
Wetland Dependent Species							
Canada Goose	0.61	0.41	0.82	0.10	-0.04	0.25	**<0.0001**
Mute Swan	0.30	0.04	0.64	0.30	0.00	0.68	0.9722
Wood Duck	1.23	0.78	1.80	0.13	-0.12	0.45	**<0.0001**
Mallard	0.37	0.04	0.82	2.10	1.28	3.20	**0.0001**
Great Blue Heron	0.23	0.08	0.39	0.15	0.00	0.31	0.3808
Great Egret	0.05	-0.10	0.23	0.28	0.07	0.53	0.1001
Black-cr. Night-Heron	0.07	-0.05	0.22	<0.01	-0.14	0.15	0.4488
Pied-billed Grebe	0.44	0.06	0.95	0.55	0.13	1.15	0.6565
Common Moorhen	0.14	0.08	0.20	0.08	0.02	0.14	0.1694
American Coot	0.08	-0.04	0.22	0.23	0.08	0.39	0.1020
Spotted Sandpiper	0.03	0.01	0.06	0.01	-0.02	0.03	0.0720
Greater Yellowlegs	0.01	-0.01	0.04	0.02	0.00	0.05	0.6089
Lesser Yellowlegs	0.03	-0.01	0.07	0.02	-0.02	0.06	0.6951
Dunlin	<0.01	-0.04	0.04	0.05	0.00	0.09	0.1072
Ring-billed Gull	0.02	-0.05	0.09	0.16	0.08	0.25	**0.0027**
Herring Gull	<0.01	-0.11	0.11	0.19	0.05	0.35	**0.0278**
Black Tern	0.56	0.14	1.14	0.48	0.04	1.12	0.8322
Forster's Tern	0.06	-0.13	0.30	0.68	0.37	1.07	**<0.0001**
Wetland Associated Species							
Killdeer	0.04	-0.02	0.10	0.02	-0.04	0.08	0.3921
Caspian Tern	0.25	0.15	0.35	0.35	0.24	0.46	0.2074

Table 9. Avian species unique to diked and open 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 9. 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

0.62 between diked and undiked sites. Although the three indices suggested substantial similarity in the breeding bird communities in the open water zone of diked and undiked wetlands, they were all lower compared to values observed for the emergent zone.

Dimension 1 of the correspondence analysis explained 40.5% of the variation in bird densities of the open water/aquatic bed zone and the second dimension 21.2% of the variation. Correspondence analysis separated the bird species/groups into two clusters along the first dimension, with dabbling ducks and rails on the negative end and the remaining groups clumped from approximately 0.4 to 0.8 on the positive end (Figure 10, Table 10). Shorebirds, diving ducks, and terns/gulls had positive dimension 2 coordinates, while Wood Ducks, herons, and geese/swans had negative values (Table 10). The majority of the diked sites had positive dimension 1 and negative dimension 2 coordinates, which indicated greater densities of Wood Ducks, herons, and geese/swans compared to the other sites. Most undiked sites seemed to be associated with greater densities of terns/gulls, diving ducks, and Pied-billed Grebes (Figure 10). However, there were a small number of diked sites associated with the same bird groups.

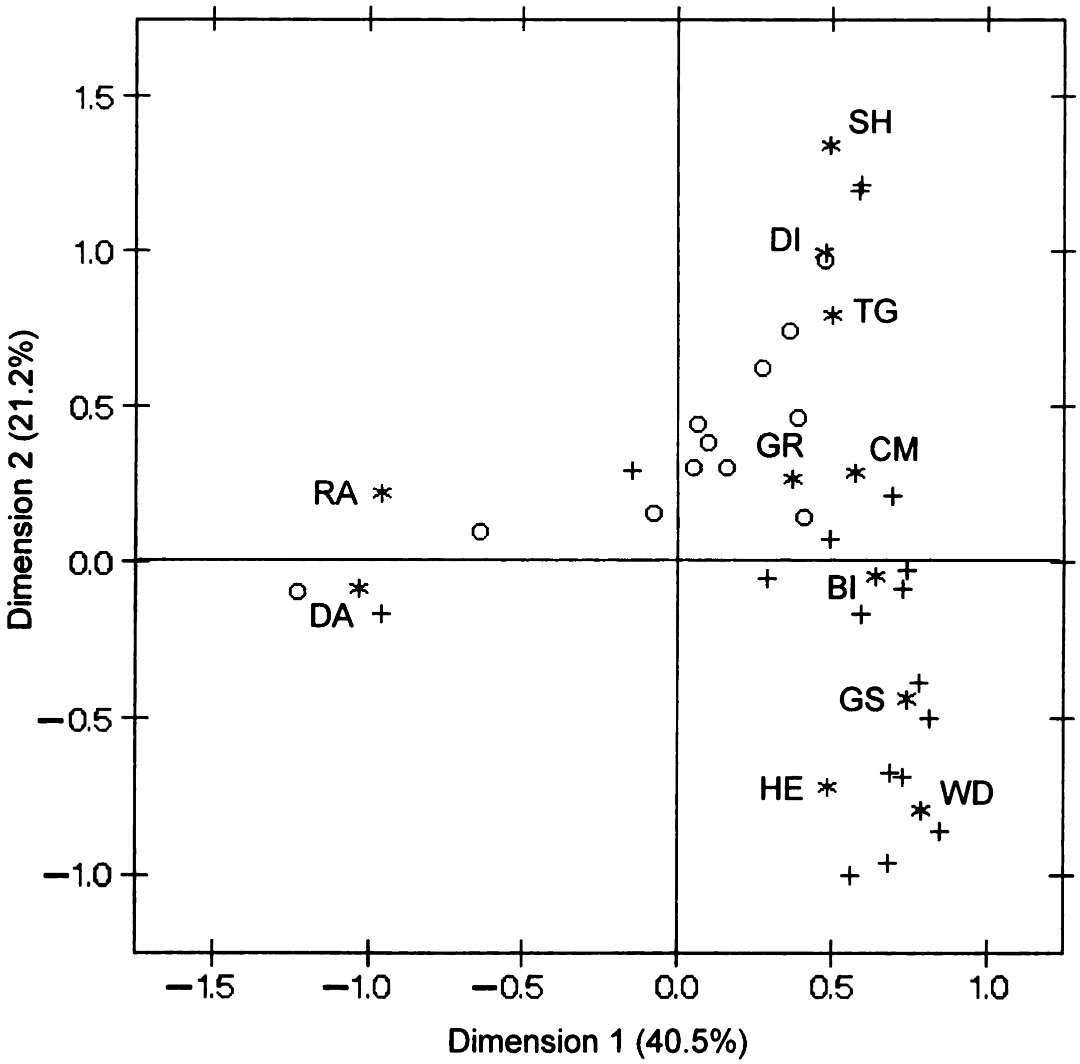

Figure 10. Biplot of site and bird group coordinates for dimensions 1 and 2 from correspondence analysis conducted using timed-area survey data collected at St. Clair Flats (SCF) and Saginaw Bay (SAG), Michigan, coastal wetlands, 2005-2007. Sites scores are coded by wetland type ("+" diked; "o" undiked). Bird groups are coded with an "*" and labeled as follows: BI = bitterns, CM = American Coots and Common Moorhens, DA = dabbling ducks, DI = diving ducks, GR = Pied-billed Grebes, GS = Canada Geese and Mute Swans, HE = herons, RA = rails, SH = shorebirds, TG = terns and gulls, and WD = Wood Ducks.

Table 10. First and second dimension coordinates for birds species/groups from correspondence analysis conducted on data from 287 timed-area surveys (144 diked and 143 undiked) at St. Clair Flats and Saginaw Bay, Michigan, coastal wetlands, 2005-2007.

Bird Species/Group	Dimension 1	Dimension 2
Dabbling Ducks (DA)	-1.0322	-0.0864
Diving Ducks (DI)	0.4771	0.9957
Canada Geese/Swans (GS)	0.7437	-0.4365
Wood Ducks (WD)	0.7897	-0.7924
Pied-Billed Grebes (GR)	0.3735	0.2695
Bitterns (BI)	0.6412	-0.0447
Herons (HE)	0.4882	-0.7209
American Coots/Common Moorhens (CM)	0.5761	0.2881
Rails (RA)	-0.9586	0.2236
Shorebirds (SH)	0.4946	1.3445
Gulls/Terns (GT)	0.4993	0.7940

Vegetation and Physical Variable Sampling

Hydrological and biogeochemical changes resulting from coastal wetland diking appear to have caused differences in vegetation and physical parameters measured at diked and undiked sites (Table 11). Mean percent cover of open water/aquatic bed wetland (p=0.0003), floating vegetation (p=0.0020), persistent deep-water vegetation (p=0.0258), and cattail (*Typha*) (p=0.0001) was greater in diked than undiked coastal wetlands. Average percent cover of several variables was greater in undiked compared to diked sites: persistent shallow-water vegetation (p=0.0033), non-persistent shallow-water vegetation (p=0.0005), bulrush (*Schoenoplectus*) (p<0.0001), common reed (*Phragmites*) (p=0.0227), surface litter (p=0.0038), and exposed sediments (p=0.0171). Percent cover of total emergent and submersed vegetation was similar between wetland types (p=0.7578 and p=0.1393, respectively). Mean density of cattail stems was greater (p<0.0001) in diked wetlands, while densities of bulrush and common reed were greater

Table 11. Least squares geometric means and lower and upper 95% confidence limits (CL) for vegetation and physical 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).

	Diked (n=771)			Undiked (n=750)			
Vegetation/Physical Variable	Mean	Lower CL	Upper CL	Mean	Lower CL	Upper CL	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**
Cattail	16.3	9.7	24.3	1.8	0.1	5.7	**0.0001**
Bulrush	<0.1	<0.1	0.2	1.8	1.0	2.8	**<0.0001**
Common Reed	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							
Cattail[1]	11.78	6.76	20.06	1.58	0.52	3.38	**<0.0001**
Bulrush[1]	0.10	-0.19	0.49	2.88	1.80	4.37	**<0.0001**
Common Reed[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).

in undiked wetlands ($p<0.0001$ and $p=0.0164$, respectively). Mean depths of water and organic sediment were greater in diked compared to undiked wetlands ($p=0.0002$ and $p=0.0069$, respectively).

The first component from the PCA explained 37.1% of the vegetation and physical variable variation among avian point count stations, while the second component explained 21.3% of the variation. The first axis appeared to represent a gradient from deep open water/aquatic bed wetland on the negative end to dense shallow-water marsh on the positive end (Figure 11). Principal component 1 (PC 1) was negatively related to percent open water, water depth, percent submersed vegetation, and percent floating vegetation, and positively related to percent cover of litter, persistent shallow-water vegetation, total emergent vegetation, and common reed, and vegetation height (Table 12). The second axis seemed to represent a gradient from cattail marsh on the positive end to common reed marsh on the negative end. The second principal component (PC 2) was positively related to percent cover of cattail, percent cover persistent deep-water emergents, and organic sediment depth, and negatively related to percent cover of persistent shallow-water emergents and common reed (Table 12). Although there was substantial overlap between diked and undiked point count stations in PC scores, undiked wetlands tended to have higher PC 1 scores and lower PC 2 scores compared to diked wetlands (Figure 11). The PCA indicates a tendency for undiked sites to have shallower water, denser vegetation, more common reed, and taller vegetation compared to diked wetlands, while diked sites typically had greater water and organic sediment depths, greater percent cover of open water, submersed vegetation, and floating plants, and more cattail compared to undiked wetlands.

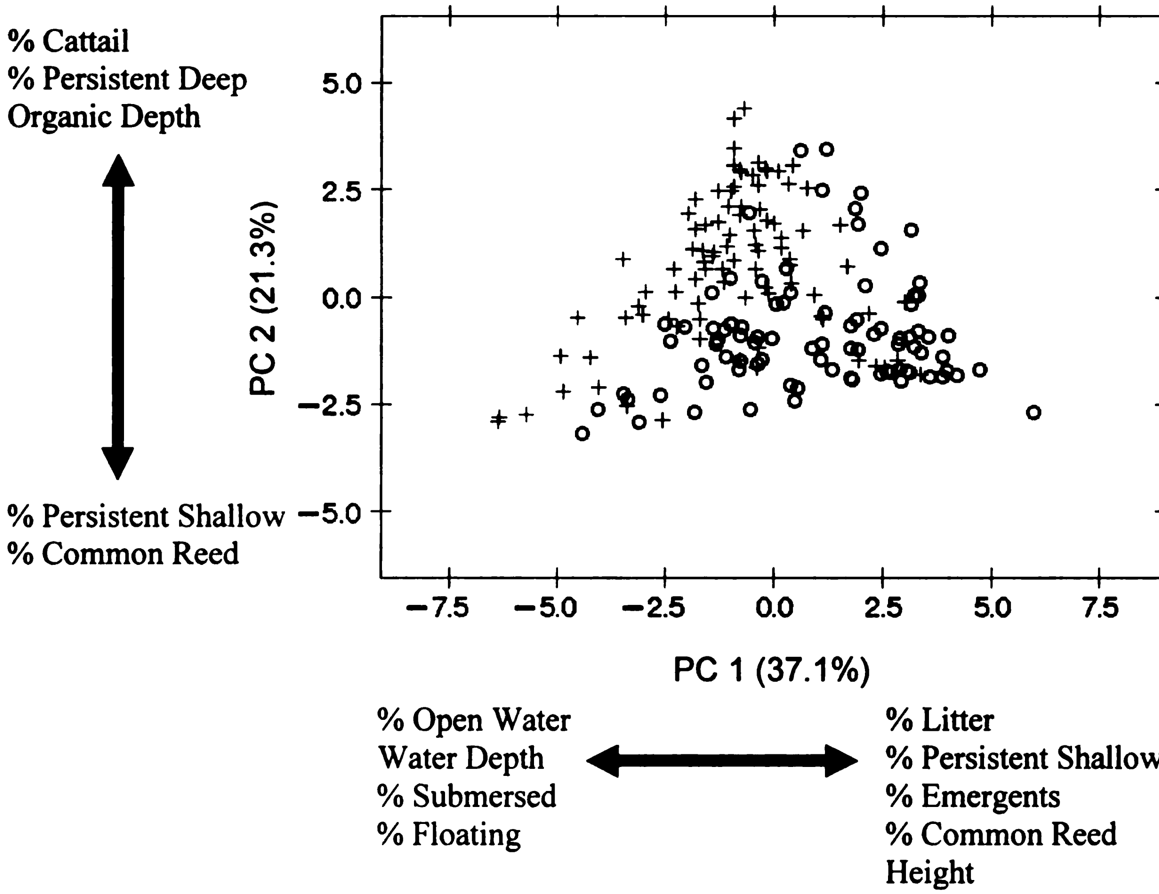

Figure 11. Bi-plot of PC 1 X PC 2 from principal components analysis conducted using 14 vegetation and physical variables gathered during quadrat sampling at 179 random avian point count stations at St. Clair Flats and Saginaw Bay, Michigan, 2006-2007. Point scores are coded by wetland type ("+" diked; "o" undiked).

Table 12. Eigenvectors for first two principal components obtained through PCA of habitat data collected at 179 point count stations located at St. Clair Flats and Saginaw Bay, Michigan, coastal wetlands, 2006-2007.

Habitat Variable	Principal Component 1	Principal Component 2
Percent Cover		
Emergent Vegetation	0.3300	0.2987
Open Water/Aquatic Bed	-0.3871	-0.0511
Submersed Vegetation	-0.3056	-0.1844
Floating Vegetation	-0.2196	0.0294
Persistent Deep-water	-0.0208	0.5271
Persistent Shallow-water	0.3446	-0.2264
Non-persistent Shallow-water	0.1968	-0.0060
Cattail	-0.0354	0.5477
Bulrush	0.0424	-0.1466
Common Reed	0.3017	-0.2179
Surface Litter	0.3562	0.0121
Vegetation Height (m)	0.2814	0.1853
Water Depth (m)	-0.3546	-0.0112
Organic Sediment Depth (m)	-0.1260	0.3750

DISCUSSION

Breeding Bird Use of Diked and Undiked Wetlands

Wildlife managers in the Great Lakes region built dikes around wetlands to provide the capability to manage water levels and enhance conditions for wetland birds. This study evaluated bird use of diked wetlands through comparisons with wetlands open to Great Lakes water level fluctuations, and examined bird use in the context of habitat conditions. I found greater densities of some wetland-dependent breeding bird species in diked coastal wetlands, while others were observed in lower densities compared to undiked sites. Most of the breeding bird density variables were not different between wetland types. Total wetland-dependent bird densities were greater in diked wetlands during point counts, but areal densities observed during timed-area surveys were similar and linear densities were greater in undiked than diked wetlands. Galloway et al. (2006) observed greater 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. I found comparable species richness in diked and undiked wetlands during both point counts and timed-area surveys. Similarity index results suggested breeding bird species composition and abundance was similar between wetland types. Approximately two-thirds of the species documented during breeding surveys were common to both wetland types, and unique species primarily consisted of species observed 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 greater cumulative species richness in diked compared to undiked wetlands for several of the marsh bird groups they compared, and only aerial forager species richness was greater in undiked wetlands. Although Galloway et al. (2006) observed greater bird abundance and species richness for several bird groups in overall comparisons of diked and undiked sites, they found few differences in wetland bird use in paired comparisons of nearby diked and undiked wetlands. Differences in the results of my 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 or annual variation in bird use and wetland conditions.

Most of the breeding species observed in greater densities in diked than undiked coastal wetlands use deep-water marshes for some part of their life cycle. Canada Geese and Wood Ducks were observed in greater 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 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 (Provence 2008), which are an important food source for nesting females and broods (Drobney and Fredrickson 1979). Densities of American and Least Bitterns were greater in diked coastal wetlands. Although he only surveyed diked wetlands, Yocum (2007) found Least Bitterns to be abundant at some sites. 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. Weller (1961) found Least Bittern nests primarily in cattail and bulrush marshes, usually near open water patches, and only occasionally in common reed. During bird surveys in cattail, marsh meadow, and common reed wetlands, Meyer (2003) only observed Least Bitterns in common reed stands. American Bitterns in Maine seemed to prefer impounded and beaver-created wetlands over wetlands of glacial origin (Gibbs et al. 1992). Higher water levels and greater percent open water in the diked wetlands may have increased interspersion of emergent vegetation and open water, which would be attractive to American and Least Bitterns. Dikes surrounding the isolated coastal wetlands may have provided nesting bitterns protection from wave action and seiches. Higher water levels in the diked wetlands may have created a more stable environment for invertebrates, amphibians, and small fish that bitterns use for food. Although densities of Common Moorhen were similar between diked and undiked wetlands during point counts, areal 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).

Mallard, American Coot, Ring-billed Gull, Herring Gull, and Forster's Tern were the only breeding species observed in greater densities in undiked compared to diked wetlands. Mean linear density of Mallard was greater in undiked sites. Mallards prefer to forage in shallow water (Fredrickson and Taylor 1982), and undiked wetlands had lower water depths than diked sites, which could account for differences in Mallard abundance. American Coot areal densities in diked and undiked emergent marsh were similar during point counts; however, densities recorded in the open water/aquatic bed zone during timed-area surveys were greater 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 between diked and undiked wetlands in total fish species richness and abundance, age class frequencies, lengths, and body condition indices for some species (Johnson et al. 1997, Markham et al. 1997). Fish abundance and composition were not measured in my study, but it would be useful to know the relative abundance of forage fish in diked and undiked wetlands to understand the effects of coastal wetland diking on these bird species. Foraging in diked wetlands may have been more difficult for gulls and Forster's Terns due to greater coverage of floating 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 lower in diked than in undiked wetlands.

Vegetation and Physical Characteristics of Diked and Undiked Wetlands

I observed greater percent cover of open water, floating vegetation, persistent deep-water emergents, and cattails, and greater mean cattail density in diked compared to undiked wetlands, and these differences were likely due to higher, more stable water levels. Although water levels of diked wetlands often dropped dramatically during the summer, the majority of the wetlands remained inundated throughout the season. Percent cover and density of bulrush and common reed were greater in undiked than diked wetlands. Albert and Brown (2008) observed similar results when comparing the vegetation at several of the same diked and undiked study sites. Most of variables in my study that differed between diked and undiked sites also tended to have high loadings in PC 1 and PC 2 of the PCA. My PCA indicated some separation of diked and undiked point count stations and generally supported the results of parametric comparisons. In vegetation comparisons between diked and undiked wetlands, Herrick and Wolf (2005) similarly found greater cattail cover in diked wetlands and greater common reed cover in undiked wetlands. Lower mean percent cover and stem density of common reed in diked than undiked wetlands may be due to higher water levels and activities (e.g., herbicide application, burning) used to control common reed 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 1992). Diked wetlands likely experience less disturbance than undiked sites due to higher water levels and infrequent complete drawdowns, and greater 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.

I found no 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. Aquatic bed zones of the diked wetlands, including excavated channels, typically had dense submersed vegetation. When I conducted PCA of habitat data gathered at point count stations, percent cover of submersed vegetation was an important variable in PC 1. There was some separation of diked and undiked wetlands along the first axis, which indicated that diked wetlands were associated with greater percent cover of submersed vegetation compared to undiked sites. 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.

Management Implications

Breeding bird use of diked and undiked coastal wetlands in Michigan was largely similar, despite clear differences in vegetation and physical variables. American Bittern, Least Bittern, and Common Moorhen, all rare species known to use deep-water marshes, appeared to benefit from diked wetland management. Several years of low Great Lakes water levels have limited the availability of deep-water cattail marshes in undiked wetlands of both study areas, which may explain greater densities of the above species in diked wetlands. Although deep-water bulrush marshes were common in undiked wetlands, they may have been of lower value to nesting bitterns and Common Moorhens than diked cattail marshes. Standing dead bulrushes from the previous season that could be used for cover and nest building are usually removed by ice scour, and new bulrush growth occurs later in the season than cattail.

A common criticism of diked coastal wetlands is that their management focuses on waterfowl or game species, potentially at the detriment of rare and/or non-game bird species. The results of my study do not support this criticism. Least Bittern is a State-threatened species, American Bittern and Common Moorhen are State special concern species, and Common Moorhen was recommended for listing as threatened in Michigan (Brewer et al. 2005). I also found no difference between diked and undiked wetlands in the densities of Black-crowned Night-Heron (State special concern), King Rail (State endangered), Marsh Wren (State special concern), and Yellow-headed Blackbird (State special concern). Forster's Tern (State special concern species) was the only rare species observed in greater densities in undiked wetlands. Albert and Brown (2008) reviewed aerial photographs taken prior to dike construction at three of the sites used in my study, and they found that much of these areas appeared to be wet meadows mixed with densely vegetated emergent marsh. At least some of the diked wetlands may not have been used extensively by breeding Forster's Terns before diking, given a predominance of wet meadow vegetation. Along with the rare species described above, I observed eight other species considered species of greatest conservation (SGCN) need in Michigan's Wildlife Action Plan (Eagle et al. 2005). I found no difference between diked and undiked wetlands in the densities of seven of the eight SGCN. I observed greater areal densities of American Coot in undiked wetlands during timed-area surveys, but linear densities from timed-area surveys and areal densities from point counts were similar between wetland types. The diking and management of coastal wetlands did not seem to cause substantial negative impacts to rare or nongame breeding bird species in the wetlands I investigated.

Invasive populations of common reed have substantially expanded in Great Lakes coastal wetlands during the recent period of low water levels (Tulbure et al. 2007, E. Kafcas, Michigan Department of Natural Resources, person. commun.). Most climate change models predict decreasing Great Lakes water levels in the future (Mortsh et al. 2000, 2006, Lofgren et al. 2002, Croley 2003), which could further increase common reed expansion in undiked wetlands and potentially reduce the value of these areas for birds species of management concern. Although the construction of dikes may have provided avenues for the expansion of invasive species (e.g., common reed) in coastal wetlands, diked wetlands now provide the opportunity to manage against invasive plant species like common reed. Given that the future status of coastal wetlands is uncertain due to the effects of climate change and invasive species, diked wetlands may provide important management opportunities to maximize use by wetland birds.

Greater linear density of Mallards in undiked than diked wetlands was not predicted, because they are a focal species in diked wetland management. My results are also surprising given that invertebrate abundance was greater in diked compared to undiked sites at St. Clair Flats (Provence 2008), which included several taxa known to be important food items for Mallards during the breeding season. Fredrickson and Taylor (1982) noted that the preferred foraging depth for Mallards is approximately 10-15 cm in seasonally flooded impoundments. Although invertebrates seemed abundant in diked wetlands during this study, Mallards may have had better access to food in undiked wetlands due to shallower water depths. Managing the diked wetlands for shallower water depths could enhance use by Mallards and many other wetland bird species by improving access to abundant invertebrate foods.

Periodic complete drawdowns of the diked wetlands could potentially improve habitats for breeding birds. Kadlec and Smith (1992) noted three potential benefits of drawdowns as nutrient release due to the decomposition of organic sediments, consolidation of loose sediments due to drying, and germination and establishment of emergent vegetation, including annual species. Drawdowns could reduce the buildup of organic matter, release nutrients and stimulate plant growth, and improve vegetation and structural diversity of the diked marshes. Recommended frequencies for drawdowns have ranged from 5 to 7 years (Harris and Marshall 1963, Whitman 1976). Areas with multiple impoundments should not be drawn down in the same season, since dewatering could cause short-term impacts to invertebrates (Kadlec 1962) and breeding bird use. Since drawdowns can encourage growth of invasive plant species (Fredrickson and Taylor 1982), I suggest close monitoring of the vegetation response if drawdowns are conducted.

Research Needs

My study occurred during a period of low Great Lakes water levels, and water level fluctuations and depths are known to affect bird use of wetlands. Timmermans et al. (2008) found annual abundances of several wetland bird species were positively correlated with annual water level changes in Lakes Michigan, Huron, and Erie. Steen et al. (2006) felt that the stabilization of water levels was an important factor contributing to the decline of some bird species using Lake Ontario coastal wetlands. Bird use of diked and undiked wetlands during normal to high water levels could differ from the results of my study, 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 hydrological conditions. Long-term studies would be beneficial to understand changes in Great Lakes coastal wetlands that occur over 5-20 years. Research is needed to understand the effects of differences in wetland conditions (e.g., water depths, floating vegetation mats, interspersion) between diked and undiked wetlands on breeding bird use. More study is required to determine if the pattern of higher invertebrate abundance in diked compared to undiked wetlands that Provence (2008) 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 and availability. Fish and amphibian populations are also likely affected by the diking of coastal wetlands, and the effects on their populations and the secondary effects on bird populations are not understood.

Management guidelines need to be developed to maximize wildlife benefits in diked wetlands in the context of changing coastal wetland conditions associated with climate change and invasive species expansion, and for specific species of concern (e.g., game, threatened, endangered, SGCN). Diked wetlands provide opportunities to conduct experimental studies that test the success of water level management regimes (e.g., lower water levels, periodic drawdowns) for selected management goals (e.g., breeding use by focal species, diverse vegetation). For example, Mallards are often a focal species for management and invertebrate abundance was greater in some diked wetlands during this study (Provence 2008), but Mallard densities tended to be greater in undiked than diked wetlands. Water levels could be experimentally lowered in the diked wetlands to evaluate if Mallard densities increase when preferred water depths for foraging are provided.

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CHAPTER 3

MIGRANT BIRD USE OF DIKED AND UNDIKED COASTAL WETLANDS IN MICHIGAN

INTRODUCTION

Great Lakes coastal wetlands provide vital breeding, migration, and wintering habitat for an array of birds. Approximately three million swans, geese, and ducks travel along migration corridors that cross the Great Lakes region (Great Lakes Basin Commission 1975, 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. Eighty bird species used coastal wetlands of Lake Huron as breeding habitat (Prince and Flegel 1995).

Impoundments 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 or shallow-water marshes dominated by moist-soil vegetation to attract migrant birds (Weller and Spatcher 1965, Fredrickson and Taylor 1982, Murkin et al. 1997). Hemi-marshes are marshes with approximately equal proportions of emergent vegetation and open water produced by natural water level fluctuations and mammal herbivory. 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) documented increased amounts of invasive species in standing vegetation and seed banks of diked compared to undiked wetlands in Saginaw Bay, Michigan and Green Bay, Wisconsin, 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 greater 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 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 between vegetation in diked and undiked Lake Erie coastal wetlands during a high water year, Thiet (2002) found greater 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 diking on animal communities. McLaughlin and Harris (1990) compared aquatic insect emergence in one diked and one undiked wetland on Green Bay, and recorded more insect taxa and greater total insect biomass emergence from the diked wetland. Burton et al. (2002) noted that both plant-community composition and exposure to wave action were important determinants of invertebrate diversity and biomass in Great Lakes marshes. Invertebrates were distributed along gradients of decreased mixing of pelagic water and increased 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 inland from Lake Huron. Although species richness was similar between coastal and inland cattail marshes, bird densities in marshes located far offshore were lower than most other sites. 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 greater abundance and species richness for several groups of birds in diked wetlands, but indicated that long-term research is needed 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.

Ecological studies of the effects of coastal wetland isolation from natural, highly variable water level fluctuations are needed so that informed decisions can be made about the management and restoration of Great Lakes wetlands. The goal of this project was to evaluate the effects of coastal wetland diking on migrant birds by comparing bird use and vegetation and physical conditions of several diked and undiked wetlands in Michigan. I tested the hypothesis that coastal impoundments with managed water levels support greater densities and more species of migrant wetland birds compared to undiked wetlands. This research is one of many comparisons needed over the long-term to better understand how diked and undiked wetlands function during the full cycle of Great Lakes water levels.

METHODS

Aerial Waterfowl Surveys

Fourteen aerial waterfowl surveys were conducted in spring (n=5), late summer (n=5), and early fall (n=4) during 2005-2007 to evaluate staging and migrant waterfowl use of three St. Clair Flats and 12 Saginaw Bay study sites (Figure 12). 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 traversed 22 transects (12 diked, 10 undiked) totaling approximately 76 km (21 km diked, 55 km undiked) in length (Table 13). Beginning in spring 2006, aerial surveys were done using a Cessna 172N fixed-wing aircraft, which was more cost efficient and had a faster flight speed better suited to surveying large flocks of waterfowl that often flushed ahead of the aircraft. Sixteen transects (8 diked, 8 undiked) totaling 66.6 km (18.7 km diked, 47.9 km undiked) in length were surveyed during subsequent surveys with fixed-wing aircraft (Table 13). Methods used were similar to the standard operating procedures used for breeding surveys (U.S. Fish and Wildlife Service/Canadian Wildlife Service 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 m for a total transect width of 400 m. Other waterbirds that could be identified from the air (e.g., Great Blue Heron [*Ardea herodias*], Great Egret [*Ardea alba*], American Coot [*Fulica americana*]) were also recorded. Transects crossing impounded wetlands were situated along the longest axis and approximately

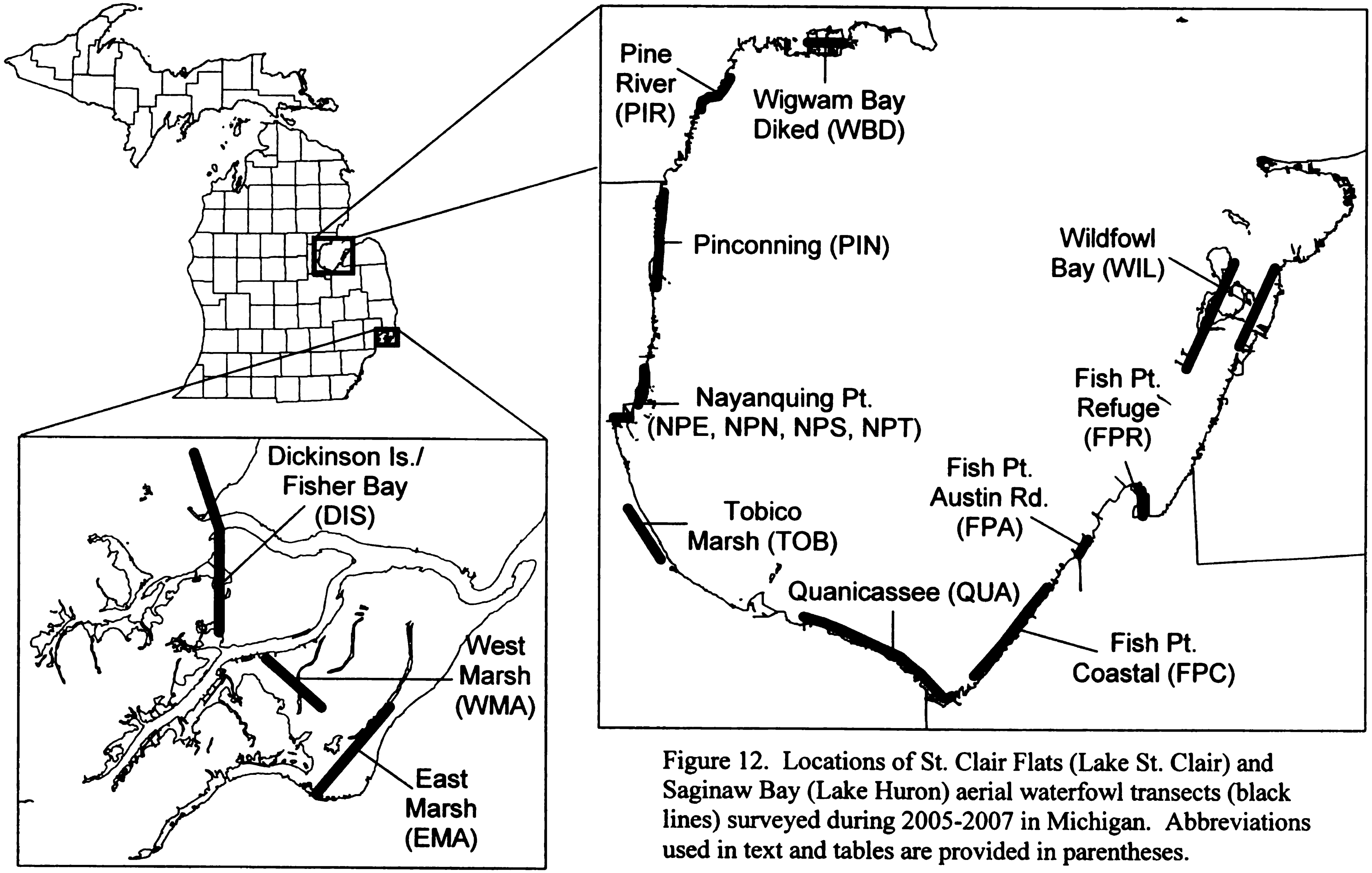

Figure 12. Locations of St. Clair Flats (Lake St. Clair) and Saginaw Bay (Lake Huron) aerial waterfowl transects (black lines) surveyed during 2005-2007 in Michigan. Abbreviations used in text and tables are provided in parentheses.

Table 13. Approximate total area, water management capability[1], number of transects/routes surveyed, and estimated area covered during migrant bird surveys at St. Clair Flats and Saginaw Bay, Michigan coastal wetlands during 2005-2007.

	St. Clair Flats				Saginaw Bay												
	Diked		Undiked		Diked								Undiked				
	EMA	WMA	DIS	LMU	FPA	FPR	NPE	NPN	NPS	NPT	TOB	WBD	FPC	PIN	PIR	QUA	WIL
Water Management[1]	A	A	N	N	P	O	P	O	O	O	P	P	N	N	N	N	N
Approximate Wetland Area	330	293	848	526	33	187	104	57	48	32	293	363	318	258	291	746	1030
Aerial Waterfowl Surveys																	
Number of Transects																	
2005	1	1	1	---	1	1	1	2	1	1	1	2	1	1	1	1	5
2006	1	1	2	---	1	1	1[2]		1	---	1	1	1	1	1	1	2
2007	1	1	2	---	1	1	1[2]		1	---	1	1	1	1	1	1	2
Area (ha) Surveyed																	
2005	93.0	91.3	129.3	---	45.0	70.7	69.8	60.8	41.3	27.7	163.3	174.4	310.5	138.6	124.0	466.9	1032.9
2006	139.9	91.3	205.7	---	45.0	70.7	101.6[2]		41.3	---	163.3	95.3	310.5	256.2	124.0	466.9	550.5
2007	139.9	91.3	205.7	---	45.0	70.7	101.6[2]		41.3	---	163.3	95.3	310.5	256.2	124.0	466.9	550.5
Transect Length (km)																	
2005	2.3	2.3	3.2	---	1.1	1.8	1.7	1.5	1.0	0.7	4.1	4.4	7.8	3.5	3.1	11.7	25.8
2006	3.5	2.3	5.1	---	1.1	1.8	2.5[2]		1.0	---	4.1	2.4	7.8	6.4	3.1	11.7	13.8
2007	3.5	2.3	5.1	---	1.1	1.8	2.5[2]		1.0	---	4.1	2.4	7.8	6.4	3.1	11.7	13.8

Table 13. Cont'd.

	St. Clair Flats				Saginaw Bay												
	Diked		Undiked		Diked								Undiked				
	EMA	WMA	DIS	LMU	FPA	FPR	NPE	NPN	NPS	NPT	TOB	WBD	FPC	PIN	PIR	QUA	WIL
Fall Ground Surveys																	
Number of Transects																	
2005	---	2	2	---	1	1	---	1	1	1	---	---	---	---	1	2	---
2006	2	2	2	2	1	1	---	1	1	1	---	1	---	---	1	1	2
2007	2	2	2	2	1	1	---	1	1	1	---	1	---	---	1	1	2
Area (ha) Surveyed																	
2005	---	51.5	121.4	---	8.4	24.7	---	5.7	14.0	6.8	---	---	---	---	33.8	92.2	---
2006	68.3	69.4	259.4	233.1	8.4	41.8	---	9.1	30.6	6.8	---	49.0	---	---	87.5	87.5	140.4
2007	68.3	69.4	259.4	233.1	14.9	28.4	---	9.1	30.6	6.8	---	49.0	---	---	87.5	87.5	140.4
Edge (km) Surveyed																	
2005	---	32.7	17.6	---	3.2	3.9	---	1.9	4.8	2.3	---	---	---	---	3.6	8.7	---
2006	44.6	45.5	25.9	31.0	3.2	10.6	---	3.5	9.3	2.3	---	29.1	---	---	9.4	7.7	22.1
2007	44.6	45.5	25.9	31.0	4.9	5.3	---	3.5	9.3	2.3	---	29.1	---	---	9.4	7.7	22.1
Edge:Area Ratio (km/ha)																	
2005	---	0.63	0.14	---	0.38	0.16	---	0.33	0.34	0.34	---	---	---	---	0.11	0.09	---
2006	0.65	0.66	0.10	0.13	0.38	0.25	---	0.38	0.30	0.34	---	0.59	---	---	0.11	0.09	0.16
2007	0.65	0.66	0.10	0.13	0.33	0.19	---	0.38	0.30	0.34	---	0.59	---	---	0.11	0.09	0.16

[1]Water Management Capability: A=Active, O=Opportunistic, P=Passive, and N=None. See Study Areas section for description.
[2]Transects combined for NPE and NPN due to short length, proximity, and reduced maneuverability of fixed-wing aircraft.

through the middle of the wetland. This positioning was used because emergent marsh and open water were interspersed throughout the impoundments, so centering transects across each diked wetland provided a consistent means of surveying impoundments, while also minimizing possible edge effects caused by dikes. 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

I 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 (Table 13, see also Figure 1, Chapter 1). Surveys were done in areas of open water/aquatic bed wetland or exposed substrate near the interface with emergent vegetation, which is the zone most likely to provide the shallow water or mudflats used by most wetland bird species for foraging (see Fredrickson and Taylor 1982, Weller 1999). I surveyed birds while moving along routes that 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. In impounded wetlands, observers either traveled by foot or vehicle along dikes or by boat so that routes generally paralleled the water-vegetation interface. Areas of open water or mudflat, as indicated by aerial photos or initial surveys, located inside of the wetland edge and not accessible by boat, were surveyed by foot as much as practicable. All shorebirds, waterbirds, and waterfowl seen within 150 m of the emergent vegetation edge were counted. I noted the approximate locations of individuals/groups of birds on aerial photographs to avoid double-counting. Routes were surveyed in the morning between sunrise and four hours after sunrise. I surveyed two routes at large study sites that could not be adequately sampled in one morning (Table 13). 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. I conducted surveys between late July and mid September and surveys of a given route were spaced approximately two to three weeks apart.

Vegetation and Physical Variable Sampling

To characterize the vegetation and physical conditions along fall ground survey routes, I collected water depth, vegetation, and soil information at the open water-emergent vegetation interface where surveys occurred. Data were collected at approximately 20 points located at equidistant intervals along each survey route. I positioned sample points at the edge of the emergent vegetation, or in the areas with diffuse interfaces of water and vegetation, where emergent vegetation became dominant (i.e., $\geq$50% vegetation). At each sample point, I measured the water depth, estimated the percent aerial coverage of dominant vegetation types within 1 m of the point (3 m^2), and categorized the soil type as either organic (i.e., muck- or peat-dominated soil) or inorganic (i.e., sand-, silt-, or clay-dominated soil). I combined similar plant species into the following structural groups: persistent deep-water emergents, persistent shallow-water emergents, non-persistent deep-water emergents, non-persistent 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, such as cattail (*Typha* spp.), bulrushes (*Schoenoplectus* spp.), and sedges (*Carex* spp.), and non-persistent 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 consisted of 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, rushes (*Juncus*, spp.), and grasses, were placed in the persistent shallow-water category. Although common reed can survive inundation, I considered it a persistent shallow-water emergent species because it often establishes in moist soils or shallow water, tends to occur near the wetland-upland interface, and its growth and survival is inhibited by long-term flooding with deep water (Roman et al. 1984, Tucker 1990, Marks et al. 1994). Species such as arrowhead (*Sagittaria* spp.), pickerelweed (*Pontedaria cordata*), and wild rice (*Zizania* spp.) were included in the non-persistent deep-water emergent category. Non-persistent shallow-water emergents consisted of species such as spikerushes (*Eleocharis* spp.), smartweeds (*Polygonum* spp.), and beggars tick (*Bidens* spp.). I also estimated percent cover individually for the three most common taxa: cattail, bulrush, and common reed (*Phragmites australis*). Water depths were measured only once in 2005, but I measured depths during each survey in 2006 and 2007 to account for fluctuating water levels. I only sampled the vegetation and soil once per year. Due to time constraints, I was only able to conduct vegetation and physical variable sampling at the Saginaw Bay area on six (three diked, three undiked) of the eight routes in 2005 and nine (five diked, four undiked) of the 10 routes in 2007.

Analysis

Aerial Waterfowl Surveys: I estimated waterfowl densities for each transect by dividing the number of birds observed by the total area surveyed. I compared 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. Density variables were log (natural) transformed prior to analysis. I analyzed avian 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. Mixed models are an effective means of analyzing multilevel data structures (Wagner et al. 2006). Some analyses produced G matrices that were not positive definite when one of the covariance parameter estimates equaled zero. In those cases, I set the lower boundary for the covariance parameters with zero estimates at a small value close to zero using the PARMS statement (SAS Institute 2004), which allowed the G matrices to be positive definite. Two values (0.0000001 and 0.00001) were used as the lower bound for covariance parameters with zero estimates in initial models. The new models achieved positive definite G matrices, but did not alter the original decisions regarding null hypotheses or parameter estimates. Values used for the lower bound of covariance parameter estimates (i.e. 0.0000001 or 0.00001) changed p-values and AIC estimates slightly, but not selection of the best-approximating models or decisions regarding null hypotheses.

Fall Migration Ground Surveys: I calculated both areal and linear bird densities as indices of abundance of migrant birds at diked and undiked wetlands. Areal bird densities for each survey route were calculated by dividing the number of birds observed by the total area of open water/aquatic bed wetland surveyed. I calculated linear bird densities at each route by dividing the number of birds observed by the total amount of edge (interface of emergent vegetation and open water) covered during surveys. I analyzed both density indices because linear density may be an appropriate measure of bird abundance for two reasons: 1) migrant wetland birds often focus foraging activity at the interface of emergent vegetation and open water, and 2) the outer boundary used to delineate survey areas along open shorelines was sometimes arbitrary. Linear density has been used previously as an index of shorebird use along shorelines (Neuman et al. 2008). I examined the relationship between the two density measures using Pearson product-moment correlation (CORR procedure, SAS Institute 2004), and used the chi-square test (FREQ procedure, SAS Institute 2004) to compare the frequencies of species with higher densities in diked and undiked wetlands between the two density calculations. The total area of wetland and length of edge surveyed along each route was estimated with ArcView 3.2 using 2005 color aerial imagery. I compared several density variables between diked and undiked 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. A list of wetland-dependent and wetland-associated species (according to Crowley et al. 1996, Brown and Smith 1998), as well as common and scientific names for all birds species observed, is provided in Appendix A (Table A-1). Nomenclature follows the American Ornithologists' Union *Check-list of North American Birds* (American Ornithologists' Union 1998) and subsequent supplements. I log (natural) transformed avian density variables prior to analysis.

I 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. I incorporated a repeated measures component to account for multiple surveys along the same route. Using the above model, I evaluated three commonly used covariance structures: autoregressive order one (AR[1]), compound symmetric (CS), and unstructured (UN) (Littell et al. 1996, Kincaid 2005). I compared models containing the repeated measures component with a standard mixed model with no repeated measures. For each bird density variable, I selected the best-approximating model using Akaike's Information Criterion (AIC). In comparisons of areal density variables, UN covariance appeared to function best of three structures used based on AIC values (Table C-1). Models containing the UN covariance structure were best-approximating in 29 of the 33 areal density variables tested. Best-approximating models for two of the variables contained the CS structure, one of the best-approximating models contained the AR(1) structure, and the standard mixed model was best-approximating for one variable. Model selection changed decisions regarding rejection of null hypotheses that areal bird densities are similar between diked and open wetlands for three species: Black-crowned Night-Heron (*Nycticorax nycticorax*), Spotted Sandpiper (*Actitis macularius*), and Wilson's Snipe (*Gallinago delicata*) (Table C-1). Parameter estimates were similar among the models tested. Some analyses produced G matrices that were not positive definite when one of the covariance parameter estimates equaled zero. In those cases, I set the lower bound for covariance parameter(s) that equaled zero using the same procedure described above. Values used for the lower bound of covariance parameter estimates (i.e. 0.0000001 or 0.00001) changed p-values and AIC estimates slightly, but not selection of the best-approximating models or decisions regarding null hypotheses (Table C-2).

Of the 33 linear density variables analyzed, 27 of the best-approximating models used UN covariance (Table C-3). Best-approximating models for four of the linear density variables contained the AR(1) structure, and the standard mixed model was best-approximating for two variable. Model selection altered decisions regarding the null hypothesis for five linear density variables (all birds, wetland-dependent birds, total waterfowl, Blue-winged Teal [*Anas discors*], and Greater Yellowlegs [*Tringa melanoleuca*]), but least squares mean estimates were similar among the models. When analyses produced G matrices that were not positive definite, I set the lower bound for covariance parameters that equaled zero using the same method described above. Setting the lower bound of the covariance parameters only altered p-values and AIC estimates slightly and did not change selections of the best-approximating models or decisions regarding null hypotheses (Table C-4).

I used three similarity indices (Jaccard, Sorensen, and Morisita) to examine the level of similarity between the migrant bird communities of diked and undiked wetlands. The Jaccard and Sorensen indices are calculated using species presence-absence data, while the Morisita index also incorporates species abundance. I calculated similarity indices between diked and undiked wetlands for all study areas and sites combined.

I conducted correspondence analysis (CA) to evaluate potential relationships in migrant bird abundance observed during ground surveys at the open water-emergent vegetation interface of diked and undiked study sites. Correspondence analysis is often used in ecological analyses of species data at different sampling sites (Legendre and Legendre 1998). I categorized the bird data for CA using the following 11 bird species/groups: dabbling ducks, diving ducks, geese and swans, Wood Ducks (*Aix sponsa*), Pied-billed Grebes (*Podilymbus podiceps*), bitterns, herons, rails, American Coots (*Fulica americana*) and Common Moorhens, shorebirds, and gulls and terns. Birds were categorized based on similarities in habitat use and feeding strategies. Areal densities were used as the index of bird abundance to account for differences in the size of survey areas. I averaged densities by site and year prior to analysis. I only interpreted the first two dimensions and the solution was not rotated.

Vegetation and Physical Variable Sampling: I compared percent cover and water depth data gathered during plot surveys between diked and undiked wetlands using mixed models (MIXED procedure, SAS Institute 2004). Percent variables were arcsine-square root transformed and water depths were log (natural) transformed prior to analysis. I compared vegetation variables using a mixed model with wetland type and study area as fixed effects, and year and site as random effects. I used a mixed model consisting of wetland type, study area, and survey (one, two, three, and four) as fixed effects and year and site as random effects to compare water depths. I used the chi-square test (FREQ procedure, SAS Institute 2004) to compare the frequencies of organic and inorganic soils observed at points between diked and undiked wetlands.

To evaluate the variation in vegetation and physical variables among diked and undiked survey routes, I conducted principal components analysis (PCA) on vegetation and physical variables gathered during plot sampling using SAS (PRINCOMP procedure, SAS Institute 2004). Vegetation and physical data gathered at all plots along a given route were averaged by year prior to analysis. I did not include percent cover of litter in the PCA, due to low frequency of occurrence (4% of total plots). The following 13 variables were used in the PCA: water depth, and percent cover of total emergents, open water/aquatic bed, submersed vegetation, floating vegetation, persistent deep-water emergents, persistent shallow-water emergents, non-persistent deep-water emergents, non-persistent shallow-water emergents, cattail, bulrush, common reed, and exposed sediments. Percent variables were arcsine-square root transformed prior to analysis. Correlation coefficients were used to form the cross-products matrix and the ordination axes were not rotated. When evaluating the importance of the principal component loadings, I only considered loadings greater than 0.34 or less than -0.34, which is an approach similar to interpreting correlation coefficient significance at a 0.01 alpha level and sample size of about 50 (Hair et al. 1987, McGarigal et al. 2000).

RESULTS

Aerial Waterfowl Surveys

Geometric mean densities (birds per ha) for most waterfowl and waterbird variables were similar between diked and undiked coastal wetlands (Table 14). Wood Duck and Gadwall (*Anas strepera*) were the only species observed in greater densities in diked than undiked wetlands (p=0.0008 and p=0.0069, respectively). Canada Goose (*Branta canadensis*) and American Black Duck (*Anas rubripes*) mean densities were greater in undiked compared to diked sites (p=0.0114 and p=0.0043, respectively). Table C-5 (Appendix C) 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

Most of the areal bird density (birds per ha) variables were similar between diked and undiked coastal wetland types (Table 15). Geometric mean areal densities of Wood Duck (p<0.0001), Great Blue Heron (p=0.0006), and Wilson's Snipe (p=0.0018) were greater in diked compared to undiked wetlands. Ring-billed Gull (*Larus delawarensis*) and Forster's Tern average areal densities were greater in undiked than diked sites (p=0.0126 and p<0.0001, respectively). Areal densities and frequencies of occurrence for all bird species observed during fall ground surveys are provided by study area and wetland type in Table C-6 (Appendix C).

Table 14. Least squares geometric means and lower and upper 95% confidence limits by wetland type for waterfowl and waterbird densities (birds per ha wetland) 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 ($p<0.05$).

	Diked (n=14)			Undiked (n=14)			
Bird Density Variable	Mean	Lower CL	Upper CL	Mean	Lower CL	Upper CL	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 15. Least squares geometric means and lower and upper 95% confidence limits (CL) by wetland type for areal bird densities (birds per ha wetland) 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 ($p<0.05$).

	Diked (n=86)			Undiked (n=69)			
Bird Density Variable	Mean	Lower CL	Upper CL	Mean	Lower CL	Upper CL	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-cr. 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

Average linear (birds per km of edge surveyed) and areal (birds per ha surveyed) densities for species observed during fall migration ground surveys were correlated ($r=0.910$, $p<0.0001$), and a chi-square test revealed no difference ($p=0.0794$) between linear and areal densities in the number of species with greatest densities in diked and undiked wetlands. Similar to the areal bird density results, I found significantly greater mean linear densities (birds per km of edge) of Wood Duck ($p=0.0001$) in diked wetlands, and greater linear densities of Ring-billed Gull ($p=0.0003$) and Forster's Tern ($p=0.0002$) in undiked wetlands (Table 16). I also observed significantly greater mean linear densities of wetland-associated birds ($p=0.0028$), dabbling ducks ($p=0.0119$), Mallard ($p=0.0064$), and Greater Yellowlegs ($p=0.0275$) in undiked than diked sites.

Total bird species richness was similar between diked and undiked wetlands with 53 species observed in both wetland types (Table 17). 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. All three similarity indices indicated the species composition of diked and undiked wetlands during fall ground surveys was similar, with a Jaccard index of 0.77, Sorensen index of 0.87, and Morisita index of 0.67.

Table 16. Least squares geometric means and lower and upper 95% confidence limits (CL) by wetland type for linear bird densities (birds per km edge) 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 ($p<0.05$).

	Diked (n=86)			Undiked (n=69)			
Bird Density Variable	Mean	Lower CL	Upper CL	Mean	Lower CL	Upper CL	P-value
All Birds	9.22	5.13	16.04	20.15	10.78	36.97	0.0564
Wetland-dependent Birds	9.18	5.07	16.06	19.12	10.13	35.35	0.0762
Wetland-associated Birds	0.19	-0.02	0.46	0.61	0.31	1.00	**0.0028**
Total Waterfowl	6.58	3.30	12.37	11.44	5.52	22.75	0.2355
Total Dabbling Ducks	1.81	0.30	5.10	11.57	4.12	29.87	**0.0119**
Total Waterbirds	2.41	1.27	4.13	3.98	2.14	6.90	0.2200
Total Shorebirds	0.76	0.15	1.70	1.17	0.34	2.52	0.4878
Calidris spp. Shorebirds	0.17	-0.08	0.49	0.15	-0.13	0.50	0.8974
Wetland-dependent Species							
Canada Goose	0.21	-0.05	0.53	0.43	0.09	0.87	0.3337
Mute Swan	0.22	-0.06	0.60	0.09	-0.19	0.46	0.4790
Wood Duck	2.37	1.49	3.56	0.38	-0.03	0.95	**0.0001**
Gadwall	0.06	-0.04	0.17	0.02	-0.10	0.15	0.6055
Mallard	1.13	0.05	3.29	8.18	3.07	19.69	**0.0064**
Blue-winged Teal	0.42	0.12	0.80	0.68	0.32	1.14	0.0682
Green-winged Teal	0.65	0.21	1.25	1.02	0.43	1.86	0.3254
Great Blue Heron	0.60	0.36	0.88	0.38	0.15	0.67	0.2413
Great Egret	0.52	0.09	1.14	1.11	0.43	2.12	0.2041
Green Heron	0.14	-0.06	0.38	<0.01	-0.20	0.24	0.3356
Black-cr. Night-Heron	0.10	0.04	0.18	0.05	-0.02	0.12	0.1460
Pied-billed Grebe	0.43	0.07	0.92	0.21	-0.14	0.70	0.4304
Common Moorhen	0.09	0.04	0.16	0.08	0.01	0.14	0.6266
American Coot	0.09	-0.04	0.23	0.19	0.05	0.34	0.3028
Spotted Sandpiper	0.13	0.02	0.24	0.06	-0.05	0.18	0.3519
Solitary Sandpiper	0.06	-0.01	0.14	0.03	-0.05	0.11	0.4755
Greater Yellowlegs	0.12	-0.03	0.30	0.40	0.19	0.65	**0.0275**
Lesser Yellowlegs	0.18	-0.14	0.62	0.41	-0.02	1.03	0.4256
Least Sandpiper	0.09	-0.08	0.29	0.18	-0.03	0.44	0.5035
Wilson's Snipe	0.21	0.11	0.31	0.11	0.01	0.22	0.0679
Ring-billed Gull	0.11	-0.08	0.33	0.61	0.32	0.96	**0.0003**
Black Tern	0.08	0.03	0.14	0.08	0.02	0.13	0.4494
Forster's Tern	<0.01	-0.04	0.05	0.13	0.07	0.18	**0.0002**
Wetland-associated Species							
Killdeer	0.17	-0.03	0.41	0.26	0.04	0.53	0.4650
Caspian Tern	0.10	-0.01	0.22	0.22	0.09	0.38	0.1574

Table 17. 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	Open
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 17. Cont'd.

Species	Diked	Common	Open
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

The first dimension of the correspondence analysis explained 45.0% of the variation and the second dimension 24.0% of the variation in bird densities among the sites during early fall migration ground surveys. Correspondence analysis separated the bird species/groups into two groups along the first dimension, with coots/moorhens alone on the negative end and the remaining groups clumped from approximately zero to about 0.55 on the positive end (Figure 13). Dabbling ducks, coots/moorhens, and shorebirds had negative coordinates in the second dimension, while all other bird species/groups had positive coordinate values, with Wood Duck and bitterns having the greatest values (Table 18). Diked and undiked sites were largely separated along the second dimension. Undiked wetlands formed two groups on the negative end of dimension two: the first consisting of undiked St. Clair Flats sites associated with greater American Coot and Common Moorhen densities, and the second made up of undiked Saginaw Bay sites that appeared related to greater dabbling duck and shorebird abundance compared to other sites (Figure 13). A small group of diked Saginaw Bay sites also had negative dimension two values and were clumped with the undiked Saginaw Bay wetlands, indicating greater dabbling duck and shorebird densities compared to other diked sites. Many of the diked wetlands appeared to be associated with greater Wood Duck and bittern densities than other sites (Figure 13).

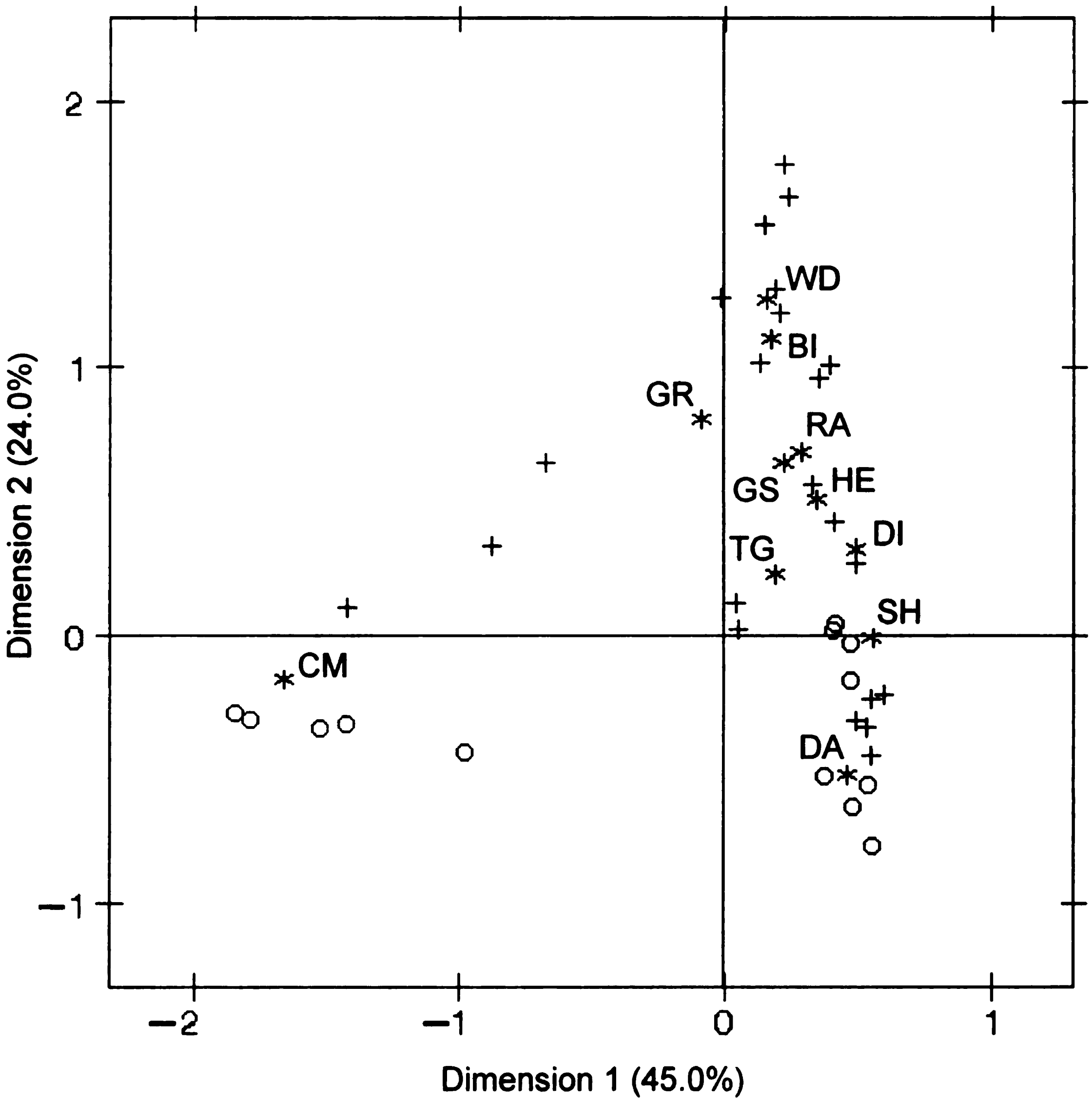

Figure 13. Biplot of site and bird group coordinates for dimensions 1 and 2 from correspondence analysis conducted using fall migration ground survey data collected at St. Clair Flats (SCF) and Saginaw Bay (SAG), Michigan, coastal wetlands, 2005-2007. Site coordinates are coded by wetland type ("+" diked; "o" undiked). Bird group coordinates are coded with an "*" and labeled as follows: BI = bitterns, CM = American Coots and Common Moorhens, DA = dabbling ducks, DI = diving ducks, GR = Pied-billed Grebes, GS = Canada Geese and swans, HE = herons, RA = rails, SH = shorebirds, TG = terns and gulls, and WD = Wood Ducks.

Table 18. First and second dimension coordinates for birds species/groups included in correspondence analysis conducted using data from 45 fall migration ground surveys done along 21 routes at St. Clair Flats and Saginaw Bay, Michigan, coastal wetlands, 2005-2007.

Bird Species/Group	Dimension 1	Dimension 2
Dabbling Ducks (DA)	0.4535	-0.5188
Diving Ducks (DI)	0.4854	0.3201
Canada Geese/Swans (GS)	0.2166	0.6395
Wood Ducks (WD)	0.1549	1.2528
Pied-Billed Grebes (GR)	-0.0921	0.8069
Bitterns (BI)	0.1721	1.1045
Herons (HE)	0.3419	0.5018
American Coots/Common Moorhens (CM)	-1.6618	-0.1646
Rails (RA)	0.2807	0.6834
Shorebirds (SH)	0.5486	-0.0087
Terns/Gulls (TG)	0.1874	0.2280

Vegetation and Physical Variable Sampling

Most vegetation and physical variables measured along fall ground survey routes were similar between diked and undiked wetlands (Table 19). I found similar mean percent cover estimates between diked and undiked wetlands for emergent, open water/aquatic bed, and submersed vegetation. I observed greater mean percent cover of floating vegetation ($p<0.0001$) in diked compared to undiked wetlands. Mean percent cover of cattail was greater in diked wetlands ($p=0.0015$), while average percent cover of bulrush was greater in undiked wetlands ($p<0.0001$). The number of plots with organic and inorganic soils differed between diked and undiked sites ($p<0.0001$). Most plots within diked wetlands were dominated by organic soils, while undiked wetlands that largely consisted of inorganic soils, such as sand or silt (Table 19).

Table 19. Least squares means and lower and upper 95% confidence limits (CL) for vegetation and habitat variables measured during three-m^2 plot sampling conducted during fall ground surveys for birds 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).

	Diked			Undiked			
Bird Density Variable	Mean	Lower CL	Upper CL	Mean	Lower CL	Upper CL	P-value
Percent Cover							
No. Samples		571			497		---
Emergent Vegetation	51.0	40.5	61.5	48.6	38.1	59.3	0.2646
Open Water/Aquatic Bed	44.1	31.8	56.8	49.2	36.1	62.4	0.3645
Submersed Vegetation	17.4	7.3	30.6	6.8	0.9	17.6	0.0907
Floating Vegetation	14.0	9.3	19.4	0.1	-0.3	1.2	**<0.0001**
Persistent Deep-water	22.3	12.0	34.6	22.2	10.9	36.0	0.9907
Persistent Shallow-water	5.7	1.9	11.4	3.6	0.6	9.0	0.4790
Non-persist. Deep-water	0.4	<0.1	2.4	1.2	<0.1	4.1	0.5264
Non-persist. Shallow-water	1.2	0.2	3.0	0.8	<0.1	2.6	0.6823
Cattail	18.1	9.0	29.5	1.5	0.1	7.3	**0.0015**
Bulrush	0.2	0.1	1.2	14.9	10.1	20.5	**<0.0001**
Common Reed	1.6	0.4	3.6	2.7	0.8	5.5	0.4144
Surface Litter	<0.1	-0.3	0.2	0.1	<0.1	0.8	0.1699
Exposed Sediments	0.8	<0.1	3.3	0.2	0.4	1.9	0.2703
Sediment Type (Proportion of Total Samples)							
No. Samples		570			497		NA
Organic	94.2	---	---	5.8	---	---	χ^2 Test
Inorganic	9.0	---	---	91.0	---	---	**<0.0001**
Water Depth							
No. Samples		1666			1527		NA
Depth (m)	0.27	0.15	0.41	0.20	0.07	0.35	0.4440

The first component from the PCA explained 27.6% of the variation in vegetation and physical variables among the fall migration ground survey routes, while the second component explained 21.3% of the variation. Principal component 1 (PC 1) primarily represented a gradient from bulrush and common reed marsh with low percent cover of floating vegetation to cattail marsh with high levels of floating vegetation (Figure 14). The first principal component was positively related to percent cover of cattail, floating vegetation, and persistent deep-water emergents, and negatively related to percent cover of bulrush, common reed, and persistent shallow-water emergents (Table 20). Principal component 2 (PC 2) represented a gradient from deep-water open wetlands dominated by submersed and non-persistent deep-water vegetation to shallower marshes dominated by deep-water persistent emergents (Figure 14). The second PC was positively related to percent cover of submersed vegetation, non-persistent deep-water emergents, and open water/aquatic bed, and water depth, and negatively related to persistent deep-water emergents (Table 20). Diked and undiked routes were largely separated along the first axis, with diked wetlands tending to have higher PC 1 scores compared to undiked wetlands (Figure 14). Diked wetland survey routes tended to be dominated by cattail with greater percent cover of floating vegetation compared to undiked sites, while undiked routes usually were dominated by bulrush and common reed. Diked and undiked survey routes had similar scores for PC 2, indicating similar variation in percent cover of submersed vegetation, non-persistent and persistent deep-water emergents, and open water/aquatic bed wetland, and water depths along the open water-emergent marsh interface (Table 20).

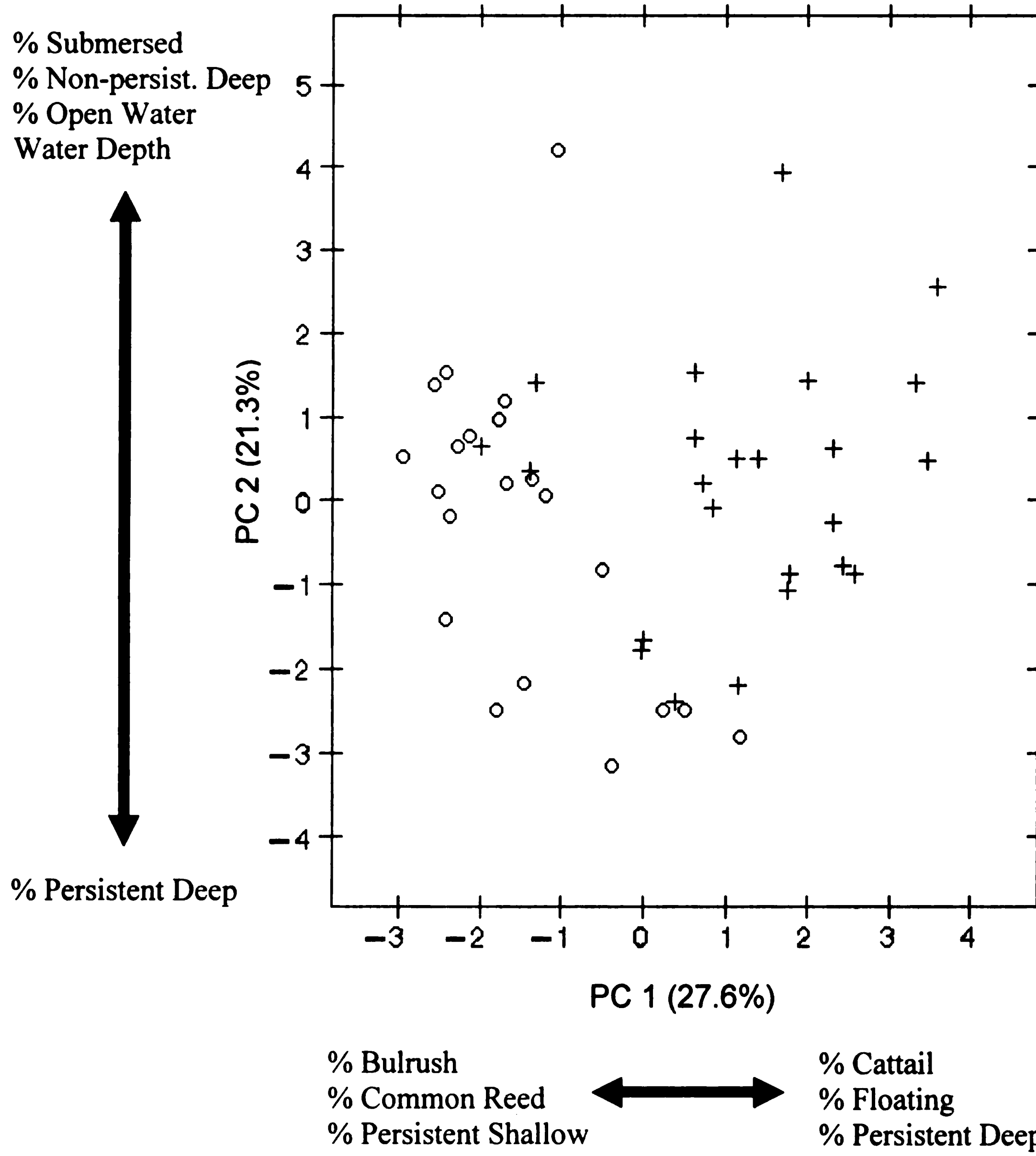

Figure 14. Bi-plot of PC 1 X PC 2 from principal components analysis conducted using 13 vegetation and physical variables gathered during plot sampling during 45 fall migration bird surveys of 21 routes at St. Clair Flats and Saginaw Bay, Michigan, 2005-2007. Point scores are coded by wetland type ("+" diked; "o" undiked).

Table 20. Eigenvectors for first two principal components obtained through PCA of habitat data collected during 45 fall migration ground surveys conducted along 21 routes at St. Clair Flats and Saginaw Bay, Michigan, coastal wetlands, 2005-2007.

Habitat Variable	Principal Component 1	Principal Component 2
Percent Cover		
Emergent Vegetation	0.0319	0.0536
Open Water/Aquatic Bed	0.0598	0.3443
Submersed Vegetation	0.1463	0.5037
Floating Vegetation	0.4042	0.1539
Persistent Deep-water	0.3402	-0.3426
Persistent Shallow-water	-0.3096	0.2207
Non-persistent Deep-water	-0.0992	0.3947
Non-persistent Shallow-water	-0.1689	0.0982
Typha	0.4725	-0.0868
Schoenoplectus	-0.3692	-0.2292
Phragmites australis	-0.3542	0.1781
Exposed Sediments	-0.0483	-0.2636
Water Depth (m)	0.2707	0.3293

DISCUSSION

Bird Use of Diked and Undiked Wetlands

I observed few differences in migrant waterfowl densities between diked and undiked coastal wetlands during aerial surveys. Most estimated mean areal densities for waterfowl species from early fall ground surveys were also similar between wetland types, but mean linear densities of dabbling ducks and Mallards were greater in undiked than diked wetlands. No studies evaluating migrant bird use of diked and undiked coastal wetlands were found for the Great Lakes region. Brasher et al. (2007) found that duck foraging resources were abundant during fall in both actively (i.e., with water-level control) and passively (i.e., no water-level control) managed wetlands in Ohio. I did not measure food resources in this study, but greater linear densities of dabbling ducks and Mallards in undiked wetlands could be due to more abundant foods and/or shallower water depths that provided better access to foods. Water depths along the emergent-open water interface were comparable between diked and undiked wetlands, but depths tended to be shallower at undiked sites. Water depths measured at randomly selected quadrats during the breeding season were greater at diked compared to undiked sites (see Chapter 2). Fredrickson and Taylor (1982) indicated that preferred foraging depths for Mallards in seasonally flooded impoundments was approximately 10-15 cm, so the shallow water depths observed in the undiked wetlands could provide better foraging habitat than diked wetlands. Canada Goose densities were greater in undiked wetlands during aerial surveys, while fall ground surveys revealed similar densities in diked and undiked wetlands. This discrepancy 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 flocks (i.e., >100 individuals) of Canada Geese were observed on undiked 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 have been secure roosting areas. Wood Duck densities were greater in diked than undiked wetlands during both aerial and early fall ground surveys. I observed the same pattern of Wood Duck densities during the breeding season, and greater use of diked sites could be related to cover provided by dense floating-leaved vegetation.

My surveys indicated fall migration shorebird use of diked and undiked coastal wetlands was similar. Wilson's Snipe was the only shorebird species observed in greater densities in diked than undiked wetlands; greater densities of Wilson's Snipe in diked wetlands may have been related to the prevalence of organic soils and high invertebrate abundance (Provence 2008). Linear densities of Greater Yellowlegs were greater in undiked compared to diked wetlands, which was the only shorebird density variable observed in greater abundance in undiked wetlands.

Ring-billed Gull and Forster's Tern densities during fall migration ground surveys were greater in undiked than diked wetlands, which is the same pattern observed during breeding surveys of the same sites (see Chapter 2). Fish are an important component of the diets of both species (see Ryder 1993, McNicholl et al. 2001), and studies conducted in Lake Erie coastal wetlands indicated differences in total fish species richness and abundance, age class frequencies, lengths, and body condition indices for some species between diked and undiked wetlands (Johnson et al. 1997, Markham et al. 1997). I did not measure fish abundance and composition in my study, but it would be useful to know the relative abundance of forage fish to understand the effects coastal wetland diking on these bird species. Foraging in diked wetlands may have been more difficult for these species due to greater coverage of floating-leaved vegetation compared to undiked wetlands.

Vegetation and Physical Characteristics of Diked and Undiked Wetlands

Plot sampling along ground survey routes indicated some differences in vegetation and physical variables at the open water-emergent interfaces of diked and undiked wetlands. I observed greater percent cover of floating vegetation and cattails in diked compared to undiked wetlands, and these differences were likely due to higher, more stable water levels in diked sites. Although water levels of diked wetlands often dropped dramatically during the summer, the majority of the wetlands remained inundated throughout the season. Percent cover of bulrush was greater in undiked than diked wetlands. Intensive quadrat sampling during the breeding season revealed similar differences in vegetation and physical characteristics of diked and undiked wetlands (see Chapter 2). Albert and Brown (2008) observed similar results when comparing the vegetation at several of the same diked and undiked study sites. Principal components analysis of the vegetation and physical data provided analogous results to parametric comparisons. Diked and undiked survey routes were primarily separated along the first axis, which indicated that diked routes were usually dominated by cattail marsh and had greater percent cover of floating vegetation than undiked sites, while undiked routes were dominated by bulrush and common reed. In vegetation comparisons between diked and undiked wetlands, Herrick and Wolf (2005) similarly found greater cattail cover in diked wetlands and greater common reed cover in undiked wetlands. Lower mean percent cover 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. In North America, cattails outcompete other plant species in wetlands with high fertility and low disturbance (Moore et al. 1989, Wisheu and Keddy 1992). Diked wetlands likely experience less disturbance than undiked sites due to higher water levels and infrequent complete drawdowns, and greater fertility due to high organic content of soils and trapped nutrients. Herrick et al. (2007) stated that diked coastal wetlands appeared to serve as traps for organic matter and nutrients.

Management Implications

Despite some differences in habitat, migrant bird use of diked and undiked wetlands was largely similar. A common criticism of diked coastal wetlands is that their management tends to focus on waterfowl or game species, potentially at the detriment of rare and/or non-game bird species. The results of my study do not support this criticism. Forster's Tern (State special concern) was the only rare species observed in greater densities in undiked than diked wetlands. In addition to Forster's Tern, I observed 13 bird species of greatest conservation need (SGCN, Eagle et al. 2005) often enough to permit statistical comparisons between diked and undiked wetlands. Mean American Black Duck density was greater in undiked wetlands, while Great Blue Heron and Wilson's Snipe densities were greater in diked sites; the remaining 10 SGCN were similar between diked and undiked wetlands. Species richness was also similar between the two wetland types, and similarity indices indicated that the bird communities of diked and undiked wetlands were comparable.

Wilcox (1995) suggested that shorebird habitat provided by continually changing Great Lakes water levels may be lost when coastal wetlands are isolated through diking. My observations during fall migration revealed that shorebird use was similar between diked and undiked wetlands. Although water depths tended to be higher in diked than 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. I also observed that low water conditions in diked wetlands sometimes created mats of organic matter and submersed vegetation that shorebirds used for foraging. Given recent comparisons of invertebrate abundance and composition in diked and undiked wetlands of St. Clair Flats (see Provence 2008), these diked habitats likely had high abundances of invertebrate foods for shorebirds. In some cases, pumping to increase water levels in diked wetlands in preparation for fall waterfowl hunting reduced available habitat for migrant shorebirds. Minor alterations to water management schedules could enhance habitat for migrant shorebirds at a time when available shorebird habitat in coastal wetlands could be limited. Differences in migrant shorebird use of diked and undiked wetlands could be more prominent in spring. The high spring water levels of diked wetlands probably limit use by migrant shorebirds compared to undiked wetlands, which tend to have lower water levels in spring than summer. In a study of impoundments in Delaware Bay, Parsons (2002) observed greatest migrant shorebird abundance in impoundments with low spring water levels. Potter et al. (2007)

noted that migrant shorebird habitat may be more limited during the fall migration compared to spring, due to vegetation coverage. However, they assumed that spring was the habitat-limited season because the migration period is short and precedes the breeding season, therefore the timing of resource availability is most critical.

Invasive populations of common reed have substantially expanded in Great Lakes coastal wetlands during the recent period of low water levels (Tulbure et al. 2007, E. Kafcas, Michigan Department of Natural Resources, person. commun.). Most climate change models predict decreasing Great Lakes water levels in the future (Mortsh et al. 2000, 2006, Lofgren et al. 2002, Croley 2003), which could further increase common reed expansion in undiked wetlands and potentially reduce the value of these habitats for birds species of management concern. Given that the future status of coastal wetlands is uncertain, diked wetlands may provide important management opportunities to maintain and improve habitats for wetland birds and reduce impacts from invasive plant species like common reed.

Greater mean linear densities of total dabbling ducks and Mallards in undiked compared to diked wetlands was not predicted because they are focal management species. I did not evaluate food resources during the early fall migration season in this study, so it is unknown whether these differences are related to food availability, access, or other factors. Fredrickson and Taylor (1982) indicated that the preferred foraging depths for Mallards, Blue-winged Teal, and Green-winged Teal ranged from about 10-20 cm in seasonally flooded impoundments. Managing the diked wetlands for shallower water depths could potentially increase dabbling duck use by providing preferred foraging conditions. According to correspondence analysis, two diked wetlands at Fish

Point State Wildlife Area appeared to be associated with greater dabbling duck abundance than other sites. One of these sites is only passively managed and does not have a water pump, while the second site has a pump that was rarely used in recent years due to low Lake Huron water levels. Both sites typically had lower water depths compared to other diked sites, especially in late summer when exposed mudflats were often present.

Periodic complete drawdowns of the diked wetlands could potentially improve habitat conditions for migrant birds. Kadlec and Smith (1992) noted three potential benefits of drawdowns: nutrient release due to the decomposition of organic sediments, consolidation of loose sediments due to drying, and the germination and establishment of emergent vegetation, including annual species. Drawdowns could reduce the buildup of organic matter, release nutrients and stimulate plant growth, and improve vegetation and structural diversity of the diked marshes. Recommended frequencies for drawdowns have ranged from 5 to 7 years (Harris and Marshall 1963, Whitman 1976). Moist-soil management requires more frequent drawdowns (Fredrickson and Taylor 1982), but could be an effective means of producing plant foods attractive to dabbling ducks during fall and spring migration. Since drawdowns can encourage growth of invasive plant species (Fredrickson and Taylor 1982), I suggest close monitoring of the vegetation response if drawdowns are conducted.

Research Needs

This study occurred during a period of low Great Lakes water levels, and water level fluctuations and depths are known to influence bird use of wetlands (e.g., Weller and Spatcher 1965, Steen et al. 2006, Timmermans et al. 2008). Migrant bird use of diked and undiked coastal wetlands could be different from the results of this study during normal to high water levels. More study is needed during other parts of the Great Lakes water level cycle to investigate if patterns of bird use change under different hydrological conditions. Long-term studies are also needed to understand changes in Great Lakes coastal wetlands that occur over 5-20 years. Research is needed to understand the effects of structural differences (e.g., water depths, floating vegetation mats, interspersion) in the habitats of diked and undiked wetlands on migrant bird use. Since shorebird habitat is thought to be limiting during spring migration in the Great Lakes region (Potter et al. 2007), comparisons of shorebird use between diked and undiked coastal wetlands during spring are needed to assess management actions. Investigations are needed to determine the availability of plant and animal foods for migrant waterfowl, waterbirds, and shorebirds in diked and undiked coastal wetlands, and to examine if wetland bird density and diversity is linked to those food resources.

Management guidelines need to be developed to maximize wildlife benefits in diked wetlands in the context of changing coastal wetland conditions associated with climate change and invasive species expansion, and for specific species of concern (e.g., game, threatened, endangered, SGCN). Diked wetlands provide opportunities to conduct experimental studies that test the success of water level management regimes (e.g., lower water levels, periodic drawdowns) for selected management goals (e.g., increased use by important migrant bird groups). For example, even though migrant dabbling ducks are often a focus of diked wetland management, linear densities tended to be greater in undiked than diked wetlands. Water levels could be experimentally lowered in diked wetlands to evaluate if dabbling duck densities increase when preferred water depths for foraging are provided.

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CHAPTER 4

MANAGEMENT IMPLICATIONS

Management actions that isolate wetlands from their natural ecological forces have become controversial. The construction of dikes in Great Lakes coastal wetlands separates the hydrology of diked wetlands from the adjacent lakes, which ultimately leads to changes in biogeochemical cycles, water levels and fluctuations, vegetation, and food resources for birds (Provence 2008). Between the 1950s and 1970s, several coastal wetlands were isolated from normal water level fluctuations through dike construction at important migrant waterfowl stop-over areas (see Bellrose 1980, Bookhout et al. 1989). These projects were initiated primarily to maintain elevated water depths and enhance wildlife use during periods of historic low Great Lakes water levels.

The vegetation and physical characteristics of diked and undiked wetlands were different during avian breeding and migration periods (Figures 15-17). Diked coastal wetlands were generally dominated by cattail and had higher water depths and more organic sediment, open water, and floating vegetation compared to undiked wetlands (Table 21). Conversely, undiked wetlands had shallower water depths, inorganic soils, and more common reed, bulrush, and litter than diked wetlands. The timing and intensity of water level fluctuations can influence bird use, and diked wetlands had fluctuations similar to those of inland wetlands, with water levels highest in early spring, declining during the breeding season, and lowest in late summer. Undiked wetlands exhibited similar water level fluctuations to diked wetlands in 2005 and 2007, with water levels

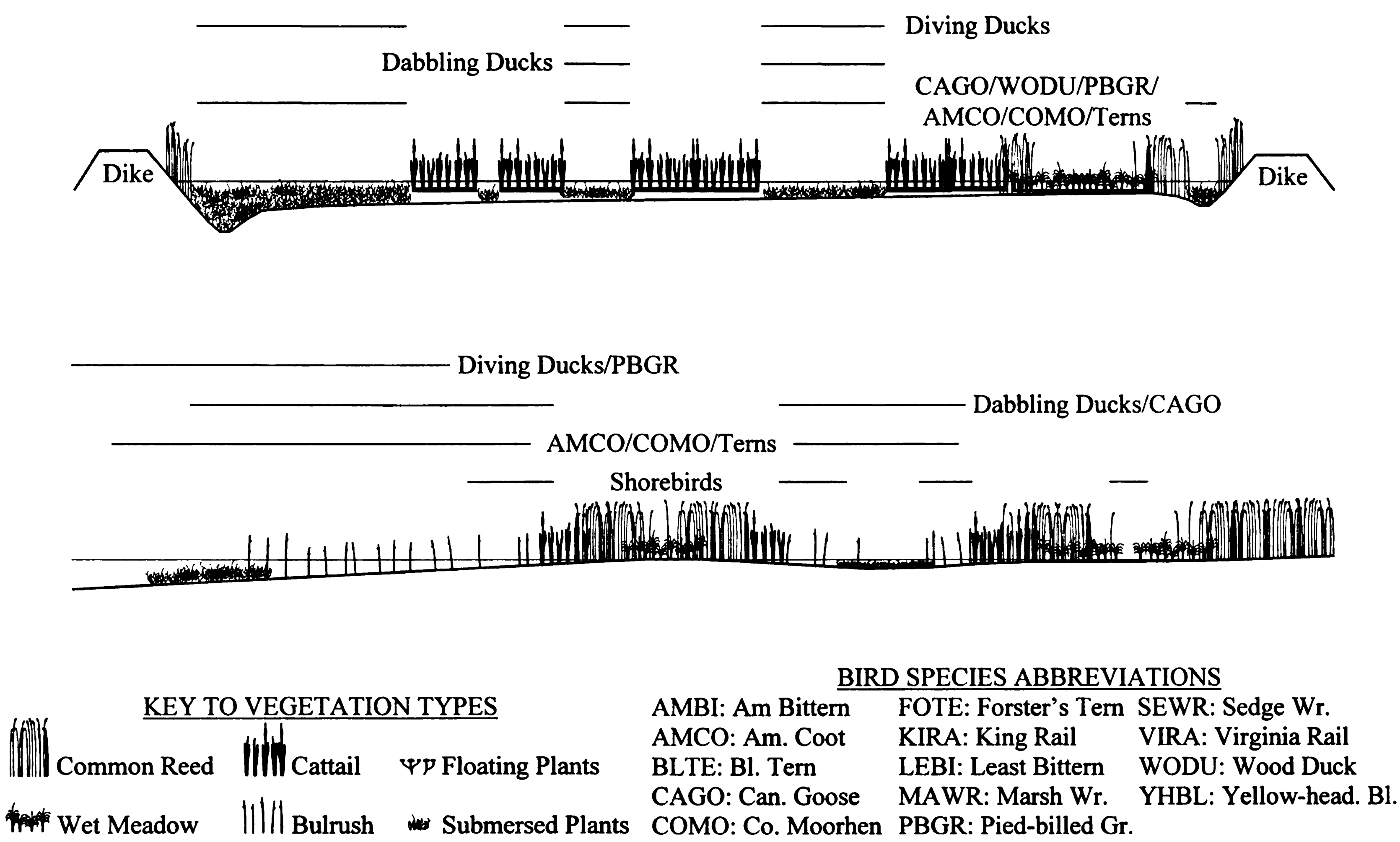

Figure 15. Typical simplified profiles of diked and undiked St. Clair Flats and Saginaw Bay coastal wetlands during early spring 2005-2007. Lines indicate vegetation zones used by bird species/groups during spring migration.

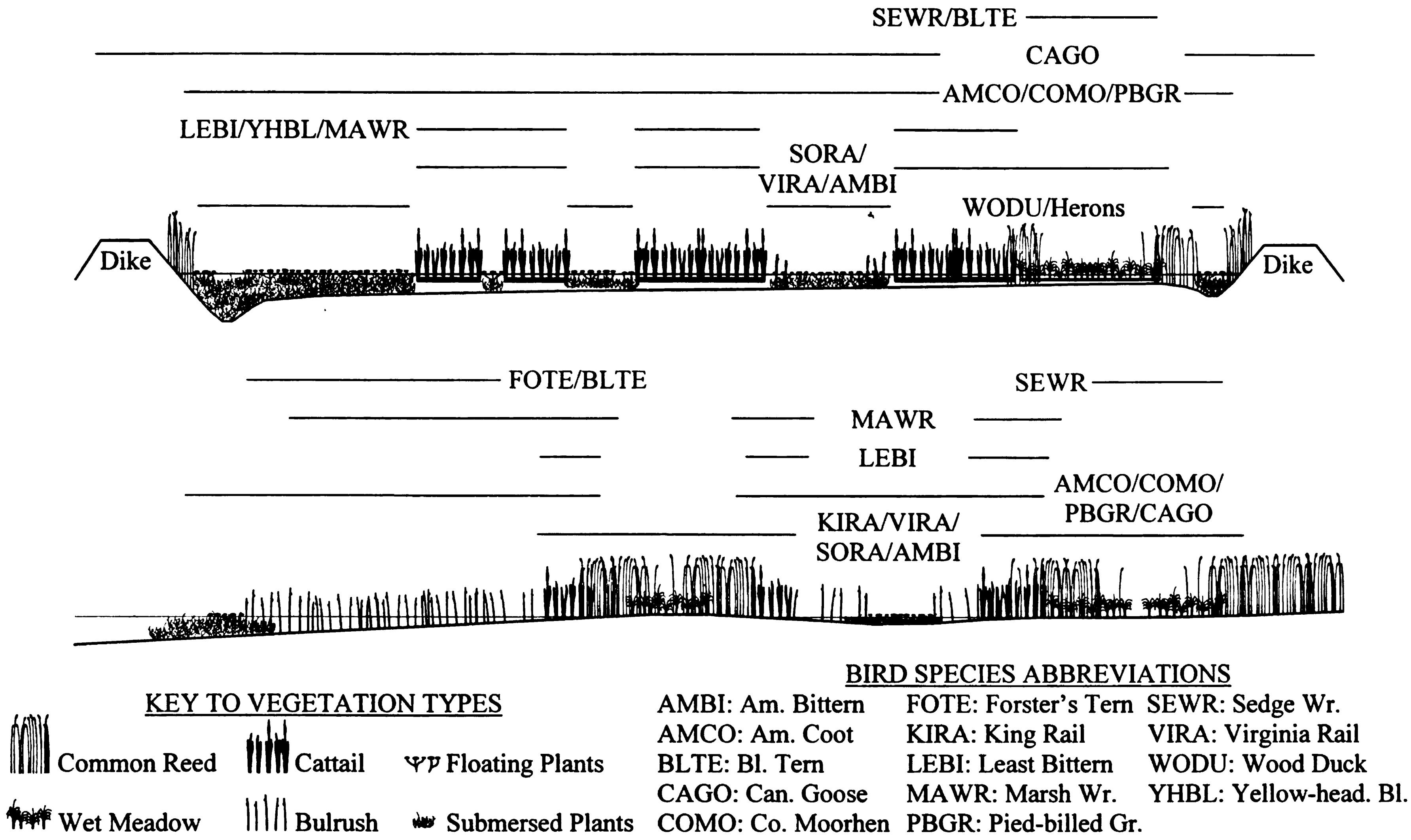

Figure 16. Typical simplified profiles of diked and undiked St. Clair Flats and Saginaw Bay coastal wetlands during late spring to mid summer 2005-2007. Lines indicate vegetation zones used by bird species/groups during the breeding season.

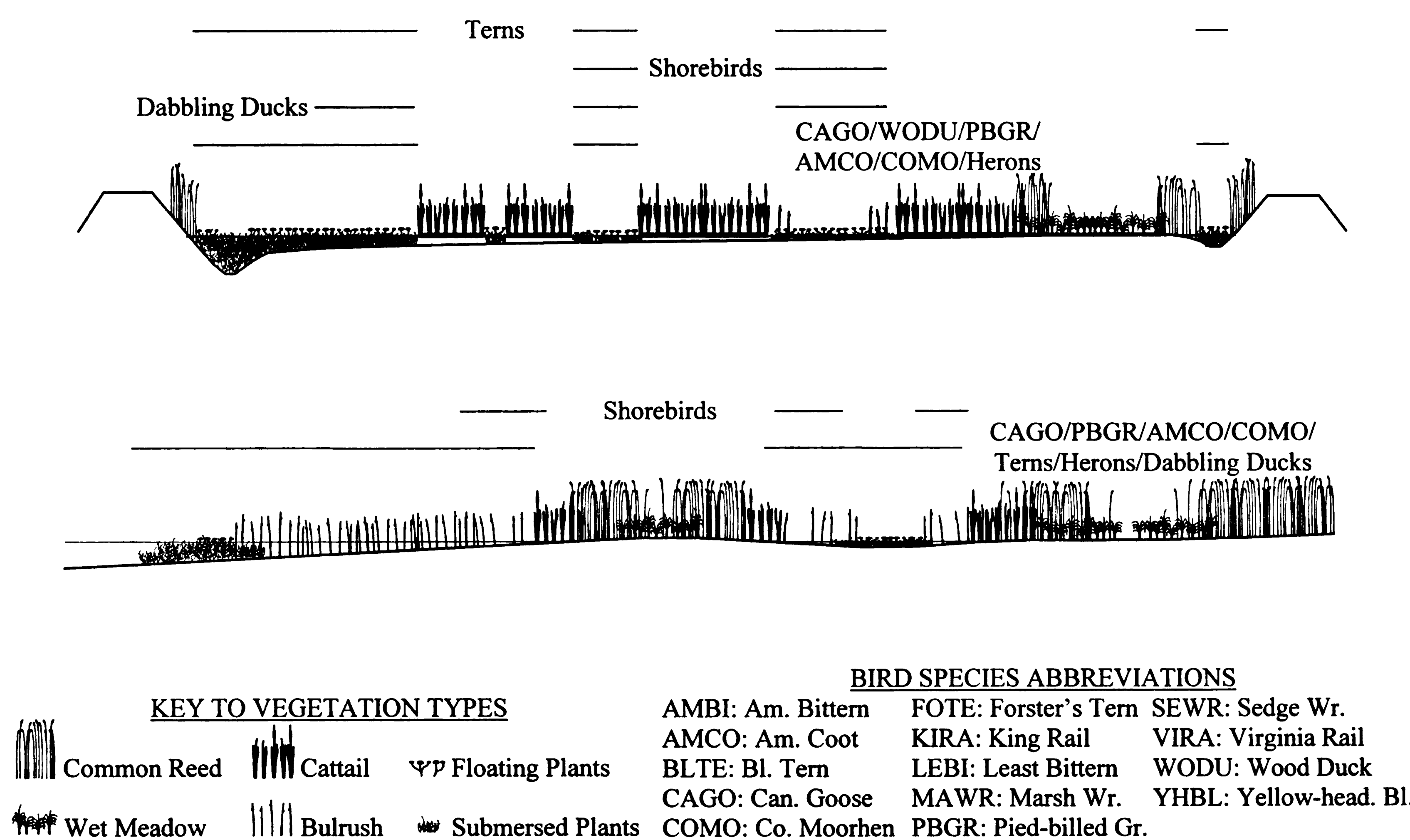

Figure 17. Typical simplified profiles of diked and undiked St. Clair Flats and Saginaw Bay coastal wetlands during late summer to early fall 2005-2007. Lines indicate vegetation zones used by bird species/groups during early fall migration.

Table 21. Matrix indicating potential relationships between bird species/groups and wetland conditions at St. Clair Flats and Saginaw Bay, Michigan, wetlands during breeding and migration periods. Estimated availability of wetland features at diked and undiked sites is coded as follows: no shading = absent to low; gray shading = low to medium; black shading = medium to high; and ? = uncertain status. Positive (+) signs indicate wetland features used by a bird species/group, based on this study or other research, and a "?" designates uncertainty due to limited data.

	Vegetation Zone									Microhabitat					Depth		Food			
	Phragmites	Cattail	Bulrush	Wet Meadow	Floating	Submersed	Non-persistent Shallow	Non-persistent Deep	Shrubs/Trees	Floating Cattail	Floating Wet Meadow	Bulrush Rack	Submersed Mat	Exposed Soil	Shallow (<20 cm)	Deep (>20 cm)	Invertebrate	Fish	Amphibians	Vegetation
Spring Migration																				
Diked																		?	?	
Undiked																		?	?	
Bird Species/Group																				
Canada Goose		+			+	+								+	+	+				+
Wood Duck		+			+	+			+							+	+			+
Dabbling Ducks		+			+	+								+	+		+			+
Diving Ducks					+	+										+	+			+
American Bittern	+	+		+						+					+	+	+	+	+	
Least Bittern	+	+								+						+	+	+	+	
Herons		+			+	+			+						+	+	+	+	+	
Pied-billed Grebe					+	+						+				+	+	+		
Rails	?	+		+						+					+		+	+	+	+
Coots/Moorhens		+			+	+				+		+			+	+	+			+
Shorebirds														+	+		+			
Gulls					+	+						+		+	+	+	+	+		

Table 21. Cont'd.

	Vegetation Zone									Microhabitat					Depth		Food			
	Phragmites	Cattail	Bulrush	Wet Meadow	Floating	Submersed	Non-persistent Shallow	Non-persistent Deep	Shrubs/Trees	Floating Cattail	Floating Wet Meadow	Bulrush Rack	Submersed Mat	Exposed Soil	Shallow (<20 cm)	Deep (>20 cm)	Invertebrate	Fish	Amphibians	Vegetation
Spring Migration																				
Black Tern					+	+					+	+			+	+	+	+		
Forster's Tern					+	+						+			+	+	+	+		
Caspian Tern					+	+								+	+	+		+		
Breeding Season																				
Diked																		?	?	
Undiked																		?	?	
Bird Species/Group																				
Canada Goose		+	+		+	+	+							+	+	+				+
Wood Duck		+			+	+		+	+							+	+			+
Dabbling Ducks		+	+		+	+	+								+		+			+
Diving Ducks		+	+		+	+					+					+	+			+
Pied-billed Grebe		+	+		+	+				+		+				+	+	+		
American Bittern	+	+	+	+			+			+					+	+	+	+	+	
Least Bittern	+	+	+					+		+						+	+	+	+	
Herons		+	+		+	+		+	+						+	+	+	+	+	
Rails	+	+	+	+			+			+					+		+	+	+	+
Coots/Moorhens	?	+	+		+	+				+	+	+			+	+	+			+
Shorebirds														+	+		+			
Gulls					+	+						+		+	+	+	+	+		

Table 21. Cont'd.

	Vegetation Zone									Microhabitat					Depth		Food			
	Phragmites	Cattail	Bulrush	Wet Meadow	Floating	Submersed	Non-persistent Shallow	Non-persistent Deep	Shrubs/Trees	Floating Cattail	Floating Wet Meadow	Bulrush Rack	Submersed Mat	Exposed Soil	Shallow (<20 cm)	Deep (>20 cm)	Invertebrate	Fish	Amphibians	Vegetation
Breeding Season																				
Black Tern		+	+		+	+					+	+			+	+	+	+		
Forster's Tern			+		+	+						+			+	+	+	+		
Caspian Tern					+	+								+	+	+		+		
Fall Migration																				
Diked																		?	?	
Undiked																		?	?	
Bird Species/Group																				
Canada Goose		+	+		+	+	+							+	+	+				+
Wood Duck		+			+	+		+	+							+	+			+
Dabbling Ducks		+	+		+	+	+	+					+	+	+		+			+
Diving Ducks					+	+											+			+
American Bittern	+	+	+	+			+			+					+	+	+	+	+	
Least Bittern	+	+	+					+		+						+	+	+	+	
Herons		+	+		+	+		+	+						+	+	+	+	+	
Pied-billed Grebe					+	+						+				+	+	+		
Rails	?	+	+	+			+			+					+		+	+	+	+
Coots/Moorhens		+	+		+	+		+		+	+	+			+	+	+			+
Shorebirds													+	+	+		+			
Gulls					+	+						+	+	+	+	+	+	+		

Table 21. Cont'd.

	Vegetation Zone									Microhabitat					Depth		Food			
	Phragmites	Cattail	Bulrush	Wet Meadow	Floating	Submersed	Non-persistent Shallow	Non-persistent Deep	Shrubs/Trees	Floating Cattail	Floating Wet Meadow	Bulrush Rack	Submersed Mat	Exposed Soil	Shallow (<20 cm)	Deep (>20 cm)	Invertebrate	Fish	Amphibians	Vegetation
Fall Migration																				
Black Tern					+	+					+	+			+	+	+	+		
Forster's Tern					+	+						+			+	+	+	+		
Caspian Tern					+	+						+		+	+	+		+		

declining during summer months, although the decrease in water levels at diked wetlands was more pronounced compared to undiked sites. In 2006, water levels in undiked wetlands peaked during late summer, which was consistent with long-term averages on the Great Lakes.

Bird Use During Spring Migration

Due to time and resource constraints, my surveys for birds during spring migration were limited to aerial waterfowl surveys. Only 14 aerial waterfowl surveys were conducted, which did not permit comparisons between diked and undiked wetlands by time period (i.e., spring, late summer, early fall). However, some predictions can be made regarding bird use of diked and undiked wetlands based on observed vegetation, water depths, and water level fluctuations (Figure 15). Canada Goose densities were greater in undiked compared to diked wetlands during migration, and large flocks (i.e., >100 individuals) of Canada Geese were observed on undiked 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 have been secure roosting areas. Wood Ducks seemed to positively respond to the deep, aquatic bed zones of diked wetlands, and were observed there in greater densities than on undiked sites regardless of season. Dabbling and diving duck species used both wetland types in spring, with diving ducks focused in deeper water depths and dabbling ducks in shallower areas (Figure 15). Gadwall density was greater in diked compared to undiked sites, and Gadwalls may have been attracted to submersed aquatic plants in diked wetlands, which are an important food source for this species (Table 21, Bellrose 1980). Based on my personal observations and the high spring water depths of diked wetlands, shorebird use was likely lower in diked compared to undiked sites (Figure 15). Parsons (2002) observed greatest migrant shorebird abundance in Delaware Bay impoundments with low spring water levels. Potter et al. (2007) assumed that the timing of resource availability for shorebirds is most critical during spring migration in the Great Lakes and Upper Mississippi River region, because the migration period is short and precedes the breeding season. Depending on the spring migration management goals, changes to water level manipulations may be required in diked wetlands to maximize use by some bird groups. For example, increasing densities of most shorebird and dabbling duck species in diked wetlands would require lower spring water levels. More study is needed to better understand bird use of diked and undiked coastal wetlands during spring migration, as well as to determine management guidelines that increase use by focal bird groups.

Bird Use During Breeding Season

Although there were clear differences in the vegetation and physical conditions of diked and undiked coastal wetlands, breeding bird use was largely similar (Figure 16). Bird species richness was similar between diked and undiked wetlands and similarity indices suggested the breeding bird communities were comparable. This similarity may reflect the ability of most wetland bird species to adapt to dynamic wetland conditions. Wetland birds often use complexes of wetlands to meet life requisites (see Dzubin 1969, Brown and Dinsmore 1986, Weller 1999), and all of the diked wetlands were within large complexes of undiked wetlands. Diking also did not appear to negatively impact use by non-game bird species of conservation concern (e.g., listed or species of greatest conservation need [SGCN, Eagle et al. 2005]). While overall bird use between the two wetland types was similar, more study is needed to compare reproductive success (e.g., nest densities, nest success) of priority species in diked and undiked wetlands.

Several species seemed to respond to differences in vegetation, hydrology, and/or food resources between the wetland types. Management of diked wetlands appeared to benefit several species that use deep-water marshes for breeding. I observed greater densities of Canada Goose and Wood Duck in diked compared to undiked wetlands during the breeding season. Higher water levels in diked wetlands likely provided attractive brood rearing habitat with abundant food for both species near nesting sites. American Bittern, Least Bittern, and Common Moorhen were observed in greater densities in diked than undiked wetlands. Higher water levels and greater percent open water in the diked wetlands may have increased interspersion of emergent vegetation and open water, which could have provided attractive breeding habitat for these species (Table 21). Deeper water levels in diked compared to undiked wetlands may have created a stable environment for the invertebrates, amphibians, small fish, and submersed vegetation used by these species for food.

Some bird species appeared more abundant in undiked compared to diked wetlands. Mallard linear density was greater in undiked sites during timed-area surveys. Mallards prefer to forage in shallow water (Fredrickson and Taylor 1982), so shallower water depths at undiked wetlands could account for greater Mallard abundance. Although invertebrates were more abundant at diked than undiked sites at St. Clair Flats (Provence 2008), deep water may have limited access to invertebrate and plant foods used by Mallards and other wetland birds. I observed greater densities of Ring-billed Gull, Herring Gull, and Forster's Tern in undiked than diked wetlands, which could be related to differences in forage fish abundance between the wetland types, conditions limiting the ability of these species to forage in diked wetlands (e.g., floating and/or submersed plants), or proximity to nesting sites. 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 (Figure 16). Percent cover and density of bulrush were lower in diked compared to undiked wetlands (Table 21).

If maximizing use of diked wetlands by breeding birds is a goal, water level manipulations could potentially increase use by some species. Managing diked wetlands for shallower water depths could enhance use by Mallards and many other wetland bird species by improving access to abundant invertebrate and plant foods. Periodic (e.g., every 5-7 yrs) complete drawdowns of diked wetlands could improve habitats for breeding birds by reducing the buildup of organic matter, releasing nutrients and stimulating plant growth, and improving vegetation and structural diversity of the diked wetlands.

Given that common reed was more prevalent in undiked than diked wetlands, it was surprising that more differences in breeding bird use were not observed between the wetland types. Due to low lake levels, I selected point count locations within 400 m of open water, which may have reduced potential effects to bird use caused by common reed in undiked wetlands. Meyer (2003) investigated wildlife use of common reed and native vegetation in one coastal wetland complex, but more research is needed to understand the effects of common reed on breeding birds. Since recent common reed expansions have occurred with low Great Lakes water levels, studies need to evaluate bird use of common reed under a variety of water depths. Some diked wetlands contained pockets of common reed, which provide opportunities to study bird use of common reed under flooded conditions.

Bird Use During Fall Migration

Vegetation and substrates along open water-emergent marsh interfaces surveyed during ground surveys differed between diked and undiked wetlands, which was consistent with quadrat sampling done during the breeding season (Table 21). Cattail, floating vegetation, and organic soils were more common in diked wetlands, while bulrush and inorganic soils were observed more often in undiked sites (Figure 17). Despite these differences, migrant bird use of diked and undiked wetlands was similar. Most bird density variables and total species richness were similar between the wetland types, and similarity indices also implied similar bird communities. Some authors (e.g., Wilcox 1995) have suggested that diked wetlands may negatively impact shorebirds and rare species. I found that most densities of rare species (i.e., threatened, endangered, special concern), SGCN, and shorebirds were similar between diked and undiked wetlands during fall migration. Migrant wetland birds are known to use a variety of wetland types within larger complexes to meet life needs (e.g., foraging, resting, escape cover). All the diked wetlands studied were located within large undiked wetland complexes, so the similarity of migrant bird use during late summer/early fall suggests that birds were using larger wetland complexes, rather than individual wetlands. More study is needed to understand why bird species were using the diked and undiked wetlands during migration.

A few species appeared to respond to differences in the vegetation and physical conditions of diked and undiked wetlands. Canada Goose densities were greater in undiked wetlands during aerial surveys, while fall ground surveys revealed similar densities in diked and undiked wetlands. This discrepancy may be due to seasonal changes in Canada Goose densities and habitat use, such as high numbers in undiked Saginaw Bay wetlands during spring migration, high variation of densities during migration, and the low number of aerial surveys conducted. Wood Duck densities were greater in diked compared to undiked wetlands during both aerial and early fall ground surveys, which is consistent with breeding season surveys. Linear densities (birds/km of edge surveyed) of dabbling ducks and Mallards were greater in undiked compared to diked wetlands. Wilson's Snipe was the only shorebird species observed in greater densities in diked wetlands and may have been attracted to organic soils and high invertebrate abundance. Greater Yellowlegs were observed in greater linear densities in undiked wetlands, but was the only shorebird species more abundant in undiked wetlands. Similar to breeding season surveys, Ring-billed Gull and Forster's Tern densities were greater in undiked than diked wetlands during early fall surveys. More study is needed to determine if fish abundance and composition or wetland microhabitats influenced use by Ring-billed Gull and Forster's Tern.

Greater abundance of dabbling ducks and Mallards in undiked wetlands could be related to food abundance or foraging habitat. These species seemed to be attracted to sites with shallow water depths (Figure 17), which may have offered preferred foraging conditions (Fredrickson and Taylor 1982). Other studies (e.g., behavioral, radio-tracking) are needed to understand why (e.g., feeding, resting) waterfowl were using diked and undiked wetlands. Assuming that maximizing use by dabbling ducks is a management goal, managing diked wetlands for shallow water levels (e.g., 10-20 cm) could increase dabbling duck densities. Periodic drawdowns could also promote growth of annual moist-soil plant species that provide valuable food for dabbling ducks and other bird species. However, close monitoring would be required, since drawdowns can also encourage invasive species, such as common reed.

My observations during fall migration revealed that shorebird use was similar between diked and undiked wetlands. Although water depths tended to be higher in diked compared to undiked wetlands, water levels in diked wetlands were usually lowest in late summer, which provided pockets of mudflats and shallow water at a time when fall shorebird migration typically peaks (Figure 17). Low water conditions in diked wetlands sometimes created mats of organic matter and submersed vegetation that shorebirds used for foraging. Dabbling ducks, such as Green-winged Teal, Blue-winged Teal, and Mallard, were observed using the same habitats (Figure 17). In some cases, pumping water into impoundments in preparation for fall waterfowl hunting flooded these shallow-water habitats and reduced use by shorebirds and dabbling ducks. Maintaining shallow water depths in impoundments further into early fall (e.g., mid to late September) could sustain habitat for shorebirds for the duration of most species' fall migration period.

Management Discussion

The primary objective of my study was to compare bird use and habitats of several diked and undiked Great Lakes coastal wetlands, rather than answer the larger question as to whether the practice of coastal wetland diking should be continued at current levels, possibly expanded, or ended. While my work provides insight into one component of this larger question, additional studies, such as wetland function comparisons, other fish and wildlife investigations, cost-benefit analyses, and value assessments, are also required. Comparisons of bird use during normal to high Great Lakes water levels are also needed. This study was also not designed to evaluate specific management practices used in diked wetlands; however, some general recommendations can be made based on my findings and likely management goals.

Biologists can manage water levels in diked coastal wetlands to achieve a variety of goals, such as improved conditions for wildlife (e.g., game, endangered, or threatened, species), vegetation diversity, recreation, and invasive species eradication. Management recommendations will vary depending on stated goals, and some goals may not be compatible at a given site. For example, managing to provide foraging habitat for spring migrant shorebirds will likely impact breeding habitat for some bird species (e.g., bitterns, Common Moorhen). In general, the differences in bird use and abundance between diked and undiked wetlands, though minor, seemed to be related to differences in water depths and vegetation resulting from coastal wetland diking. There appears to be potential for managers to increase use of diked wetlands by some bird species by providing shallow water depths and conducting periodic drawdowns. Occasional drawdowns of diked wetlands could improve habitats for breeding birds by improving vegetation and structural diversity, and shallow water depths increase access to invertebrate and plant foods by many wetland bird species. Densities of Mallards, other dabbling ducks, and shorebirds in diked wetlands would likely equal or surpass those of undiked wetlands if managers provide shallow water in diked wetlands during peak migration periods. Drawdowns could also be used to increase the production of annual plant seeds as a food source for migrating dabbling ducks. Where complexes of diked wetlands exist, water levels could be manipulated to provide a variety of wetland conditions (e.g., deep marsh, shallow marsh, mudflat) among the impoundments that address multiple management goals (e.g., multiple bird groups, both breeding and migration periods). Water levels could be changed within each diked wetland periodically on a rotational basis to mimic natural water level fluctuations, while maintaining a diversity of wetland types for birds. Drawdowns must be conducted with caution and constantly monitored to avoid the spread of invasive plant species. Late summer drawdowns are recommended to reduce the expansion of common reed (Avers et al. 2007).

Management guidelines need to be developed for focal species (e.g., game, threatened and endangered, SGCN) in the context of changing coastal wetland conditions, such as climate change and invasive species expansion. Most climate change models predict decreasing Great Lakes water levels in the future (Mortsh et al. 2000, 2006, Lofgren et al. 2002, Croley 2003). Long-term low water levels could increase common reed expansion in undiked wetlands and reduce their value to bird species of management concern. Diked wetlands may provide management opportunities to maximize use by wetland birds and reduce impacts from invasive plant species like common reed. Experimental studies could be implemented in diked wetlands to test the success of new or modified water level management regimes for selected management goals (e.g., use by focal bird species, diverse vegetation).

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APPENDIX A

Common and scientific names for bird species observed during surveys.

Table A-1. Common and scientific names of avian species observed during bird surveys conducted at St. Clair Flats and Saginaw Bay, Michigan coastal wetlands during 2005-2007. Species are listed by wetland use category.

Species	Scientific Name
Wetland-dependent Species	
Canada Goose	*Branta canadensis*
Mute Swan	*Cygnus olor*
Trumpeter Swan	*Cygnus buccinator*
Wood Duck	*Aix sponsa*
Gadwall	*Anas strepera*
American Wigeon	*Anas americana*
American Black Duck	*Anas rubripes*
Mallard	*Anas platyrhynchos*
Blue-winged Teal	*Anas discors*
Northern Shoveler	*Anas clypeata*
Northern Pintail	*Anas acuta*
Green-winged Teal	*Anas crecca*
Canvasback	*Aythya valisineria*
Redhead	*Aythya americana*
Ring-necked Duck	*Aythya collaris*
Scaup (species unknown)	*Aythya spp.*
Bufflehead	*Bucephala albeola*
Hooded Merganser	*Lophodytes cucullatus*
Ruddy Duck	*Oxyura jamaicensis*
Pied-billed Grebe	*Podilymbus podiceps*
Double-crested Cormorant	*Phalacrocorax auritus*
American Bittern	*Botaurus lentiginosus*
Least Bittern	*Ixobrychus exilis*
Great Blue Heron	*Ardea herodias*
Great Egret	*Ardea alba*
Green Heron	*Butorides virescens*
Black-crowned Night-Heron	*Nycticorax nycticorax*
Northern Harrier	*Circus cyaneus*
King Rail	*Rallus elegans*
Virginia Rail	*Rallus limicola*
Sora	*Porzana carolina*
Common Moorhen	*Gallinula chloropus*
American Coot	*Fulica americana*
Sandhill Crane	*Grus canadensis*
Semipalmated Plover	*Charadrius semipalmatus*
Spotted Sandpiper	*Actitis macularius*

Table A-1. Cont'd.

Species	Scientific Name
Wetland-dependent Species, Cont'd	
Solitary Sandpiper	*Tringa solitaria*
Greater Yellowlegs	*Tringa melanoleuca*
Lesser Yellowlegs	*Tringa flavipes*
Semipalmated Sandpiper	*Calidris pusilla*
Least Sandpiper	*Calidris minutilla*
Baird's Sandpiper	*Calidris bairdii*
Pectoral Sandpiper	*Calidris melanotos*
Dunlin	*Calidris alpina*
Stilt Sandpiper	*Calidris himantopus*
Short-billed Dowitcher	*Limnodromus griseus*
Wilson's Snipe	*Gallinago delicata*
American Woodcock	*Scolopax minor*
Red-necked Phalarope	*Phalaropus lobatus*
Bonaparte's Gull	*Chroicocephalus philadelphia*
Ring-billed Gull	*Larus delawarensis*
Herring Gull	*Larus argentatus*
Black Tern	*Chlidonias niger*
Forster's Tern	*Sterna forsteri*
Belted Kingfisher	*Megaceryle alcyon*
Alder Flycatcher	*Empidonax alnorum*
Willow Flycatcher	*Empidonax traillii*
Tree Swallow	*Tachycineta bicolor*
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*
Bank Swallow	*Riparia riparia*
Sedge Wren	*Cistothorus platensis*
Marsh Wren	*Cistothorus palustris*
Swamp Sparrow	*Melospiza georgiana*
Red-winged Blackbird	*Agelaius phoeniceus*
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*
Wetland-associated Species	
Bald Eagle	*Haliaeetus leucocephalus*
Merlin	*Falco columbarius*
Black-bellied Plover	*Pluvialis squatarola*
Killdeer	*Charadrius vociferus*
Caspian Tern	*Hydroprogne caspia*
Common Tern	*Sterna hirundo*
Black-billed Cuckoo	*Coccyzus erythropthalmus*
Eastern Kingbird	*Tyrannus tyrannus*

Table A-1. Cont'd.

Species	Scientific Name
Wetland-associated Species, Cont'd	
Warbling Vireo	*Vireo gilvus*
Purple Martin	*Progne subis*
Cliff Swallow	*Petrochelidon pyrrhonota*
Barn Swallow	*Hirundo rustica*
Gray Catbird	*Dumetella carolinensis*
Yellow Warbler	*Dendroica petechia*
Common Yellowthroat	*Geothlypis trichas*
Common Grackle	*Quiscalus quiscula*
Nonwetland Species	
Ring-necked Pheasant	*Phasianus colchicus*
Rock Pigeon	*Columba livia*
Mourning Dove	*Zenaida macroura*
Chimney Swift	*Chaetura pelagica*
Northern Flicker	*Colaptes auratus*
Blue Jay	*Cyanocitta cristata*
Black-capped Chickadee	*Poecile atricapillus*
American Robin	*Turdus migratorius*
European Starling	*Sturnus vulgaris*
Cedar Waxwing	*Bombycilla cedrorum*
Yellow-rumped Warbler	*Dendroica coronata*
American Redstart	*Setophaga ruticilla*
Scarlet Tanager	*Piranga olivacea*
Song Sparrow	*Melospiza melodia*
Northern Cardinal	*Cardinalis cardinalis*
Rose-breasted Grosbeak	*Pheucticus ludovicianus*
Indigo Bunting	*Passerina cyanea*
Brown-headed Cowbird	*Molothrus ater*
Baltimore Oriole	*Icterus galbula*
American Goldfinch	*Carduelis tristis*

APPENDIX B

Data tables from breeding bird surveys and analyses.

Table B-1. Estimated mean densities ± SE for priority and common marsh bird species observed during surveys at St. Clair Flats (SCF) and Saginaw Bay (SAG), Michigan in 2005-2007 by wetland type and distance category.

	Study	Diked Wetlands				Undiked Wetlands			
Species	Area	0-18 m	18-50 m	50-100m	100-200 m	0-18 m	18-50 m	50-100m	100-200 m
Pied-billed	SCF	---	0.02±0.01	0.02±0.01	0.02±<0.01	0.05±0.05	0.07±0.03	0.06±0.01	0.04±0.01
Grebe	SAG	---	0.03±0.02	0.02±0.01	0.01±<0.01	---	---	---	<0.01±<0.01
American	SCF	0.11±0.08	0.12±0.03	0.08±0.01	0.03±<0.01	---	0.05±0.02	0.03±0.01	0.02±<0.01
Bittern	SAG	---	0.04±0.02	0.04±0.01	0.02±<0.01	---	0.02±0.01	0.03±0.01	0.01±<0.01
Least Bittern	SCF	---	0.07±0.03	0.05±0.01	0.01±<0.01	---	---	0.01±<0.01	<0.01±<0.01
	SAG	---	0.11±0.03	0.03±0.01	0.01±<0.01	---	0.01±0.01	0.01±<0.01	<0.01±<0.01
Virginia Rail	SCF	0.61±0.20	0.31±0.06	0.05±0.01	0.01±<0.01	0.19±0.10	0.22±0.05	0.06±0.01	0.01±<0.01
	SAG	0.47±0.16	0.31±0.07	0.07±0.01	0.01±<0.01	0.50±0.19	0.34±0.07	0.05±0.01	0.01±<0.01
Sora	SCF	0.11±0.08	0.07±0.03	0.01±0.01	<0.01±<0.01	---	0.07±0.02	<0.01±<0.01	<0.01±<0.01
	SAG	0.06±0.06	0.08±0.03	0.03±0.01	<0.01±<0.01	0.06±0.06	0.05±0.02	0.02±0.01	<0.01±<0.01
Common	SCF	---	0.07±0.03	0.01±<0.01	<0.01±<0.01	---	0.09±0.03	0.02±0.01	<0.01±<0.01
Moorhen	SAG	0.06±0.06	0.04±0.02	0.01±0.01	---	---	0.02±0.02	<0.01±<0.01	<0.01±<0.01
American	SCF	0.06±0.06	0.19±0.05	0.06±0.01	0.01±<0.01	0.10±0.07	0.28±0.06	0.15±0.02	0.03±<0.01
Coot	SAG	0.18±0.13	0.08±0.03	0.04±0.01	0.01±<0.01	0.12±0.09	0.11±0.05	0.04±0.01	<0.01±<0.01
Black Tern	SCF	0.61±0.24	0.10±0.03	0.02±0.01	0.01±<0.01	3.35±0.86	0.58±0.14	0.14±0.03	0.03±0.01
	SAG	1.06±0.75	0.20±0.09	0.08±0.03	0.02±0.01	---	---	---	---
Forster's	SCF	0.39±0.14	0.06±0.02	0.01±0.01	<0.01±<0.01	3.49±0.95	0.60±0.13	0.14±0.02	0.04±0.01
Tern	SAG	---	0.02±0.01	---	<0.01±<0.01	0.25±0.15	0.06±0.03	0.03±0.01	0.01±<0.01
Marsh Wren	SCF	9.30±0.84	2.32±0.16	0.41±0.04	0.03±0.01	7.18±0.77	1.88±0.14	0.40±0.03	0.05±0.01
	SAG	5.10±0.63	1.72±0.12	0.39±0.04	0.04±0.01	4.16±0.60	1.68±0.13	0.38±0.04	0.05±0.01
Yellow	SCF	0.22±0.14	0.04±0.02	0.01±0.01	<0.01±<0.01	0.15±0.08	0.10±0.03	0.01±<0.01	<0.01±<0.01
Warbler	SAG	0.82±0.23	0.48±0.07	0.11±0.02	0.01±<0.01	0.74±0.24	0.30±0.06	0.09±0.02	0.02±<0.01
Common	SCF	0.89±0.24	0.47±0.06	0.11±0.02	0.01±<0.01	2.23±0.42	0.78±0.08	0.16±0.02	0.02±<0.01
Yellowthroat	SAG	1.76±0.37	0.70±0.07	0.19±0.02	0.02±<0.01	1.05±0.26	0.63±0.07	0.18±0.02	0.03±<0.01

Table B-1. Cont'd.

Species	Study Area	Diked Wetlands 0-18 m	Diked Wetlands 18-50 m	Diked Wetlands 50-100m	Diked Wetlands 100-200 m	Undiked Wetlands 0-18 m	Undiked Wetlands 18-50 m	Undiked Wetlands 50-100m	Undiked Wetlands 100-200 m
Swamp	SCF	2.40±0.43	1.10±0.10	0.21±0.02	0.02±<0.01	2.76±0.45	0.77±0.08	0.22±0.02	0.03±<0.01
Sparrow	SAG	5.52±0.57	1.43±0.10	0.38±0.03	0.05±0.01	4.41±0.52	1.42±0.10	0.35±0.03	0.05±0.01
Red-winged	SCF	10.58±0.86	3.48±0.16	0.88±0.07	0.17±0.02	11.69±1.02	2.97±0.16	0.79±0.05	0.16±0.02
Blackbird	SAG	6.22±0.68	2.10±0.13	0.63±0.04	0.11±0.01	5.89±0.81	1.78±0.14	0.59±0.04	0.13±0.01

Table B-2. Estimated frequency of occurrence (number of points with species present/number of points surveyed) for priority and common marsh bird species observed during surveys at St. Clair Flats (SCF) and Saginaw Bay (SAG), Michigan in 2005-2007 by wetland type and distance category.

	Study	Diked Wetlands					Undiked Wetlands				
Species	Area	0-18 m	18-50 m	50-100m	100-200 m	>200 m	0-18 m	18-50 m	50-100m	100-200 m	>200 m
Pied-billed	SCF	---	0.01	0.05	0.15	0.44	<0.01	0.03	0.10	0.28	0.73
Grebe	SAG	---	0.01	0.04	0.09	0.31	---	---	---	0.01	0.14
American	SCF	0.01	0.07	0.18	0.23	0.31	---	0.03	0.06	0.18	0.25
Bittern	SAG	---	0.02	0.09	0.14	0.34	---	0.01	0.03	0.11	0.32
Least Bittern	SCF	---	0.04	0.11	0.09	0.03	---	---	0.02	0.02	<0.01
	SAG	---	0.07	0.06	0.07	---	---	0.01	0.02	0.01	---
Virginia Rail	SCF	0.06	0.15	0.09	0.09	---	0.02	0.10	0.11	0.07	<0.01
	SAG	0.05	0.14	0.14	0.06	0.01	0.04	0.17	0.11	0.10	0.03
Sora	SCF	0.01	0.04	0.02	0.03	0.01	---	0.04	<0.01	<0.01	---
	SAG	0.01	0.05	0.06	0.02	---	0.01	0.03	0.04	0.02	0.01
Common	SCF	---	0.03	0.02	<0.01	---	---	0.04	0.04	<0.01	0.01
Moorhen	SAG	0.01	0.02	0.01	---	---	---	0.01	0.01	<0.01	---
American	SCF	0.01	0.10	0.13	0.10	0.05	0.01	0.14	0.26	0.20	0.19
Coot	SAG	0.01	0.05	0.08	0.08	0.04	0.01	0.04	0.05	0.04	0.03
Black Tern	SCF	0.05	0.05	0.03	0.06	---	0.13	0.14	0.13	0.09	0.08
	SAG	0.02	0.04	0.06	0.05	0.06	---	---	---	---	0.01
Forster's	SCF	0.04	0.03	0.02	<0.01	0.01	0.15	0.20	0.18	0.16	0.13
Tern	SAG	---	0.01	---	<0.01	0.01	0.02	0.03	0.05	0.09	0.04
Marsh Wren	SCF	0.53	0.68	0.54	0.19	0.02	0.39	0.60	0.52	0.27	0.01
	SAG	0.35	0.63	0.62	0.24	0.03	0.29	0.60	0.54	0.32	0.04
Yellow	SCF	0.02	0.03	0.03	0.02	---	0.01	0.06	0.02	<0.01	---
Warbler	SAG	0.08	0.26	0.25	0.12	0.01	0.06	0.15	0.16	0.14	0.04
Common	SCF	0.08	0.27	0.22	0.12	0.01	0.14	0.38	0.27	0.17	0.01
Yellowthroat	SAG	0.14	0.40	0.39	0.18	0.01	0.10	0.37	0.40	0.28	0.03

Table B-2. Cont'd.

Species	Study Area	Diked Wetlands 0-18 m	18-50 m	50-100m	100-200 m	>200 m	Undiked Wetlands 0-18 m	18-50 m	50-100m	100-200 m	>200 m
Swamp	SCF	0.18	0.48	0.39	0.17	---	0.20	0.39	0.40	0.23	<0.01
Sparrow	SAG	0.41	0.66	0.65	0.33	0.02	0.36	0.66	0.61	0.37	0.04
Red-winged	SCF	0.60	0.92	0.77	0.61	0.10	0.56	0.82	0.77	0.53	0.13
Blackbird	SAG	0.41	0.77	0.81	0.62	0.15	0.31	0.67	0.73	0.64	0.24

Table B-3. Akaike's Information Criterion (AIC) statistics and P-values for mixed models used to compare bird densities in diked and open wetlands during point counts conducted at St. Clair Flats and Saginaw Bay, Michigan, 2005-2007. Models that included a repeated measures component are listed by covariance structure. Bolded values indicate the most desirable model for a given variable based on AIC statistics. An asterisk "*" was placed after an AIC value if the G matrix for the given model was not positive definite. The notation "---" indicates that the model did not converge.

	Repeated Measures Models							
	Autoregressive (AR[1])		Compound Symmetric (CS)		Unstructured (UN)		Standard Mixed Models	
Bird Density Variable	AIC	P-value	AIC	P-value	AIC	P-value	AIC	P-value
All Birds	826.5	0.1945	830.0	0.2436	**821.1**	**0.3318**	829.4	0.2265
Wetland-dependent Birds	836.8	0.0352	841.4	0.0389	**836.2**	**0.0461**	839.6	0.0394
Wetland-associated Birds	1237.2	0.8442	---	---	1240.1	0.7404	**1235.6**	**0.8260**
Nonwetland Birds	733.2	0.4443	737.1	0.4410	**731.0**	**0.4132**	735.6	0.4398
Wetland-dependent Species								
Canada Goose	-551.6*	0.4072	---	---	---	---	**-551.8***	**0.3903**
Mute Swan	-999.9*	0.1715	-1008.6*	0.1944	**-1072.4***	**0.5089**	-1001.7*	0.1738
Wood Duck	-872.1*	0.6048	-872.1*	0.6024	**-914.6***	**0.7895**	-874.0*	0.6063
Mallard	-141.2*	0.0366	-144.3*	0.0249	**-184.7***	**0.1286**	-132.9*	0.0253
Pied-billed Grebe	**-1275.5***	**0.7927**	---	---	---	---	-1248.8*	0.8178
American Bittern	-1040.4*	0.0007	-1039.2	0.0006	**-1065.0***	**0.0012**	-1039.1*	0.0008
Least Bittern	-613.9*	0.0037	-611.7*	0.0031	**-666.3***	**0.0024**	-613.5*	0.0031
King Rail	**-1460.2***	**0.2402**	-1385.5*	0.2226	---	---	-1385.8*	0.2136
Virginia Rail	593.2*	0.2882	**593.0***	**0.2816**	596.2*	0.2508	591.4*	0.2854
Sora	**-341.1***	**0.6132**	-338.2*	0.6416	---	---	-337.3	0.6622
Common Moorhen	-362.9	0.9616	-381.2*	0.8893	**-460.7***	**0.0864**	-358.3	0.8826
American Coot	240.8	0.9283	241.9	0.8033	**226.0**	**0.8550**	249.3	0.9051
Black Tern	592.3	0.5530	605.6	0.5918	**529.2**	**0.2105**	605.3	0.6091
Forster's Tern	444.9*	0.0056	---	---	446.8	0.0028	**443.1***	**0.0057**

Table B-3. Cont'd.

Bird Density Variable	Repeated Measures Models: Autoregressive (AR(1)) AIC	P-value	Compound Symmetric (CS) AIC	P-value	Unstructured (UN) AIC	P-value	Standard Mixed Models AIC	P-value
Wetland-dependent Species								
Tree Swallow	785.9	0.3622	785.1	0.3302	786.8	0.4047	**784.5**	**0.3515**
Willow Flycatcher	-530.1*	0.2875	**-538.4***	**0.2605**	---	---	-532.0*	0.2882
Sedge Wren	**-1296.7***	**0.4389**	---	---	---	---	-1070.8*	0.4297
Marsh Wren	1168.1	0.2024	1168.2	0.2023	1172.9	0.1934	**1166.2**	**0.2023**
Swamp Sparrow	997.1	0.7819	998.1	0.7898	1003.3	0.8077	**996.5**	**0.7846**
Red-winged Blackbird	1043.3	0.4322	1044.6	0.4583	**1038.4**	**0.4379**	1043.2	0.4843
Yellow-headed Blackbird	**-842.8***	**0.2766**	---	---	---	---	-795.6*	0.2754
Wetland-associated Species								
Caspian Tern	-1053.0*	0.4415	-1053.1*	0.4382	**-1295.4***	**0.3155**	-1054.8*	0.4426
Eastern Kingbird	**-800.9**	**0.3972**	-793.9*	0.4956	---	---	-789.2	0.5272
Barn Swallow	348.8*	0.0881	345.6*	0.0799	**335.4**	**0.0986**	348.3*	0.0960
Yellow Warbler	280.0	0.5997	---	---	**254.0**	**0.5182**	278.6*	0.5939
Common Yellowthroat	**857.3**	**0.3868**	859.7	0.3813	860.8	0.3849	858.2	0.3756
Common Grackle	696.1	0.0283	---	---	**680.2**	**0.0612**	700.7	0.0399
Nonwetland Species								
Song Sparrow	249.1	0.1677	241.3	0.1549	**216.2**	**0.1751**	248.0	0.1693

Table B-4. Akaike's Information Criterion (AIC) statistics and P-values for mixed models with lower bounds set for covariance parameters with zero estimates to achieve positive definite G matrices. Models were used to compare bird densities between diked and open wetlands during point counts conducted at St. Clair Flats and Saginaw Bay, Michigan, 2005-2007. Models that included a repeated measures component are listed by covariance structure. Bolded values indicate the most desirable model for a given variable based on AIC statistics. The notation "---" indicates that the model did not converge.

Bird Density Variable by Lower-bound of Covariance Parameters		Repeated Measures Models: Autoregressive (AR[1])		Repeated Measures Models: Compound Symmetric (CS)		Repeated Measures Models: Unstructured (UN)		Standard Mixed Models	
		AIC	P-value	AIC	P-value	AIC	P-value	AIC	P-value
Wetland-dependent Species									
Canada Goose	0.0000001	-551.6	0.4072	---	---	---	---	**-551.8**	**0.3904**
	0.00001	-551.6	0.4073	---	---	---	---	**-551.7**	**0.3950**
Mute Swan	0.0000001	-999.9	0.1715	-1008.6	0.1944	**-1072.4**	**0.5091**	-1001.7	0.1739
	0.00001	-999.9	0.1716	-1008.6	0.1945	**-1072.2**	**0.5241**	-1001.5	0.1855
Wood Duck	0.0000001	-872.1	0.6048	-872.1	0.6024	**-914.6**	**0.7895**	-874.0	0.6063
	0.00001	-872.1	0.6048	-872.1	0.6024	**-914.6**	**0.7908**	-873.8	0.6117
Mallard	0.0000001	-141.2	0.0366	-144.3	0.0249	**-184.7**	**0.1286**	-132.9	0.0253
	0.00001	-141.2	0.0366	-144.3	0.0253	**-184.7**	**0.1310**	-132.8	0.0261
Pied-billed Grebe	0.0000001	**-1275.5**	**0.7927**	---	---	---	---	-1248.8	0.8175
	0.00001	**-1275.5**	**0.7926**	---	---	---	---	-1248.6	0.8080
American Bittern	0.0000001	-1040.4	0.0007	-1039.2	0.0006	**-1065.0**	**0.0012**	-1039.1	0.0008
	0.00001	-1040.4	0.0007	-1039.2	0.0006	**-1064.9**	**0.0012**	-1039.0	0.0008
Least Bittern	0.0000001	-613.9	0.0037	-611.7	0.0031	**-666.3**	**0.0024**	-613.5	0.0031
	0.00001	-613.9	0.0037	-611.7	0.0031	**-666.2**	**0.0024**	-613.5	0.0030
King Rail	0.0000001	**-1460.2**	**0.2402**	-1385.5	0.2226	---	---	-1385.8	0.2137
	0.00001	**-1460.2**	**0.2403**	-1385.5	0.2227	---	---	-1385.7	0.2255
Virginia Rail	0.0000001	593.2	0.2882	**593.0**	**0.2816**	596.2	0.2509	591.4	0.2854
	0.00001	593.2	0.2884	**593.0**	**0.2817**	596.3	0.2519	591.5	0.2865

Table B-4. Cont'd.

Bird Density Variable by Lower-bound of Covariance Parameters		Repeated Measures Models: Autoregressive (AR[1])		Compound Symmetric (CS)		Unstructured (UN)		Standard Mixed Models	
Sora	0.0000001	**-341.1**	**0.6132**	-338.2	0.6416	---	---	-337.3	0.6622
	0.00001	**-341.1**	**0.6132**	-338.2	0.6416	---	---	-337.3	0.6622
Common Moorhen	0.0000001	-362.9	0.9616	-381.2	0.8893	**-460.7**	**0.0864**	-358.3	0.8826
	0.00001	-362.9	0.9616	-381.2	0.8892	**-460.5**	**0.0908**	-358.3	0.8826
Forster's Tern	0.0000001	444.9	0.0056	---	---	446.8	0.0028	**443.1**	**0.0057**
	0.00001	444.9	0.0057	---	---	446.8	0.0028	**443.1**	**0.0057**
Willow Flycatcher	0.0000001	-530.1	0.2875	**-538.4**	**0.2605**	---	---	-532.0	0.2882
	0.00001	-530.1	0.2875	**-538.4**	**0.2606**	---	---	-531.9	0.2900
Sedge Wren	0.0000001	**-1296.7**	**0.4389**	---	---	---	---	-1070.8	0.4297
	0.00001	**-1296.7**	**0.4388**	---	---	---	---	-1070.7	0.4313
Yellow-headed Blackbird	0.0000001	**-842.8**	**0.2766**	---	---	---	---	-795.6	0.2754
	0.00001	**-842.8**	**0.2766**	---	---	---	---	-795.5	0.2753
Wetland-associated Species									
Caspian Tern	0.0000001	-1053.0	0.4415	-1053.1	0.4382	**-1295.4**	**0.3155**	-1054.8	0.4428
	0.00001	-1053.0	0.4415	-1053.1	0.4382	**-1294.9**	**0.3132**	-1054.4	0.4479

Table B-5. Mean areal 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 B-5. Cont'd.

Species	St. Clair Flats		Saginaw Bay	
	Diked	Open	Diked	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 B-5. 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 B-5. 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 B-6. Mean areal 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 B-6. 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)	---	---

APPENDIX C

Data tables from migrant bird surveys and analyses.

Table C-1. Akaike's Information Criterion (AIC) statistics and P-values for mixed models used to compare migrant bird areal densities (birds per ha wetland) in diked and undiked wetlands during ground surveys conducted at St. Clair Flats and Saginaw Bay, Michigan, 2005-2007. Models that included a repeated measures component are listed by covariance structure. Bolded values indicate the most desirable model for a given variable based on AIC statistics. An asterisk "*" was placed after an AIC value if the G matrix for the given model was not positive definite. The notation "---" indicates that the model did not converge.

	Repeated Measures Models							
	Autoregressive (AR[1])		Compound Symmetric (CS)		Unstructured (UN)		Standard Mixed Models	
Bird Density Variable	AIC	P-value	AIC	P-value	AIC	P-value	AIC	P-value
All Birds	288.3*	0.2136	303.8*	0.1938	**273.4***	**0.1436**	304.1*	0.2214
Wetland-dependent Birds	287.6*	0.2068	302.8*	0.1886	**275.8***	**0.1150**	302.9*	0.2136
Wetland-associated Birds	-59.8*	0.3118	-55.5*	0.2342	**-104.5***	**0.8096**	-52.9*	0.3970
Total Waterfowl	307.9*	0.4865	316.3*	0.5328	**301.0***	**0.1285**	314.3*	0.5299
Total Dabbling Ducks	323.0*	0.3240	335.3	0.2829	**320.4***	**0.5801**	334.1	0.2617
Total Waterbirds	**150.3***	**0.0555**	154.9*	0.0542	158.0*	0.1099	159.0*	0.0690
Total Shorebirds	177.3*	0.2427	174.0*	0.1790	**157.3***	**0.6142**	193.9*	0.2906
Calidris Shorebirds	-58.4*	0.3405	**-68.1***	**0.2686**	---	---	-44.2*	0.3769
Wetland-dependent Species								
Canada Goose	-17.8*	0.9713	-23.4*	0.8878	**-105.5***	**0.7272**	-19.8*	0.9712
Mute Swan	-224.3*	0.2686	-216.1*	0.2531	**-269.6***	**0.3284**	-214.4*	0.2526
Wood Duck	67.8	<0.0001	69.5	<0.0001	**32.9***	**<0.0001**	68.3	<0.0001
Gadwall	-181.0*	0.5198	-180.6*	0.5155	---	---	**-182.6***	**0.5173**
Mallard	278.8*	0.1675	286.1*	0.1436	**276.4***	**0.2350**	284.3*	0.1354
Blue-winged Teal	151.7*	0.1625	138.5*	0.1295	**10.4***	**0.6210**	152.6*	0.1508
Green-winged Teal	216.8*	0.8990	228.1*	0.8022	**143.8***	**0.1489**	230.7*	0.9184
Great Blue Heron	-176.2*	<0.0001	-173.9*	<0.0001	**-187.2***	**0.0006**	-175.0*	<0.0001
Great Egret	153.2*	0.4343	156.8*	0.3987	**148.3***	**0.7065**	154.8*	0.3991
Green Heron	-269.0*	0.3774	**-292.6**	**0.3862**	---	---	-270.3*	0.3890

Table C-1. Cont'd.

	Repeated Measures Models							
	Autoregressive (AR(1))		Compound Symmetric (CS)		Unstructured (UN)		Standard Mixed Models	
Bird Density Variable	AIC	P-value	AIC	P-value	AIC	P-value	AIC	P-value
Wetland-dependent Species								
Black-cr. Night-Heron	-163.9*	0.0773	-168.3*	0.0444	**-299.6***	**0.4514**	-151.8*	0.0955
Pied-billed Grebe	-179.1*	0.0999	-179.0*	0.1001	**-211.5***	**0.1177**	-181.0*	0.0999
Common Moorhen	-245.2	0.1427	-249.4*	0.1536	**-354.5***	**0.3922**	-240.7	0.1468
American Coot	-383.6	0.8020	-383.9	0.8323	**-403.0***	**0.7090**	-385.4	0.8181
Spotted Sandpiper	-291.8*	0.0373	-290.5*	0.0513	**-351.8***	**0.2636**	-288.7*	0.0249
Solitary Sandpiper	-286.8*	0.1427	-281.9*	0.1859	**-378.1***	**0.0574**	-282.0*	0.1914
Greater Yellowlegs	-66.0*	0.6685	-68.8*	0.5966	**-139.7***	**0.1637**	-48.4*	0.6428
Lesser Yellowlegs	-84.1*	0.8374	-67.0*	0.9306	**-99.3***	**0.9876**	-41.4*	0.7422
Least Sandpiper	-108.2*	0.1867	-112.8*	0.1286	**-179.9***	**0.5715**	-106.5*	0.2616
Wilson's Snipe	-91.4*	0.0888	-91.1*	0.0863	**-200.9***	**0.0018**	-93.0*	0.0862
Ring-billed Gull	-114.3*	0.0081	-110.1*	0.0071	**-151.0***	**0.0126**	-110.1*	0.0048
Black Tern	-199.6*	0.0902	-198.4*	0.0666	**-505.6***	**0.2319**	-201.6*	0.0906
Forster's Tern	-541.3*	0.0069	-541.4*	0.0084	**-615.4***	**<0.0001**	-542.8*	0.0081
Wetland-associated Species								
Killdeer	-76.8*	0.6992	-73.9*	0.6451	**-144.2**	**0.7229**	-72.0*	0.7911
Caspian Tern	-315.4*	0.4647	-314.5*	0.4213	**-395.1***	**0.6692**	-315.1*	0.4560

Table C-2. Akaike's Information Criterion (AIC) statistics and P-values for mixed models with lower bounds set for covariance parameters with zero estimates to achieve positive definite G matrices. Models were used to compare migrant areal bird densities (birds per ha wetland) between diked and undiked wetlands during ground surveys conducted at St. Clair Flats and Saginaw Bay, Michigan, 2005-2007. Models that included a repeated measures component are listed by covariance structure. Bolded values indicate the most desirable model for a given variable based on AIC statistics. The notation "---" indicates that the model did not converge. Data from the original model was reported if the G matrix was positive definite (denoted by the "†" symbol).

		Repeated Measures Models						Standard Mixed Models	
		Autoregressive (AR[1])		Compound Symmetric (CS)		Unstructured (UN)			
Bird Density Variable		AIC	P-value	AIC	P-value	AIC	P-value	AIC	P-value
All Birds	0.0000001	288.3	0.2136	303.8	0.1938	**273.4**	**0.1436**	304.1	0.2214
	0.00001	288.3	0.2136	303.8	0.1938	**273.5**	**0.1436**	304.1	0.2214
Wetland-dependent Birds	0.0000001	287.6	0.2068	302.8	0.1886	**275.8**	**0.1150**	302.9	0.2136
	0.00001	287.6	0.2068	302.8	0.1886	**275.8**	**0.1150**	302.9	0.2136
Wetland-associated Birds	0.0000001	-59.8	0.3118	-55.5	0.2342	**-104.5**	**0.8096**	-52.9	0.3971
	0.00001	-59.8	0.3119	-55.5	0.2342	**-104.5**	**0.8126**	-52.9	0.3963
Total Waterfowl	0.0000001	307.9	0.4865	316.3	0.5328	**301.0**	**0.1285**	314.3	0.5299
	0.00001	307.9	0.4865	316.3	0.5328	**301.0**	**0.1285**	314.3	0.5299
Total Dabbling Ducks	0.0000001	323.0	0.3240	335.3†	0.2829	**320.4**	**0.5801**	334.1†	0.2617
	0.00001	323.0	0.3240	335.3†	0.2829	**320.4**	**0.5801**	334.1†	0.2617
Total Waterbirds	0.0000001	**150.3**	**0.0555**	154.9	0.0542	158.0	0.1099	159.0	0.0690
	0.00001	**150.3**	**0.0555**	154.9	0.0542	158.0	0.1099	159.0	0.0690
Total Shorebirds	0.0000001	177.3	0.2427	174.0	0.1790	**157.3**	**0.6142**	193.9	0.2906
	0.00001	177.3	0.2427	174.0	0.1790	**157.3**	**0.6142**	193.9	0.2906
Calidris Shorebirds	0.0000001	-58.4	0.3405	**-68.1**	**0.2686**	---	---	-44.2	0.3769
	0.00001	-58.4	0.3405	**-68.1**	**0.2686**	---	---	-44.2	0.3768
Wetland-dependent Species									
Canada Goose	0.0000001	-17.8	0.9713	-23.4	0.8878	**-105.5**	**0.7272**	-19.8	0.9712
	0.00001	-17.8	0.9713	-23.4	0.8878	**-105.5**	**0.7282**	-19.8	0.9709

Table C-2. Cont'd.

Bird Density Variable		Repeated Measures Models: Autoregressive (AR[1])		Repeated Measures Models: Compound Symmetric (CS)		Repeated Measures Models: Unstructured (UN)		Standard Mixed Models	
		AIC	P-value	AIC	P-value	AIC	P-value	AIC	P-value
Wetland-dependent Species									
Mute Swan	0.0000001	-224.3	0.2686	-216.1	0.2531	**-269.6**	**0.3284**	-214.4	0.2527
	0.00001	-224.3	0.2686	-216.1	0.2531	**-269.5**	**0.3286**	-214.3	0.2527
Wood Duck	0.0000001	67.8†	<0.0001	69.5†	<0.0001	**32.9**	**<0.0001**	68.3†	<0.0001
	0.00001	67.8†	<0.0001	69.5†	<0.0001	**32.9**	**<0.0001**	68.3†	<0.0001
Gadwall	0.0000001	-181.0	0.5198	-180.6	0.5155	---	---	**-182.6**	**0.5173**
	0.00001	-181.0	0.5198	-180.6	0.5155	---	---	**-182.5**	**0.5173**
Mallard	0.0000001	278.8	0.1675	286.1	0.1436	**276.4**	**0.2350**	284.3	0.1354
	0.00001	278.8	0.1675	286.1	0.1436	**276.4**	**0.2351**	284.3	0.1354
Blue-winged Teal	0.0000001	151.7	0.1625	138.5	0.1295	**10.4**	**0.6210**	152.6	0.1508
	0.00001	151.7	0.1625	138.5	0.1295	**10.9**	**0.6205**	152.6	0.1507
Green-winged Teal	0.0000001	216.8	0.8990	228.1	0.8022	**143.8**	**0.1489**	230.7	0.9184
	0.00001	216.8	0.8990	228.1	0.8022	**143.8**	**0.1492**	230.7	0.9184
Great Blue Heron	0.0000001	-176.2	<0.0001	-173.9	<0.0001	**-187.2**	**0.0006**	-175.0	<0.0001
	0.00001	-176.2	<0.0001	-173.9	<0.0001	**-187.2**	**0.0006**	-175.0	<0.0001
Great Egret	0.0000001	153.2	0.4343	156.8	0.3987	**148.3**	**0.7065**	154.8	0.3991
	0.00001	153.3	0.4344	156.8	0.3987	**148.3**	**0.7065**	154.8	0.3992
Black-cr. Night-Heron	0.0000001	-163.9	0.0773	-168.3	0.0444	**-299.6**	**0.4514**	-151.8	0.0954
	0.00001	-163.9	0.0773	-168.3	0.0444	**-299.5**	**0.4539**	-151.8	0.0954
Pied-billed Grebe	0.0000001	-179.1	0.0999	-179.0	0.1001	**-211.5**	**0.1177**	-181.0	0.0999
	0.00001	-179.1	0.0999	-179.0	0.1001	**-211.4**	**0.1175**	-181.0	0.0999
Common Moorhen	0.0000001	-245.2†	0.1427	-249.4	0.1536	**-354.4**	**0.3923**	-240.7†	0.1468
	0.00001	-245.2†	0.1427	-249.4	0.1536	**-352.2**	**0.3942**	-240.7†	0.1468
American Coot	0.0000001	-383.6†	0.8020	-383.9†	0.8323	**-403.0**	**0.7091**	-385.4†	0.8181
	0.00001	-383.6†	0.8020	-383.9†	0.8323	**-402.9**	**0.7162**	-385.4†	0.8181

Table C-2. Cont'd.

		Repeated Measures Models							
		Autoregressive (AR[1])		Compound Symmetric (CS)		Unstructured (UN)		Standard Mixed Models	
Bird Density Variable		AIC	P-value	AIC	P-value	AIC	P-value	AIC	P-value
Wetland-dependent Species									
Spotted Sandpiper	0.0000001	-291.8	0.0373	-290.5	0.0513	**-351.7**	**0.2636**	-288.7	0.0249
	0.00001	-291.8	0.0373	-290.5	0.0513	**-349.5**	**0.2656**	-288.5	0.0247
Solitary Sandpiper	0.0000001	-286.8	0.1427	-281.9	0.1859	**-378.1**	**0.0575**	-282.0	0.1914
	0.00001	-286.8	0.1427	-281.9	0.1859	**-378.1**	**0.0597**	-281.9	0.1911
Greater Yellowlegs	0.0000001	-66.0	0.6685	-68.8	0.5966	**-139.7**	**0.1637**	-48.4	0.6428
	0.00001	-66.0	0.6685	-68.8	0.5966	**-139.6**	**0.1616**	-48.4	0.6428
Lesser Yellowlegs	0.0000001	-84.1	0.8374	-67.0	0.9306	**-99.3**	**0.9876**	-41.4	0.7422
	0.00001	-84.1	0.8374	-67.0	0.9306	**-99.3**	**0.9875**	-41.4	0.7423
Least Sandpiper	0.0000001	-108.2	0.1867	-112.8	0.1286	**-179.9**	**0.5715**	-106.5	0.2615
	0.00001	-108.2	0.1867	-112.8	0.1287	**-179.7**	**0.5706**	-106.5	0.2612
Wilson's Snipe	0.0000001	-91.4	0.0888	-91.1	0.0863	**-200.9**	**0.0018**	-93.0	0.0862
	0.00001	-91.4	0.0888	-91.1	0.0863	**-200.6**	**0.0017**	-93.0	0.0861
Ring-billed Gull	0.0000001	-114.3	0.0081	-110.1	0.0071	**-151.0**	**0.0126**	-110.1	0.0048
	0.00001	-114.3	0.0081	-110.1	0.0071	**-151.0**	**0.0129**	-110.1	0.0048
Black Tern	0.0000001	-199.6	0.0902	-198.4	0.0666	**-505.6**	**0.2330**	-201.6	0.0906
	0.00001	-199.6	0.0903	-198.4	0.0666	**-505.6**	**0.3943**	-201.5	0.0934
Forster's Tern	0.0000001	-541.3	0.0069	-541.4	0.0084	**-615.4**	**<0.0001**	-542.8	0.0081
	0.00001	-541.3	0.0069	-541.4	0.0084	**-614.2**	**0.0002**	-542.7	0.0086
Wetland-associated Species									
Caspian Tern	0.0000001	-315.4	0.4647	-314.5	0.4213	**-395.1**	**0.6692**	-315.1	0.4561
	0.00001	-315.4	0.4647	-314.5	0.4213	**-394.8**	**0.6679**	-315.1	0.4566

Table C-3. Akaike's Information Criterion (AIC) statistics and P-values for mixed models used to compare linear densities of migrant bird (birds per km edge) in diked and undiked wetlands during ground surveys conducted at St. Clair Flats and Saginaw Bay, Michigan, 2005-2007. Models that included a repeated measures component are listed by covariance structure. Bolded values indicate the most desirable model for a given variable based on AIC statistics. An asterisk "*" was placed after an AIC value if the G matrix for the given model was not positive definite. The notation "---" indicates that the model did not converge.

	Repeated Measures Models							
	Autoregressive (AR[1])		Compound Symmetric (CS)		Unstructured (UN)		Standard Mixed Models	
Bird Density Variable	AIC	P-value	AIC	P-value	AIC	P-value	AIC	P-value
All Birds	352.9*	0.0403	368.6	0.0368	**347.4***	**0.0564**	368.0	0.0322
Wetland-dependent Birds	353.3*	0.0431	366.7*	0.0390	**348.1***	**0.0762**	368.1	0.0342
Wetland-associated Birds	204.9*	0.0298	210.2*	0.0538	**200.0***	**0.0028**	222.6	0.0375
Total Waterfowl	399.1*	0.0494	408.6	0.0310	**397.4***	**0.2355**	406.7	0.0328
Total Dabbling Ducks	**432.2***	**0.0119**	443.3	0.0082	434.9	0.0439	441.6	0.0074
Total Waterbirds	**287.2***	**0.2200**	290.7*	0.2578	296.7*	0.1879	291.2*	0.2496
Total Shorebirds	346.1*	0.7712	345.2*	0.9372	**342.7***	**0.4878**	373.5*	0.7089
Calidris Shorebirds	171.0*	0.8968	164.5*	0.8425	**148.5***	**0.8974**	198.3*	0.9895
Wetland-dependent Species								
Canada Goose	236.4*	0.3494	237.8*	0.2850	**214.3***	**0.3337**	237.0*	0.3079
Mute Swan	69.7*	0.6569	77.2*	0.5961	**18.5***	**0.4790**	78.3	0.5842
Wood Duck	193.2*	<0.0001	195.2*	<0.0001	**186.8**	**0.0001**	197.0*	<0.0001
Gadwall	26.7*	0.6075	26.0*	0.6022	---	---	**25.8***	**0.6055**
Mallard	400.9*	0.0028	---	---	**399.5***	**0.0064**	405.9*	0.0018
Blue-winged Teal	329.3*	0.0387	331.5	0.0255	**267.2***	**0.0682**	332.7	0.0308
Green-winged Teal	375.4*	0.3184	383.1*	0.3407	**340.3***	**0.3254**	382.7*	0.3044
Great Blue Heron	63.2*	0.2660	64.7*	0.2586	68.1*	0.2740	**63.1***	**0.2413**
Great Egret	**335.0***	**0.2041**	341.8*	0.2473	339.2*	0.1434	339.9*	0.2434
Green Heron	**-102.1***	**0.3356**	-101.4*	0.3260	---	---	-96.0*	0.3632

Table C-3. Cont'd.

Bird Density Variable	Repeated Measures Models						Standard Mixed Models	
	Autoregressive (AR(1))		Compound Symmetric (CS)		Unstructured (UN)			
	AIC	P-value	AIC	P-value	AIC	P-value	AIC	P-value
Wetland-dependent Species								
Black-cr. Night-Heron	1.8*	0.1018	-5.4*	0.0655	**-96.2***	**0.1460**	20.8*	0.1301
Pied-billed Grebe	97.2*	0.3846	96.6*	0.4137	**82.0***	**0.4304**	100.8*	0.3770
Common Moorhen	-36.7	0.3069	-45.5*	0.3080	**-113.9***	**0.6266**	-35.7*	0.2995
American Coot	-30.1	0.3083	-35.4	0.3002	**-38.4***	**0.3028**	-28.1	0.2819
Spotted Sandpiper	-26.3*	0.1381	-27.9*	0.1982	**-76.8**	**0.3519**	-26.2*	0.1247
Solitary Sandpiper	-65.9*	0.1228	-61.7*	0.1831	**-144.3***	**0.4756**	-61.7*	0.1875
Greater Yellowlegs	175.0*	0.6203	177.5*	0.7427	**164.5***	**0.0275**	192.0*	0.6262
Lesser Yellowlegs	206.2*	0.3088	229.9*	0.3396	**203.8***	**0.4256**	258.6*	0.2185
Least Sandpiper	121.9*	0.9266	127.7*	0.8268	**82.3***	**0.5035**	141.3*	0.9553
Wilson's Snipe	71.5*	0.1932	71.6*	0.1916	**14.1***	**0.0679**	69.6*	0.1917
Ring-billed Gull	198.4*	0.0002	199.3*	0.0003	**181.6***	**0.0003**	208.2	0.0040
Black Tern	13.7*	0.7541	13.7*	0.7536	**-178.9***	**0.4493**	11.7*	0.7540
Forster's Tern	-64.6*	0.0006	-64.6*	0.0009	**-101.5***	**0.0002**	-65.7*	0.0008
Wetland-associated Species								
Killdeer	184.8*	0.3354	195.4*	0.4529	**125.6***	**0.4650**	211.3	0.3116
Caspian Tern	-7.4*	0.1458	2.0*	0.1642	**-34.8***	**0.1574**	1.0*	0.2104

Table C-4. Akaike's Information Criterion (AIC) statistics and P-values for mixed models with lower bounds set for covariance parameters with zero estimates to achieve positive definite G matrices. Models were used to compare linear migrant bird densities (birds per km edge) between diked and undiked wetlands during ground surveys conducted at St. Clair Flats and Saginaw Bay, Michigan, 2005-2007. Models that included a repeated measures component are listed by covariance structure. Bolded values indicate the most desirable model for a given variable based on AIC statistics. The notation "---" indicates that the model did not converge. Data from the original model was reported if the G matrix was positive definite (denoted by the "†" symbol).

		Repeated Measures Models							
	Lower	Autoregressive (AR[1])		Compound Symmetric (CS)		Unstructured (UN)		Standard Mixed Models	
Bird Density Variable	Bound	AIC	P-value	AIC	P-value	AIC	P-value	AIC	P-value
All Birds	0.0000001	352.9	0.0403	368.6†	0.0368	**347.4**	**0.0564**	368.0†	0.0322
	0.00001	352.9	0.0403	368.6†	0.0368	**347.4**	**0.0564**	368.0†	0.0322
Wetland-dependent Birds	0.0000001	353.3	0.0431	366.7	0.0390	**348.1**	**0.0762**	368.1†	0.0342
	0.00001	353.3	0.0431	366.7	0.0390	**348.1**	**0.0762**	368.1†	0.0342
Wetland-associated Birds	0.0000001	204.9	0.0298	210.2	0.0538	**200.0**	**0.0028**	222.6†	0.0375
	0.00001	204.9	0.0298	210.2	0.0538	**200.0**	**0.0028**	222.6†	0.0375
Total Waterfowl	0.0000001	399.1	0.0494	408.6†	0.0310	**397.4**	**0.2355**	406.7†	0.0328
	0.00001	399.1	0.0494	408.6†	0.0310	**397.4**	**0.2355**	406.7†	0.0328
Total Dabbling Ducks	0.0000001	**432.2**	**0.0119**	443.3†	0.0082	434.9†	0.0439	441.6†	0.0074
	0.00001	**432.2**	**0.0119**	443.3†	0.0082	434.9†	0.0439	441.6†	0.0074
Total Waterbirds	0.0000001	**287.2**	**0.2200**	290.7	0.2578	296.7	0.1879	291.2	0.2496
	0.00001	**287.2**	**0.2200**	290.7	0.2578	296.7	0.1879	291.2	0.2496
Total Shorebirds	0.0000001	346.1	0.7712	345.2	0.9372	**342.7**	**0.4878**	373.5	0.7089
	0.00001	346.1	0.7712	345.2	0.9372	**342.7**	**0.4878**	373.5	0.7089
Calidris Shorebirds	0.0000001	171.0	0.8968	164.5	0.8425	**148.5**	**0.8974**	198.3	0.9895
	0.00001	171.0	0.8968	164.5	0.8425	**148.5**	**0.8973**	198.3	0.9895
Wetland-dependent Species									
Canada Goose	0.0000001	236.4	0.3494	237.8	0.2850	**214.3**	**0.3337**	237.0	0.3079
	0.00001	236.4	0.3494	237.8	0.2851	**214.3**	**0.3337**	237.0	0.3079

Table C-4. Cont'd.

Bird Density Variable		Repeated Measures Models: Autoregressive (AR[1]) AIC	P-value	Compound Symmetric (CS) AIC	P-value	Unstructured (UN) AIC	P-value	Standard Mixed Models AIC	P-value
Wetland-dependent Species									
Mute Swan	0.0000001	69.7	0.6569	77.2	0.5961	**18.5**	**0.4790**	78.3†	0.5842
	0.00001	69.7	0.6570	77.2	0.5961	**18.5**	**0.4790**	78.3†	0.5842
Gadwall	0.0000001	26.7	0.6075	26.0	0.6022	---	---	**25.8**	**0.6055**
	0.00001	26.7	0.6075	26.0	0.6022	---	---	**25.8**	**0.6054**
Mallard	0.0000001	400.9	0.0028	---	---	**399.5**	**0.0064**	405.9	0.0018
	0.00001	400.9	0.0028	---	---	**399.5**	**0.0064**	405.9	0.0018
Blue-winged Teal	0.0000001	329.3	0.0387	331.5†	0.0255	**267.2**	**0.0682**	332.7†	0.0308
	0.00001	329.3	0.0387	331.5†	0.0255	**267.2**	**0.0682**	332.7†	0.0308
Green-winged Teal	0.0000001	375.4	0.3184	383.1	0.3407	**340.3**	**0.3254**	382.7	0.3044
	0.00001	375.4	0.3184	383.1	0.3407	**340.3**	**0.3255**	382.7	0.3044
Great Blue Heron	0.0000001	63.2	0.2660	64.7	0.2586	68.1	0.2740	**63.1**	**0.2413**
	0.00001	63.2	0.2660	64.7	0.2586	68.1	0.2740	**63.1**	**0.2414**
Great Egret	0.0000001	**335.0**	**0.2041**	341.8	0.2473	339.2	0.1434	339.9	0.2434
	0.00001	**335.0**	**0.2041**	341.8	0.2473	339.2	0.1434	339.9	0.2434
Green Heron	0.0000001	**-102.1**	**0.3356**	-101.4	0.3260	---	---	-96.0	0.3632
	0.00001	**-102.1**	**0.3356**	-101.4	0.3260	---	---	-95.9	0.3632
Black-cr. Night-Heron	0.0000001	1.8	0.1018	-5.4	0.0655	**-96.2**	**0.1460**	20.8	0.1301
	0.00001	1.8	0.1018	-5.4	0.0655	**-96.1**	**0.1464**	20.8	0.1301
Pied-billed Grebe	0.0000001	97.2	0.3846	96.6	0.4137	**82.0**	**0.4304**	100.8	0.3770
	0.00001	97.2	0.3846	96.6	0.4137	**82.0**	**0.4304**	100.8	0.3769
Common Moorhen	0.0000001	-36.7†	0.3069	-45.5	0.3080	**-113.9**	**0.6266**	-35.7†	0.2995
	0.00001	-36.7†	0.3069	-45.5	0.3080	**-113.6**	**0.6254**	-35.7†	0.2995
American Coot	0.0000001	-30.1†	0.3083	-35.4†	0.3002	**-38.4**	**0.3028**	-28.1†	0.2819
	0.00001	-30.1†	0.3083	-35.4†	0.3002	**-38.4**	**0.3031**	-28.1†	0.2819

Table C-4. Cont'd.

Bird Density Variable		Repeated Measures Models: Autoregressive (AR[1]) AIC	P-value	Compound Symmetric (CS) AIC	P-value	Unstructured (UN) AIC	P-value	Standard Mixed Models AIC	P-value
Wetland-dependent Species									
Solitary Sandpiper	0.0000001	-65.9	0.1228	-61.7	0.1831	**-144.3**	**0.4755**	-61.7	0.1875
	0.00001	-65.9	0.1228	-61.7	0.1831	**-144.1**	**0.4753**	-61.7	0.1875
Greater Yellowlegs	0.0000001	175.0	0.6203	177.5	0.7427	**164.5**	**0.0275**	192.0	0.6262
	0.00001	175.0	0.6203	177.5	0.7427	**164.5**	**0.0275**	192.0	0.6262
Lesser Yellowlegs	0.0000001	206.2	0.3088	229.9	0.3396	**203.8**	**0.4256**	258.6	0.2185
	0.00001	206.2	0.3088	229.9	0.3396	**203.8**	**0.4256**	258.6	0.2185
Least Sandpiper	0.0000001	121.9	0.9266	127.7	0.8268	**82.3**	**0.5035**	141.3	0.9553
	0.00001	121.9	0.9266	127.7	0.8268	**82.4**	**0.5014**	141.3	0.9553
Wilson's Snipe	0.0000001	71.5	0.1932	71.6	0.1916	**14.1**	**0.0679**	69.6	0.1917
	0.00001	71.5	0.1932	71.6	0.1916	**14.2**	**0.0682**	69.6	0.1917
Ring-billed Gull	0.0000001	198.4	0.0002	199.3	0.0003	**181.6**	**0.0003**	208.2†	0.0040
	0.00001	198.4	0.0002	199.3	0.0003	**181.6**	**0.0003**	208.2†	0.0040
Black Tern	0.0000001	13.7	0.7541	13.7	0.7536	**-178.9**	**0.4494**	11.7	0.7540
	0.00001	13.7	0.7541	13.7	0.7536	**-178.6**	**0.4549**	11.7	0.7536
Forster's Tern	0.0000001	-64.6	0.0006	-64.6	0.0009	**-101.5**	**0.0002**	-65.7	0.0008
	0.00001	-64.6	0.0006	-64.6	0.0009	**-101.5**	**0.0002**	-65.7	0.0008
Wetland-associated Species									
Killdeer	0.0000001	184.8	0.3354	195.4	0.4529	**125.6**	**0.4650**	211.3†	0.3116
	0.00001	184.8	0.3354	195.4	0.4529	**125.6**	**0.4649**	211.3†	0.3116
Caspian Tern	0.0000001	-7.4	0.1458	2.0	0.1642	**-34.8**	**0.1574**	1.0	0.2104
	0.00001	-7.4	0.1458	2.0	0.1642	**-34.8**	**0.1580**	1.0	0.2103

Table C-5. 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 14 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	Undiked	Diked	Undiked
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 C-5. Cont'd.

Species		St. Clair Flats		Saginaw Bay	
		Diked	Undiked	Diked	Undiked
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 C-6. 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)	Undiked (n=36)	Diked (n=50)	Undiked (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 C-6. Cont'd.

Species	St. Clair Flats		Saginaw Bay	
	Diked (n=36)	Undiked (n=36)	Diked (n=50)	Undiked (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 C-6. Cont'd.

Species	St. Clair Flats		Saginaw Bay	
	Diked (n=36)	Undiked (n=36)	Diked (n=50)	Undiked (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)