UNIVERSITY OF WISCONSIN SEA GRANT

Green Bay Wetlands Project:

An Expanded Bibliography Summarizing Nearly 50 Years of Research

Wetlands and nest photos: Hallet J. "Bud" Harris; Bittern photo: Joel Trick

Sea Grant
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INTRODUCTION AND PURPOSE

There is nothing permanent except change.

The adage, while well-worn, aptly categorizes the treasured ecosystem that is Green Bay, Lake Michigan. As the world's largest freshwater estuary, an area spanning 6,640 square miles, it is a place of interlocked systems and shifting complexity.

Through the millennia, the region has supported natural cycles and varied flora and fauna. It has served humankind from Indigenous people's wild rice harvest to the French fur trade to the 520-foot freighters that now ply its waters bearing grain, cement and other cargo to more distant ports.

This publication documents conditions and changes. It is a testament to the inquisitive and diligent approach of researchers who followed a strategy and captured a lineage of understanding of the ecosystem. It demonstrates the value of a commitment to scholarship by the University of Wisconsin-Green Bay, the Wisconsin Sea Grant College Program and University of Wisconsin-Extension.

Primarily focused on the coastal wetlands of the west shore of Green Bay from 1974 to 2005, this sentinel collection of University of Wisconsin-Green Bay graduate students' research on the west shore of the bay comes at a critical moment.

In 2022, Sea Grant commemorates its 50th anniversary and the bay is at the precipice of becoming the object of a new National Estuarine Research Reserve. Reserves dot the country and are charged with protecting varied biogeographic spaces through long-term research, water-quality monitoring, education and coastal stewardship. How appropriate Green Bay would join this community.

The work gathered here—a summary of theses and related peer-reviewed articles that have been catalogued from 1974 to 2005—marks a bridge between past and future understanding, embracing the changes in this remarkable body of water, and its coastlines and wetlands. It also helps frame the question: Where do we want to be in the next 50 years?

CONTENTS

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The Rooted Vegetation of West Green Bay with Reference to Environmental Change

George F. Howlett, Jr.

A thesis submitted in partial fulfillment of the requirements for the Master of Science degree, State University of New York, College of Environmental Science and Forestry, Syracuse, New York

September 1974

INTRODUCTION

The serious and long-continued pollution of the Lower Fox River in northeastern Wisconsin has caused significant changes in the physical, chemical, and biotic components of the aquatic environment in the southern portion of Lake Michigan's Green Bay. (Figure 1) Studies begun in the 1920's and continued into the present have documented various aspects of the pollution effects. Several governmental agencies, the University of Wisconsin, and the paper industry have contributed to this surveillance (Wisconsin State Board of Health, 1927; Wisconsin State Committee on Water Pollution, 1939; Surber and Cooley, 1952; Balch et al, 1956; Howmiller, 1966; Federal Water Pollution Control Administration, 1966; Schraufnagel et al, 1968; Ahrnsbrak and Ragotzkie, 1970; Sager, 1971; Howmiller and Beeton, 1971; Sager and Wiersma, 1972; Adams and Stone, 1973; and others). These investigations have concentrated on plankton, bacteria, and benthic fauna; and on physical and chemical parameters.

However, no in-depth investigation of the rooted aquatic vegetation has been attempted, although a significant benthic plant zone extended from Point Sable to the mouth of the Fox River and thence along the west shore to Peshtigo Point and Seagull Bar. This rooted hydrophyte assemblage has been greatly disrupted within inner Green Bay (Figure 2) Along the west shore of the outer bay the emergent plant associations remain established, but species components have disappeared and extant populations have declined at some locations. The submergent associations of the outer bay are disrupted based on previous condition reports provided by area residents.

Previous work on the aquatic vegetation of Wisconsin lakes (Rickett, 1921, 1924; Denniston, 1921; Fassett, 1930; Wilson, 1935, 1937, 1941; Potzger and Van Engel, 1943; Natelson, 1954; Swindale and Curtis, 1957; and Lind and Cottam, 1969) concentrated on the vegetation of inland lakes. These investigations developed workable study methods, but provide little information on plant association dynamics in a large water body of very shallow bottom slope, great water level fluctuation, large volume river inflow, and multiple environmental tensions resulting from human activity. Zimmerman (1953) provided a useful but incomplete record of vegetation growing in the Peaks Lake portion of inner Green Bay immediately prior to the post World War II growth in pollution input to the bay. Curtis (1959) integrated common aquatic plant community types into a vegetational analysis of the plant communities of Wisconsin. I have used Curtis's analysis as the reference base for my interpretation of the Green Bay plant associations. The Bureau of Research, Wisconsin Department of Natural Resources, began an inventory of Lake Michigan and Green Bay wetlands in 1969 to record their value for wildlife habitat (Kleinert, 1970), but staff reassignment caused abandonment of the project.

UNIVERSITY OF WISCONSIN SEA GRANT

Green Bay's West Shore Coastal Wetlands—A History of Change

Timothy Rustin Bosley

A dissertation submitted to the graduate faculty of the University of Wisconsin–Green Bay in partial fulfillment of the requirements for the degree of Master of Environmental Arts and Sciences

1976

Major Advisor: H.J. Harris, Ph.D.

INTRODUCTION

Value of Wetlands

The coastal wetlands of the Great lakes, like the tidal marshes of the oceans, are an essential habitat for many living organisms. Numerous fish and wildlife species require wetland habitat for feeding and reproduction and many species of birds concentrate in coastal wetlands during their annual migrations. along the lakeshore (Kleinert, 1970}. The coastal wetlands are environmental buffer zones. The buffering characteristics include moderating shoreline erosion, trapping sediments in tributary runoff, and absorbing excess amounts of nutrients present in the water. The absorption of nutrients may reduce the magnitude of algal blooms, which often cause harmful water turbidity and dissolved oxygen depletion. Wetlands are natural classrooms for scientific study and provide opportunities for outdoor recreation through fishing, hunting, boating and photography. Esthetic benefits are also provided by wetlands. These areas give continuity and character to the landscape and are often places of beauty where a sense of wilderness can still be experienced.

Coastal wetlands in Wisconsin now cover less than 30 miles of the 498 miles of Lake Michigan shoreline (Kleinert, 1970). These wetlands occur along the west shore of Green Bay, the eastern tip of the Door peninsula, and the lower portions of several rivers tributary to Lake Michigan. In Wisconsin, as elsewhere, wetlands are caught In the mounting tension between exploitation and preservation. The question of their best use is an ecological and economic problem requiring scientific evaluation before perceptive decisions are possible. Bedford, et. al. (1975) discussed the need for improved ecological understanding of Wisconsin's coastal wetlands. Three of their concerns are addressed in this thesis: (I) improved site-specific study of Wisconsin's individual Great Lakes wetlands; (2) improved understanding of the impacts resulting from dredging and dredge soils disposal; and (3) improved understanding of the impact dredge spoils disposal has on shoreline disposal sites. Bedford, et al concur with my belief that it is difficult to protect the integrity of an ecosystem which is only partially understood.

Early Observations of Green Bay

A review of the observations in the Green Bay region by the early explorers and inhabitants is necessary in order to gain an historical perspective of changing conditions. Jean Nicolet, who landed at Red Banks (Figure I), failed to record any observations on the natural conditions in the Green Bay region (Neville, 1926; Thwaites, 1959). In 1669–1670, Claude Allouez mentioned seeing many swans, bustards and ducks as he proceeded to the head of the bay. In autumn the birds would seek the wild oats (Allouez was probably referring to wild rice, *Zizania aquatica*) growing at the mouth of the Rivies des Puants (Fox River) that the wind had shaken off in September (Kellogg, 1917). Allouez also commented on the "tide" in the bay that was more noticeable than on larger lakes. Jolliet and Marquette explored the region in 1673. The first Indian nation they came to was that of Folle Avoine (Menominee). Jolliet and Marquette noted that "the wild oat, whose name they bear because it is found in their country, is a sort of grass that grows naturally in the small rivers with muddy bottoms, and in swampy places…The ears grow hollow stems, jointed at intervals; they emerge from the water about the month of June and continue growing until they rise about two feet above it."[1] Jolliet and Marquette proceeded to the bottom of Baye des Puants (Green Bay), concluding that this name had been given to it "on account of the quantity of mud and mire which is seen there."[2] They noted that the bay is "about thirty leagues in depth and eight leagues in width at its mouth and narrows gradually to the bottom."[3] Marquette noted a tide which had a regular ebb and flow like the sea and he believed the water level fluctuations were caused by very remote winds,

1. Journal of Jolliet and Marquette; In: L. P. Kellogg (ed.).1917. *Early Narratives of the Northwest, 1634–1699.* Barnes and Noble, Inc., New York, p. 230.

2. Ibid., p. 232.

3. Ibid., p. 232.

pressing on the middle of the lake, thus causing the edges to rise and fall. Jolliet and Marquette then left the bay and entered the Fox River, noting that the river was full of "bustards, ducks, teal and other birds being attracted there by the wild oats."[4] In 1676, Louis André questioned the effect of the wind on water movement and favored lunar causes, though he felt the wind may interact to a degree (Thwaites, 1959).

Father Joseph Marest, writing to Commander Cadillac at Detroit In 1701, referred to a "strip of sandy level ground on which stood clumsy buildings and stockade of the French close to the (Fox) river; back of this lonely outpost the gloomy depths of a dark tamarack swamp, and further inland a great barrier forest."[5] A similar description of conditions near the mouth of the Fox River was given by Lt. James Gorrell in 1761: "The heavy forest to the West of the Fort (Fort la Baye) was separated from the river shore by a tamarack and cedar Swamp, dark, impenetrable."[6]

Jonathan Carver made some observations on the Green Bay region during his 1766–1768 exploration of the Great Lakes area. He remarked that the French called the bay, Baye des Puants, which meant "stinking bay," but when the English gained possession, they called it Green Bay, the name coming from its appearance. Carver noted that the bay lies nearly northeast to southwest and is about ninety miles long, but differs much in breadth; some places were only fifteen miles wide, while others were from twenty to thirty miles wide. "The land on the south-east side of the Green Bay is very indifferent, with a heavy growth of hemlock, pine, spruce and fir trees. The land adjoining the bottom of this bay is very fertile, the country in general level, and the perspective view of it pleasing and extensive."[7]Carver included in his notes lists and descriptions of plant and animal species common to the Great Lakes area or different from those familiar to him. These species lists (found in Appendix I) apply to the general area of the Great Lakes and any further details are lacking regarding their geographic location.

In 1822, when Colonel John McNeil was the commanding officer at Fort Howard, the U.S. Inspector of Fortifications stated that Fort Howard:

> "stands on the left bank of the Fox River nearly two miles above its junction with the Bay. The land is twelve feet above the surface of the river and several feet higher than the adjacent plain to the rear: The plain is interspersed with shallow ponds and bordered easterly to the Bay with grassy marsh, subject to frequent inundation by the swell of the Bay produced by the strong easterly winds. Ponds near the Fort have lately been partially drained by the troops. The soil is of black loam, based upon fine sand, but with little appearance of clay. The water is very bad. It consists of that which the pond and river afford, it is muddy and often filled with the chaff and fragments of wild rice, and other decayed vegetable productions."[8]

I examined many maps that indicated the natural characteristics of Green Bay's coastal areas during presettlement and early settlement years. The most helpful maps were Rapids des Peres, 1671; Private Claims at Green Bay, 1828; Military Reserve, 1829; U. S. Sawmill on Duck Creek, 1829; Map of Green Bay, Brown County, Wisconsin, 1836; and Chart of Green Bay, 1845. Each map indicated marsh and swamp areas on the east and west shorelines of the Fox River, along with similar notation on Green Bay's west shore. However, these maps gave only a vague idea of where marsh and swamp areas were located (Figure 2) and not until the Federal Survey of Wisconsin from 1832–1866 was the land between the Fox and Menominee Rivers charted In a systematic manner.

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4. Ibid., p. 232.

5. D.B. Martin. 1926a. The bourough of Fort Howard. *Green Bay Historical Bulletin* 2:1: 11–19. p. 11.

6. 1bid., p. 16.

7. J. Carver, 1956. *Travels Through the Interior Parts of North American in the Years 1766, 1767, 1768* (3rd ed.). Ross and Haines Inc., Minneapolis, p. 26–27.

8. Report of 1822, U. S. Inspector of Fortifications, In: D. B. Martin. 1926b. The bourough of Fort Howard. *Green Bay Historical Bulletin* 2:2: 13–20. p. 14.

Scope of Thesis

This thesis is founded upon the premise that only through an historical examination of the changes in wetland areas caused by natural and human influences can ecologically-sound decisions be made with a greater degree of perception and understanding than is the case at present. The thesis contains two basic parts: (l) a comparison of the amount of coastal marsh and swamp along Wisconsin's west shore of Green Bay, Lake Michigan, before major settlement to the current amount of this habitat; and (2) an examination of the broad range of influences that have caused the changes in coastal wetland area. The term *wetland* refers to the habitat encompassing Howlett's (1974) Emergent Zone, Sedge Meadow, and Shrub and Forest Complexes. The comparison of the past and present condition of these wetlands is mainly quantitative. The quantitative data are the areas ($mi.^2$) occupied by the coastal marshes and swamps. The documentation of the qualitative conditions of the west shore in the past is poor; however, qualitative data have been included whenever possible based upon the material I examined. The material on the influences responsible for the changes in wetland area ranges from specific, well-documented activities to my interpretations of likely influences. Associated with my interpretations are comments on possible directions further research may take for obtaining a clearer understanding of the influences I have not been able to precisely identify. My research should not be regarded as the definitive examination of Green Bay's west shore wetlands. This thesis is a preliminary survey, and many questions await further investigation.

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Green Bay's Coastal Wetlands—A Picture of Dynamic Change

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In Wetlands—Ecology, Values and Impacts, Proceedings of Waubesa Conference on Wetlands, Madison, WI, June 2–5, 1977.

Along Wisconsin's 495 mile Lake Michigan shoreline there remains today somewhat less than 30 linear miles of wetlands, a large percentage of which occurs along the west shore of Green Bay. In the past two decades wetland research has focused on inland wetlands or on coastal salt marshes. Coastal freshwater wetlands of Green Bay are unique insofar as they represent a wetland ecosystem possessing some characteristics of small inland glacial marshes and some characteristics of large marine estuarian systems. This report summarizes some results of a series of estuaries undertaken in the past four years directed toward an elucidation of both man-made and natural changes occurring in the freshwater coastal wetlands of Green Bay.

INTRODUCTION

Along Wisconsin's 495 mile Lake Michigan shoreline the remaining coastal ecosystems include less than 30 linear miles of wetlands, a large percentage of which occurs along the west shore of Green Bay. The coastal wetlands may be in the form of swamps, bogs, marshes, sloughs, or river deltas (Kleinert, 1970). These wetland ecosystems possess some characteristics of inland glacial marshes and at the same time are subject to physical forces which are more characteristic of a large marine estuarine system. In these freshwater coastal wetlands disturbance conditions accompanying normal long-term water movement are accentuated by the tide-like seiche activity. The west shore of Green Bay-Lake Michigan has a relatively flat or gradual sloping topography and a change in water level of only several inches can dramatically alter the amount of land that is inundated or exposed. This area undergoes natural long-term and short-term water level fluctuations.

Long-term water fluctuations are related to climatic change and occur within a time span of 10-30 years. Short term water level fluctuations occur daily and are due to wind and seiche activity which produce irregular and often large temporary changes in the water level. Water levels, both long-term and short-term, constitute a physical force which brings about structural and functional changes in the freshwater level fluctuations.

Managers of inland wetlands have long understood the importance of the relationship between changing water levels and concommitent changes in semiaquatic and aquatic vegetation. Laing (1941). Low and Bellrose (1944), McDonald (1955), and Kadlec (1962) have studied changes in aquatic vegetation associated with changing water levels. Johnsgard (1956), Weller and Spatcher {1965}, and Weller and Fredrickson (1974), have documented changes in bird species abundance and distribution related to water level and vegetational changes in glacial marshes or impoundments of the northern Great Plains.

Much of the information gained from the studies of inland wetlands is important with regard to understanding the dynamics of freshwater coastal wetlands. Yet these freshwater coastal ecosystems are sufficiently unique as to warrant intensive investigations before management objectives and practices can be formulated. The intent of this report is not so much to describe in detail the results of the several

separate studies we have conducted on some of the freshwater coastal marshes of Green Bay but rather to draw from these studies and portray in broad brush strokes insights gained into the dynamic changes occurring in these ecosystems.

UNIVERSITY OF WISCONSIN SEA GRANT

Response of the Yellowheaded Blackbird to Vegetation and Water Level Changes in Coastal Marshes of Green Bay

Frank Dean Roznik

A dissertation submitted to the graduate faculty of the University of Wisconsin–Green Bay in partial fulfillment of the requirements for the degree of Master of Environmental Arts and Sciences

January 24, 1978

Major Advisor: H.J. Harris, Ph.D.

INTRODUCTION

The vegetation of any community plays a direct and vital role in determining the use of the area by birds. Wetlands constantly undergo vegetation changes, resulting primarily from water fluctuation, which influence avian diversity, distribution and abundance. Each species develops adaptive responses to the changing conditions which are exhibited in habitat selection and nest success.

Along Wisconsin's 495 mile Lake Michigan shoreline the remaining coastal communities include less than 30 linear miles of wetlands today, of which a large percentage occurs along the west shore of Green Bay. The coastal wetlands along the Green Bay shoreline may be in the form of swamps, marshes, potholes, sloughs or river deltas (Kleinert, 1970). These areas experience vegetational changes similar to that of small inland glacial marshes and tide-like seiche activity found in marine estuarian systems. Disturbance in freshwater coastal wetlands results primarily from normal long term water level fluctuation which is exacerbated by the seiche activity.

The west shore of Green Bay–Lake Michigan (Figure 1) has a relatively flat or gradual sloping topography and a change in water level of several inches can dramatically alter the amount of land that is inundated or exposed. This area undergoes natural long term and short term water level fluctuations. Long term water level fluctuations are related to climatic changes occurring within an irregular time span of 10 to 30 years (Lake Survey Center, 1969). Short term water level fluctuations occur daily and are due to wind and seiche activity, which produce irregular and often large temporary changes in the water level.

The long term water level fluctuation results in the advance or retreat of vegetation communities along the Green Bay shoreline and as the vege tation changes, birds utilizing this habitat are influenced.

The major objectives of this study were: (1) to examine the long term and short term water level fluctuations in Green Bay from 1920 to 1976; (2) to assess the vegetation of four sample areas during the high water years of 1975 and 1976, examining density, percent cover, interspersion, and edge; (3) to intensively study the adaptive response of the Yellowheaded Blackbird *(Xanthocephalus xinthocephalus)* (Bonaparte), to vegetation and water level changes in four sample areas using nest-site selection, nest density, nest success, and territory size as objective measures of adaptability; and (4) to record incidental observations on the nesting success of five marsh birds, the Forster's Tern *Sterna forsteri* (Nuttall), Black Tern *Chlidonias niger* (Gmelin), American Coot *Fulica americana* (Gmelin), Common Gallinule *Gallinula chloropus* (Bangs), and the Least Bittern *Ixobrychus exilis* (Gmelin), made along with the Yellowheaded Blackbird investigation.

UNIVERSITY OF WISCONSIN SEA GRANT

Loss of Wetlands on the West Shore of Green Bay

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In: Selected Proceedings of the Midwest Conference on Wetland Values and Management, University of Wisconsin Sea Grant Program, University of Wisconsin–Green Bay, June 17–19, 1981. Edited by Brandt Richardson

ABSTRACT

The Land Survey of 1832–66 found 86 square miles of coastal marshes and swamps on Green Bay's west shore. In recent years, marsh and swamp habitat on the west shore have been reduced severely until approximately 24.3 square miles remain at low water and 17.5 at high levels. Both natural and human influences have contributed wetland diminution and species composition has been altered at several sites.

INTRODUCTION

Freshwater and marine coastal wetlands may serve exclusive (fish spawning habitat versus site for disposal of dredge spoils) or complementary (wildlife refuge and environmental education) purposes. In contrast to marine coastal wetlands, the impact of human alterations upon freshwater coastal wetlands is more difficult to assess, because there are few baseline studies of prealteration natural conditions. Both ecological and economic evaluations are required before a reliable assessment can be made of the probable impact of a proposed wetland use. An evaluation would be enhanced by a review of the environmental changes associated with each of the previous uses of a wetland site. This historical perspective provides for a more accurate assessment of the beneficial and deleterious influences affecting ecological integrity.

Bedford, *et al.* (1975) called for improved ecological data for the coastal wetlands of Lakes Michigan and Superior. The 495 miles of Lake Michigan shoreline in Wisconsin now support less than 30 miles of coastal wetland (Kleinert, 1970). These wetlands occur on the west shore of Green Bay, the eastern tip of the Door County peninsula and the lower portions of several rivers tributary to Lake Michigan. This paper (Bosley, 1976) investigates the loss of coastal wetlands on the west shore of Green Bay between the Fox and Menominee Rivers. The early explorers (Kellogg, 1917; Martin, 1926a and b; Neville, 1926; Carver. 1956; Thwaites, 1959) provided only weak documentation of the species composition and appearance of the prominent marsh areas on the west shore this precluded evaluation by recent wetland classifications (Shaw and Fredine, 1956; Cowardin and Johnson, 1973; Golet and Larson, 1974).

UNIVERSITY OF WISCONSIN SEA GRANT

Recovery Processes and Habitat Quality in a Freshwater Coastal Marsh Following a Natural Disturbance

H.J. Harris, G. Fewless, M. Milligan and W. Johnson

In: Selected Proceedings of the Midwest Conference on Wetland Values and Management, University of Wisconsin Sea Grant Program, University of Wisconsin–Green Bay, June 17–19, 1981. Edited by Brandt Richardson

ABSTRACT

This paper describes secondary successional patterns occurring in three coastal marshes on Green Bay, Lake Michigan following the destruction of vegetation due to high lake levels. Primary productivity, Sorenson's index of similarity, and cover type, edge and bird species diversity were used to characterize successional patterns. During the second year of recovery, above-ground primary production attained levels comparable to published accounts of similar wetlands in an established condition. A slight increase was noted in the third year. Changes in plant species composition and distribution were assessed using quadrat data and aerial imagery. First year annuals (*Bidens, Polygonum* etc.) were replaced in the second year by the perennial *Scirpus validus* which shared a co-dominant position with *Bidens* the first year. Other common marsh plants (*Typa, Sparganium Sagittaria, Calamagrostis,* etc.) continue to succeed *Scirpus Validus* on most sites. Nine cover types were present by the third year, however, some appeared earlier than others, and not all were present in all marshes. Similarity indices of plant species show substantial compositional change continuing through the fourth year. Species of marsh nesting birds were found to be influenced by vegetational changes. The relationship between vegetation changes and bird species diversity (BSD) was revealed through a multiple regression of BSD and cover type diversity (CTD) and edge diversity (ED). A significant linear relationship with CTD and a significant quadratic relationship with ED was found. We believe that BSD, an indicator of habitat quality, can be established from vegetation parameters readily assessed from remote sensing. The application of the results of this study to marsh management are discussed.

UNIVERSITY OF WISCONSIN SEA GRANT

Resource Partitioning: Spatial and Behavioral Patterns in a Freshwater Coastal Marsh Avian Community

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science
University of Wisconsin–Green Bay

August 1981

Major Advisor: H.J. Harris, Ph.D.

INTRODUCTION

Avian community diversity is directly associated with the structure and complexity of the vegetation. Avian community structure depends ultimately on the partitioning of that vegetation.

These relationships have been well documented within series of similar forested habitats (MacArthur 1958, MacArthur and MacArthur 1961, MacArthur et al. 1962, MacArthur et al. 1966, MacArthur and Levins 1967, Recher 1969, Anderson and Saugart 1974 and Whitmore 1975, 1977); and also on gradients of dissimilar vegetation types (Karr and Roth 1971, James 1971, Willson 1974, Roth 1976, and Stauffer and Best 1980) and in grasslands (Cody 1968, Weins 1969,1973, 1974a,1974b). Extensive research on resource partitioning and species diversity exists in the literature. However, literature on resource partitioning and species diversity of avian communities in coastal marshes, is sparse. With recent data estimating the loss of wetlands in the U.S. to be 510,000 acres annually (Envl. Law Institute 1980), this gap along with gaps in other ecological aspects of the coastal marsh should no longer be ignored.

Over the past two decades some progress in assessing and characterizing the important functions of wetlands has been made, but more research is needed. Existing research on wetland avian communities has focused mainly on the qualitative assessment of vegetation, and its subsequent role in avian diversity; and habitat occupancy and utilization during the breeding season (Beecher 1942, Johnsgard 1956, Weller and Spatcher 1965, Burt 1970, and Weller and Fredrickson 1974). The lack of quantitative analysis in these studies has limited their theoretical contribution to understanding avian community structure. In order to test accepted hypothesis on resource utilization, niche differentiation, competition, and coexistence among ecologically similar avian species in coastal marshes, a more quantitative representation of these breeding avian communities is needed.

A methodology that can assess resource partitioning in these avian communities must be identified so that relevant quantitative data on the structural and functional aspects of the avian community in coastal marshes may be collected. The methodology for my study, adapted from Cody (1968) and Wiens (1974), is based on the fact that niche is a functional characteristic of a species and determines the structure of avian communities through interspecific competition. The adaptation and use of this methodology in examining resource partitioning will at a minimum provide useful baseline data thus providing a greater probability of detecting deviations in these bird communities that ultimately reflect subtle changes in the environment.

Specifically, I will investigate the following questions:

l. What structural variables of the marsh vegetation influence the spatial and feeding patterns of the breeding avifauna?

2. What bird species are added or eliminated with changes in structural variables?

3. What characteristics the marsh vegetation influences bird species diversity?

4. What changes occur in the ecological relationships among the breeding avifauna once a species is added? Specifically, does the cover type accommodating the new species exhibit an Increase in habitat heterogeneity, or is there an increase in the horizontal spatial overlap by species in their utilization of the existing patches available (Roth 1976)?

UNIVERSITY OF WISCONSIN SEA GRANT

Reproductive Success and Foraging Success as Related to Populations of Forster's Terns *(Sterna forsteri)* on Green Bay, Wisconsin

Joel A. Trick

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Studies, University of Wisconsin–Green Bay

June 1982

Major Advisor: H.J. Harris, Ph.D.

INTRODUCTION

This thesis consists of an assessment of factors affecting the population dynamics of Forster's Tern on the bay of Green Bay, and a detailed investigation of the relation of food availability to reproductive success.

The Forster's Tern *(Sterna forsteri)* is not well known, and the Master Thesis of Martin K. McNicholl (1971) provides the only detailed information on its life history. In Wisconsin, several observers noted a decline in numbers of Forster's Terns in the mid-1970's. The lack of information on the status and distribution of this species in Wisconsin prompted the DNR to fund a study in 1978 (Harris and Trick, 1979), which provided the basis for placing the Forster's Tern on the Wisconsin Endangered Species List on October 1, 1979. One of the observations of this study was that the population was apparently not producing enough young to maintain its numbers.

Several factors were noted as influencing reproductive success, most notably lack of available nesting substrate and nest loss to water level fluctuation and wave damage. These two factors were actually closely related, as the lack of suitable nesting substrate had forced many birds to nest in suboptimal habitat, and made them succeptible to nest loss through wind and wave action. Another finding of the study was that approximately 75 percent of the Forster's Terns nesting in Wisconsin were found on the bay of Green Bay.

The Green Bay population was chosen for more detailed study, in an effort to determine the future fate of the population and to identify more specifically those factors which have an influence on nesting success. Food availability was chosen as a factor deserving close scrutiny within the Green Bay population because at the time that the present study was initiated, it was felt that it may prove to be an important factor influencing the reproductive success of this population.

The main questions to be addressed are:

What is the present status and future fate of Forster's Tern on the bay of Green Bay?

Is food availability a primary limiting factor in the reproductive success of Forster's Tern on Green Bay?

The study area is shown in Appendix 1 (map). It encompasses all of the west shore of Green Bay from the mouth of the Fox River at the city of Green Bay, to the mouth of the Menominee River at Marinette. A brief description of each colony site may be found in Appendix 1.

UNIVERSITY OF WISCONSIN SEA GRANT

Diversity: Quantification and Ecological Evaluation in Freshwater Marshes

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Biological Conservation 27: 99–110 1983

ABSTRACT

The primary objective of this study was to test the usefulness of two indices—edge diversity and cover type diversity—in assessing bird species diversity for breeding avian communities in freshwater coastal marshes. Bird species diversity was used in this study as an indicator of ecological quality. Permanent transects in three marshes on the bay of Green Bay, Michigan, provided the basis for vegetation assessments and breeding bird censuses. Four years of field data were subjected to regression analysis. The best equation was found to be a multiple regression of bird species diversity on cover type diversity and edge diversity, showing a significant linear relationship with cover type diversity and a significant curvilinear relationship with edge diversity. Cover type diversity and edge diversity can be readily assessed from aerial imagery. The results are most applicable to ecological evaluation where objectives stress species diversity rather than single-species management.

UNIVERSITY OF WISCONSIN SEA GRANT

Aquatic Insect Emergence Patterns of Two Marshes on Green Bay, Lake Michigan

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Studies, University of Wisconsin–Green Bay

December 1985

Major Advisor: H.J. Harris, Ph.D.

ABSTRACT

Floating emergence traps were used to collect emerging adult aquatic insects from open water, sparse emergent, dense emergent, and wet meadow cover types in a diked and an undiked marsh on Green Bay, Lake Michigan from 11 June to 26 August, 1984. Temporal and spatial patterns in the number, biomass, and species composition of insects emerging in these marshes were evaluated. Of 6657 insects collected, over 90% were from the Order Diptera, and 67% were Chironomidae. Approximately 45% more insects and 80% more insect biomass were collected from the diked marsh. Most insects and insect biomass were collected from sparse emergent vegetation in both marshes. Total insects and insect biomass collected in the diked marsh were highest in June and declined gradually into August. No distinguishable pattern was apparent in the undiked marsh regarding total insect numbers, but biomass increased from low values in June to a peak on 26 August. These results agree with other studies suggesting that marsh productivity is enhanced by abundant areas of interspersed water and emergent vegetation. They further suggest that diking may have increased aquatic insect productivity within this Green Bay coastal marsh.

UNIVERSITY OF WISCONSIN SEA GRANT

Preliminary Observations on the Seiche-Induced Flux of Carbon, Nitrogen and Phosphorus in a Great Lakes Coastal Marsh

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In: Coastal Wetlands—Proceedings of the Great Lakes Coastal Wetlands Colloquium, Nov. 5–7, 1984. National Sea Grant Program and Environment Canada. Harold H. Prince and Frank M. D'Itri, editors. 1985.

This paper is a preliminary report on a study of a segment of Peter's Marsh on lower Green Bay. The study was initiated in June, 1983. The object of the investigation is to assess the flux of carbon, nitrogen and phosphorus between the marsh and the waters of Green Bay and determine the potential value of exported particulates for filter-feeding zooplankton species of the adjacent open waters.

The study was designed to take advantage of periodic water level fluctuations associated with a standing wave or surface seiche in the bay. Heaps et al (1982) noted the mean period for the seiche to be 10.8 hrs at the southern end of the bay and that amplitude was observed to range as high as 25-30 cm. Hence a regular water level change, comparable in effect to tidal changes in salt marshes, provides a mechanism to drive an exchange of substances between marsh and bay.

The short term seiche-induced flux of carbon, nitrogen and phosphorus are examined. The marsh appears to behave as a nutrient transformer, seasonal changes are discussed. In general, particulate components are retained by the marsh and dissolved components are released based on ebb/flow ratios for seiche-induced water movements.

UNIVERSITY OF WISCONSIN SEA GRANT

Ecology of Softstem Bulrush (*Scirpus Validus* Vahl.) in a Freshwater Coastal Marsh Ecosystem

Gary Fewless

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, University of Wisconsin–Green Bay

August 1986

Major Advisor: H.J. Harris, Ph.D.

ABSTRACT

Several aspects of the life history of softstem bulrush (*Scirpus validus* Vahl) were examined In a series of freshwater coastal marshes along the west shore of Green Bay, Lake Michigan. During the four years 1978–1981 net aerial primary production was, respectively, 1014, 1309, 1997, and 1122 g dry weight/m2. A preliminary study of below ground primary production indicates great variability among years. The estimate for 1980 (12731 g dry weight/m2/yr) is among the highest reported for this species, and was followed by a net decrease in belowground standing crop in 1981. The rise and then rapid decline of both above and belowground production reflects the transitory nature of this species, which flourishes only on recently exposed mudflats.

In laboratory studies of the environmental requirements for germination of the seeds (achenes) of *Scirpus validus*, a period of cold, wet storage in excess of 30 days was required to break dormancy, and the proportion of germinating seeds increased with time of cold storage, to a maximum of 77% at 895 days. Germination required the presence of light, and alternating diurnal temperatures, and significantly better germination success was realized for achenes submersed under several cm of water than for achenes pressed lightly Into the surface of wet sand. Several positive interactions of environmental variables affecting the germination of seeds were identified in a factorial experiment.

A simple model is proposed for vegetation dynamics in the Green Bay coastal marshes, and several adaptations of *Scirpus validus* to the Green Bay marsh ecosystem are discussed. The germination requirements appear to coordinate germination of *Scirpus* seeds with the presence of exposed mudflats. In general the life history characteristics of *Scripus validus* examined in this study and the accounts of this species elsewhere in North America, are consistent with those expected of a species adapted to recurring disturbance resulting primarily from fluctuating water levels.

UNIVERSITY OF WISCONSIN SEA GRANT

Importance of the Nearshore Area for Sustainable Redevelopment in the Great Lakes with Observations on the Baltic Sea

ROYAL SWEDISH ACADEMY OF SCIENCES

AMBIO, A Journal of the Human Environment

17(2): 112–120 1988

Hallett J.Harris, Victoria A. Harris, Henry A. Regier and David J. Rapport

The ecological systems of the nearshore waters and wetlands play similar ecosystemic roles in the Baltic and Great Lakes Basins. A major difference in the more detailed features relates to the *phytal* dominated by *Fucus* spp. (bladderwrack) in the more saline parts of the Baltic: the attached algae community in the Great Lakes that is broadly comparable to the Baltic's phytal is relatively less important, or so it seems now. Nearshore waters and wetlands are the loci for key self-organization processes within large aquatic ecosystems. They provide locales and resources for critical reproductive and feeding periods of large organisms (fish, shellfish, mammals, birds) that dominate and regulate other species in the aquatic realm. They tend to modulate sharp influences such as nutrient pulses, floods, etc. The nearshore waters of the Baltic and Great Lakes have all been degraded in part but especially those near industrialized urban centers. Efforts toward rehabilitation of such ecological slums and toward preservation of relatively pristine heritage areas are now getting underway, if only slowly. Postindustrial societies are coming to value nearshore waters and wetlands far more than previous societies.

UNIVERSITY OF WISCONSIN SEA GRANT

Microcontaminants and Reproductive Impairment of the Forster's Tern on Green Bay, Lake Michigan—1983

Environ. Contam. Toxicol 18, 706-727 (1989)

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ABSTRACT

For the 1983 nesting season, Forster's tern *(Sterna forsteri)* reproductive success was significantly impaired on organochlorine contaminated Green Bay, Lake Michigan compared to a relatively uncontaminated inland location at Lake Poygan, Wisconsin. Compared with tern eggs from Lake Poygan, eggs from Green Bay had significantly higher median concentrations of 2,3,7,8-tet rachlorodibenzo-p-dioxin (TCDD), other polychlorinated dibenzo-p-dioxins (PCDDs), total polychlorinated biphenyls (PCBs), total (three congeners) non-ortho, ortho' PCBs, five individual PCB congeners known to induce aryl hydrocarbon hydroxylase (AHH) and several other organochlorine contaminants. Conversions of analytical concentrations of TCDD and PCB congeners based on relative AHH induction potencies allowed for estimation of total 2,3,7,8-TCDD equivalents. Two PCB congeners, 2,3,3',4,4'- and 3.3',4,4',5-pentachlorobiphenyl (PeCB) accounted for more than 90% of the median estimated TCDD equivalents at both Green Bay and Lake Poygan. The median estimated TCDD equivalents were almost 11-fold higher in tern eggs from Green Bay than in eggs from Lake Poygan (2175 and 201 pg/g), The hatching success of Green Bay sibling eggs from nests where eggs were collected for contaminant analyses was 75% lower at Green Bay than at Lake Poygan. Hatchability of eggs taken from other nests and artificially incubated was about 50% lower for Green Bay than for Lake Poygan. Among hatchlings from laboratory incubation, those from Green Bay weighed approximately 20% less and had a mean liver weight to body weight ratio 26% greater than those from Lake Poygan. In both field and laboratory, mean minimum incubation periods were significantly longer for eggs from Green Bay compared to Lake Poygan (8.25 and 4.58 days, respectively). Mean minimum incubation time for Green Bay eggs in the field was 4.37 days longer than in the laboratory. Hatchability was greatly improved when Green Bay eggs were incubated by Lake Poygan adults in an egg-exchange experiment, but was sharply decreased in Lake Poygan eggs incubated in Green Bay nests. Nest abandonment and egg disappearance were substantial at Green Bay but nil at Lake Poygan. Thus, not only factors intrinsic to the egg, but also extrinsic factors (parental attentiveness), impaired reproductive outcome at Green Bay. The epidemiological evidence from this study strongly suggested that contaminants were a causal factor. AHH-active PCB congeners (intrinsic effects) and PCBs in general (extrinsic effects) appeared to be the only contaminants at the concentrations measured in eggs, capable of producing the effects that were observed at Green Bay.

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Aquatic Insect Emergence in Two Great Lakes Marshes

Wetlands Ecology and Management, vol. 1 no. 2 p. 111–121 (1990)

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ABSTRACT

This study determined total number, biomass, taxa, and seasonal occurrence of adult aquatic insects emerging from four vegetation zones in one diked and one undiked freshwater coastal marsh on hypereutrophic lower Green Bay, Lake Michigan, USA during the summer of 1984. Floating box traps were placed in open water, sparse emergent, dense emergent, and wet meadow vegetation zones in each marsh. Insects were collected during 20 24-hour periods, each four days apart, from June 11 to August 26. Two-way ANOVA was used to test differences in number and biomass of insects between marshes and among vegetation zones. Polynomial regression was used to evaluate seasonal emergence patterns. More insects, insect biomass, and insect taxa were found in the diked marsh, especially during the first half of the sampling period. Damselflies were much more abundant in the diked marsh. Most insects and insect biomass were found in the sparse emergent vegetation zone of both marshes. The emerging insect community in the diked marsh appears enhanced by its separation from the hypereutrophic and turbid waters of lower Green Bay.

UNIVERSITY OF WISCONSIN SEA GRANT

Great Lakes Wetlands: Impacts of Nutrients, Sediment, and Turbidity on Coastal Marshes of Green Bay, Lake Michigan

Hallet J. Harris, Ph.D., Lynne McAllister and Douglas McLaughlin

Great Lakes Wetlands, vol 2, #2, Spring 1991

In the first issue of "Great Lakes Wetlands," Robert Wetzel briefly addressed the nutrient retention processes in wetlands, and in a broader sense, how wetlands effect water quality. This article takes a different approach and discusses some ecological implications of degraded water quality on wetlands, specifically the impacts of nutrients, sediment, and turbidity on submerged macrophytes and secondary impacts on insect production.

Dr. Hallet "Bud" Harris is a professor at the University of Wisconsin–Green Bay and has investigated Green Bay's coastal marshes for the past 15 years. Many of these studies, including those cited in this article, have provided valuable information for the development of Green Bay's Remedial Action Plan. Lynne McAllister and Douglas McLaughlin served as graduate research assistants with Dr. Harris. Ms. McAllister is currently a consultant with Mantec Services in Corvalis, Oregon. Mr. McLaughlin is pursuing his doctorate at the University of Wisconsin's Institute for Environmental Studies.

UNIVERSITY OF WISCONSIN SEA GRANT

Factors Influencing the Distribution of Submerged Macrophytes in Green Bay, Lake Michigan: A Focus on Light Attenuation and *Vallisneria Americana*

Lynne S. McAllister

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

February 1991

Major Advisor: H.J. Harris, Ph.D.

ABSTRACT

This study focused on the importance of light as a factor limiting depth distribution and abundance of *Vallisneria americana* along the west shore of Green Bay from Duck Creek to the Pensaukee River. Light penetration parameters were assessed weekly at 5 study sites, lying along the bay's north-south trophic gradient, from June to August in 1989 and 1990. Sampling was also done at each site for end-of-season submerged macrophyte density and biomass. In addition, a model was developed, which predicts potential increases in depth distribution of *Vallisneria* for improvements in water clarity as remedial action progresses.

The maximum depth of *Vallisneria* growth and persistence (Z_c) could be determined with certainty at two of the five sites. Average summer light intensity at Z_c was 30-38 uE/m^2/s, which represented 2.4–3.7% of the light intensity at Z_0.The compensation light intensity of *Vallisneria* was experimentally determined as 18 uE/m^2/s using an oxygen production method. *Vallisneria* depth distribution is probably limited by light availability in some areas. Based on predictions of the model, it appears that the scarcity of *Vallisneria* in the area south of Long Tail Point is due to light limitation. It is also probable that other factors—e.g. wave action, substrate composition, nutrient availability—interact with light to influence macrophyte production and depth distribution in some places.

The model predicted that the goal of 0.7 m Secchi depth established by the Green Bay Remedial Action Plan for improving water clarity in southern Green Bay would be sufficient for re-establishment of light conditions favorable for macrophyte growth. Resuspension of particulates appears to have the greatest influence on light attenuation in the nearshore zone. A stronger focus on abiotic suspended solids control may be appropriate in encouraging and managing submerged macrophytes.

UNIVERSITY OF WISCONSIN SEA GRANT

Measures of Reproductive Success and Polychlorinated Biphenyl Residues in Eggs and Chicks of Forster's Terns on Green Bay, Lake Michigan, Wisconsin—1988

Arch. Environ. Contam. Toxicol. 25, 304–314 (1993)

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ABSTRACT

Data on reproductive success of Forster's tern *(Sterna forsteri)* from Green Bay, Lake Michigan in 1983 are compared with data collected in 1988. In 1988 measures of reproductive performance (hatching success, number of young fledged, and length of incubation) were improved. Concentrations of total polychlorinated biphenyls (PCBs) and planar PCB congeners in the eggs were compared between years. Median total PCB residue was 67% lower in 1988 (X = 7.3 g/g). This corresponds to a 42% reduction in tetrachlorodibenzo-p-dioxin equivalents (TCDD-EQ) from 1983 to 1988. We suggest that contaminant reduction and improved reproductive performance were due to low river flows in 1988 and associated reduced PBC loading into Green Bay. Forty-two percent of the matured chicks died before fledgling, and their body weight growth curves were much lower than normal. Young accumulate total PCBs at a rate of 17.6 µ.gf day. A no-observable-adverse-effects level (NOAEU of 40-84 µ.g/kg/day was estimated from the two year results using the least observable adverse effects level (LOAEL)/NOAEL rating values.

UNIVERSITY OF WISCONSIN SEA GRANT

Factors Affecting the Nearshore Light Environment and Submersed Aquatic Vegetation in Lower Green Bay

Patrick Robinson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, Environmental Science and Policy, University of Wisconsin–Green Bay

May 1996

Major Advisor: H.J. Harris, Ph.D.

ABSTRACT

This study focused on the re-establishment of submersed angiosperms in lower Green Bay. The decline in submersed angiosperms is believed to be partially due to water level changes and decreases in water clarity. The study had two objectives: (1) to determine the ability of brush fences to reduce wind and wave energy and improve water clarity for the purpose of promoting growth of submersed angiosperms in lower Green Bay, and (2) to quantify the contribution of algae (as indicated by chlorophyll *a*), ashed solids, and detritus to the high attenuation of light in the nearshore waters of lower Green Bay.

The brush fence experiment utilized a transplanted propagule source from Montana Lake, Marinette County, WI. Brush fences (4.5 x 2.0 m x 1.2 m) were constructed at three sites on the west shore of lower Green Bay. Germination trays (50.8 cm x 38.1 cm x 12.7 cm) containing the propagule source were placed inside and outside the brush fence on 1 June, 1995. Wave energy, chlorophyll *a*, light extinction, total suspended solids, and ashed solids were recorded weekly from 8 June, 1995 to 10 August, 1995. Harvesting was done on 25 July, 1995 and shoot densities were recorded. The brush fences were not able to significantly decrease wave energy ($p=.147$), chlorophyll *a* ($p=.162$), light extinction ($p=.398$), total suspended solids ($p=.054$), or ashed solids ($p=.692$). There was no significant increase in shoot densities ($p=.803$) due to the brush fences.

Light extinction, chlorophyll a, detritus, and ashed solids values were used to perform simple and multiple regressions. Detrital values were calculated indirectly using chlorophyll *a* concentrations and ashed solids values. Simple regression showed that chlorophyll a explained the greatest amount of variability in light extinction at all sites ($R2=.764$ to $.862$). Multiple regression found chlorophyll *a* and detritus to be the largest contributors to light extinction in the nearshore waters on the west shore of lower Green Bay, while ashed solids contributed relatively little.

It was found that multiple stressors, including water clarity, wave energy, deposition, carp, and zebra mussels, are acting to inhibit growth of submersed angiosperms at the three sites. The magnitude and identity of the stressors is not the same at each location. Because of this, a single solution which causes submersed angiosperm re-establishment systemwide does not appear likely.

UNIVERSITY OF WISCONSIN SEA GRANT

Determination of Total Mercury Using Microwave Digestion on Emergent Insects Colllected from Two Coastal Marshes of Green Bay, Lake Michigan

Andrew D. Wenzel

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

December 1996

Major Advisor: H.J. Harris, Ph.D.

ABSTRACT

An analytical method was developed utilizing microwave digestion to analyze total mercury in emergent insects. The digestion time was reduced from 16 to 2 hr as well as reducing the amount and type of reagents used in the process. Emergent aquatic insects and sediments from two coastal marshes, one diked (Sensiba) and one undiked (Peters) marsh, of the lower Green Bay, Lake Michigan were analyzed for total mercury. A significant difference in mercury levels of the diked versus the undiked marsh exists. Peters Marsh had a 1992 seasonal average mercury insect concentration of 56 ng/g wet weight and Sensiba Marsh of 13 ng/g. Spatial and temporal differences in insect mercury concentrations were detected but the differences were inconsistent. The inconsistencies are most probably related to factors not examined in this study. A significant spatial relationship exists within Peters Marsh where the sediment concentrations decrease landward from the mouth of the channel. A significant temporal relationship was present in 1993 with lower mercury sediment concentrations earlier than later in the season. The difference is related to the increased Fox River flow in mid summer 1993. Sediment samples of the west shore of the lower Green Bay are an order of magnitude lower than sediments from the Fox River. Mercury concentrations of the sediments from which the insects emerge were on the same order of magnitude. A comparison of total mercury levels in the emergent insects and the sediments indicates that the insects are not bioconcentrating but are bioaccumulating mercury.

UNIVERSITY OF WISCONSIN SEA GRANT

Regional, Habitat, and Human Development Influences on Coastal Wetland and Beach Fish Assemblages in Green Bay, Lake Michigan

Journal of Great Lakes Research

Volume 23, Issue 1, 1997, Pages 36–51

John C. Brazner

ABSTRACT

High levels of coastal wetland degradation, limited knowledge of fishes that utilize these habitats, and the potentially high ecological importance of coastal wetlands in Great Lakes ecosystems all provided an impetus to characterize fish assemblages associated with coastal wetland and other littoral habitats in Green Bay, Lake Michigan. From May to September 1990 and 1991, I sampled 24 coastal wetland and beach sites spanning Green Bay. Half the sites represented habitats modified by physical alterations, such as dikes and landfills, to allow documentation of the effect of human modifications along the shoreline. A total of 41,867 primarily immature fishes, representing 20 families and 54 species, was captured. Species richness and total fish abundance were highest in undeveloped wetland habitats and in the lower bay, which was typified by warmwater, turbidity-tolerant fishes. The upper bay had a more cool and clearwater assemblage. Undeveloped wetlands were characterized by the presence of several important commercial and sport fishes. Sites adjacent to human development had fewer fish and fish species characterized by a more disturbance-tolerant assemblage. The high biodiversity and large numbers of ecologically and economically important fishes associated with wetlands lend increased significance to maintaining and restoring these habitats in the Great Lakes.

UNIVERSITY OF WISCONSIN SEA GRANT

Patterns in Fish Assemblages from Coastal Wetland and Beach Habitats in Green Bay, Lake Michigan: A Multivariate Analysis of Abiotic and Biotic Forcing Factors

John C. Brazner and Edward W. Beals

Can. J. Aquat. Sci. 54:1743-1761 (1997)

ABSTRACT

From May to September in 1990 and 1991, 24 coastal wetland and beach sites in Green Bay, Lake Michigan, were sampled to investigate abiotic and biotic factors influencing fish assemblages; half the sites were modified by human developments, and half were relatively undeveloped. The greatest assemblage differences were observed among regions, but there also were strong differences among assemblages from different habitats. Degree of development had less of an effect on site differences, although assemblages at undeveloped wetlands were unique, and those from developed and undeveloped sites in the upper bay were relatively distinct. The most influential abiotic factors were turbidity, reflecting the trophic gradient in the bay, and a suite of variables associated with macrophyte coverage and diversity, which were critical components of nursery habitats for the primarily immature fishes we captured. The volatile and unpredictable nature of shoreline habitats in the Great Lakes apparently precluded competition and predation from having a strong organizing role. This study demonstrates that undeveloped wetlands are a valuable and intensely utilized fish habitat, particularly as nursery areas, that should receive special consideration in ecosystem management plans for the Great Lakes.

UNIVERSITY OF WISCONSIN SEA GRANT

The Effects of PCB-Contaminated Environments on the Leopard Frog *(Rana pipiens)*

Susan M. Kersten

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science, University of Wisconsin–Green Bay

December 1997

Major Advisor: Paul Sager, Ph.D.

ABSTRACT

Leopard frog eggs were placed in field enclosures at eight sites along a PCB contamination gradient in the Fox River and Green Bay area wetlands. Growth and development was followed up to metamorphosis which took a total of 146 days. Percent hatch was significantly different between sites and was negatively correlated with sediment PCB levels. Percent surviving to metamorphosis was also significantly different between sites, but positively correlated to chlorophyll ***a***. Growth rates showed significant differences between sites. Growth rates were influenced by two major factors, density which had a negative impact and chlorophyll *a* which had a positive influence. It was found that tadpoles had bioaccumulated PCBs in four months. Deposit A metamorphs had tissue PCB levels higher than the Food and Drug Administrations human consumption limit. In addition, four sites including Deposit A, Deposit X, Railroad Museum and Bay Port had tadpoles with higher tissue PCB levels than recommended by the International Joint Commission for wildlife health.

PCB contaminated eggs (from Bay Port) and "clean" eggs (from Barkhausen Reserve) were raised in the laboratory until metamorphosis was completed. Percent hatch and percent surviving to metamorphosis were not significantly different between eggs from the two sites. Growth rates were significantly different, and were negatively correlated with density as the field study also showed. Finally, there was a significant difference in the number of deformities in metamorphs from the two sites. Pearson's chi square showed that metamorphs from Bay Port had a significantly higher number of deformities than metamorphs from Barkhausen Reserve.

UNIVERSITY OF WISCONSIN SEA GRANT

The Nesting Success and PCB Burdens of Yellow-Headed Blackbirds Found in Diked Marshes Along Green Bay, Lake Michigan

Kiersten J. Rattray

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

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Major Advisor: H.J. Harris, Ph.D.

ABSTRACT

While there is evidence suggesting impaired reproductive success in fish eating bird colonies on Green Bay due to PCB contamination (Kubiak et al. 1989, Gilbertson et al. 1991, Tillitt et al. 1992), little evidence is available for insectivorous marsh birds. The reproductive success of the yellow-headed blackbird was studied for two field seasons in 1995 and 1996 to compare hatching and fledging success, and the growth of young between a reference site and two likely contaminated sites, as well as to documented any potential effects of PCB contamination. The selected wetland areas included Sensiba Marsh, Ken Euers Park and Atkinson's Marsh, all of which were located in Brown County, Wisconsin, adjacent to Green Bay, Lake Michigan.

Accumulated levels of PCBs were found in eggs and chicks from all three sites signifying that all study areas were contaminated to some extent. Total PCB concentrations found in the blackbirds from all three sites were low, not exceeding 0.5 ppm, and no gross embryo mortality or chick deformities were noted at any of the three sites. Abnormal growth patterns of chicks with high accumulated levels of PCBs have been documented in the literature (Harris et al. 1993) but average tarsus and weight growth curves generated for yellow-headed blackbirds for all areas in this study not only showed very similar patterns of growth across all sites for both years, but also demonstrated patterns closely consistent with those found in the literature.

An approximate 3:1 ratio of female to male chicks fledging from nests in Atkinson's Marsh and Sensiba Marsh was documented in 1996. PCBs and other contaminants have been documented as endocrine-disrupters, interfering with sex hormones and having the potential to disturb normal brain sexual development (Gimeno et al. 1996).

Among the many studies documenting the toxic effects that PCBs have had on birds in the Lower Fox River-Green Bay area, this study provides positive documentation that not all avian species may be as detrimentally affected as previously believed.

UNIVERSITY OF WISCONSIN SEA GRANT

PCBs, DDE, and Mercury in Young-of-The-Year Littoral Fishes from Green Bay, Lake Michigan

Journal of Great Lakes Research

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John Brazner and William DeVita

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ABSTRACT

Forage fish were collected in August and September, 1991 to characterize the influence of human disturbance at 23 coastal wetlands and beaches in Green Bay, Lake Michigan. Disturbance characterization included analysis of contaminant residues (total PCBs, p,p′-DDE, and total mercury) in young-of-the-year fish for at least one species per site. Yellow perch (Percaflavescens) and spottail shiners *(Notropis hudsonius)* were the primary species sampled. Residue concentration differences among species were minimal. Residues of PCBs were highest of the three compounds measured and were the only residues that exceeded International Joint Commission Aquatic Life Guidelines: all 14 fish samples from the lower bay exceeded the 100 ng/g PCB guideline. Based on the concentration gradient measured, the Fox River is the primary source of PCBs; whereas, the more evenly distributed p,p′-DDE and mercury appear to originate mostly from non point sources. The high percentage of more-chlorinated PCB homologs in upper bay fish supports the hypothesis that less-chlorinated PCBs volatilize more quickly and therefore are less abundant farther from their source. Habitat-specific data suggest that contaminants (particularly PCBs) are more available to biota at beaches than at wetlands.

UNIVERSITY OF WISCONSIN SEA GRANT

Waterfowl Use of Lower Green Bay Before (1977–78) and After (1994–97) Zebra Mussel Invasion

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

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Major Advisor: Robert Howe, Ph.D.

Lower Green Bay of Lake Michigan is one of the most important migration stopovers on the Great Lakes for North American waterfowl, particularly diving ducks. Water quality degradation and coastal wetland destruction over this century have reduced traditional aquatic vegetation and macroinvertebrate food supplies for diving ducks. The zebra mussel *(Dreissena polymorpha)* invaded Green Bay circa 1991 and now provides an abundant new food resource for diving ducks. Sixty-three comprehensive surveys, conducted in six different years over a 20-year period, establish waterfowl use (species abundance, duck use days, chronology and distribution) of lower Green Bay during pre- and post-mussel invasion periods (1977–78 and 1994–97).

Diving duck "use days" (a measure integrating waterfowl numbers and duration of stay) exceeded dabbling duck use days by an order of magnitude or more in each season, indicating that Green Bay is far more important as migration habitat for diving duck populations. Pre-invasion surveys established a baseline of .825 million diving duck use days in fall 1977 and .315 million diving duck use days in spring 1978. When zebra mussels first became abundant in Green Bay, diving duck use was initially lower (.574 million duck use days for fall 1994) than fall 1977. During the post-invasion study period, diving duck use steadily increased by 220 percent to 1.83 million duck use days by fall 1997, primarily due to increases in mollusc-feeding ducks—goldeneye *(Bucephala clangula)*, lesser scaup *(Aythya affinis)*, and greater scaup *(A. marila)*.

The most dramatic change in waterfowl use was a 26,360 percent increase in goldeneye duck use days from 1977 to 1997. Goldeneye represented less than one percent of the diving ducks using lower Green Bay in 1977. Their relative abundance increased to 44.7 percent by 1997. Scaup were the most abundant waterfowl during all survey periods, but their relative abundance declined from 80.6 to 49.2 percent during 1977-97 because of the large increase in goldeneye. During the post-invasion period (1994-97), scaup use days increased by 128 percent despite a concurrent 9 percent decrease in the mid-continent breeding populations of scaup. By 1997, scaup and goldeneye accounted for 93.9 percent of diving duck use on lower Green Bay.

Smaller increases in diving duck use days were also documented for canvasback *(A. valisineria)* and redhead *(A. americana)*. These increases were consistent with increases in the mid-continent breeding populations. There were no notable changes in duck use for ring-necked duck *(A. collaris)*, bufflehead *(B. albeola)*, common merganser *(Mergus merganser)*, or red-breasted merganser *(M. serrator)*. Ruddy duck *(Oxyura jamaicensis)* use declined from 90,000 duck use days in fall 1977 to 2,000 in fall 1997.

During both study periods, large rafts of diving ducks gathered to forage in shallow areas (2–10m deep) along the west shore, where the mean total density of preferred macroinvertebrate foods exceeded 2000–4000/n/. In 1977–78, only two areas along the east shore were regularly used by diving ducks—the shoals between Red Banks and Bayshore Park and the inner Bay south of Point au Sable. Following zebra mussel invasion, diving duck distribution shifted toward several rock/gravel shoals—near Rush Point, Point au Sable reef and Point Comfort-Red Banks—where zebra mussel densities exceeded 4000/m^2. Both the percent occurrence and the size of diving duck rafts increased at these locations.

In 1978 and 1994, mean total densities and relative abundances of native macroinvertebrate taxa reportedly preferred by diving ducks (Pelecypoda-Sphaeriidae, Gastropoda, Amphipoda and Isopoda) were higher along the west shore, in the areas where diving ducks concentrated in large numbers. For 27 common stations sampled in 1952 (Surber and Cooley), 1969 (Howmiller 1971) and 1978, mean total densities and relative abundances of these same taxa and other pollution intolerant macro invertebrates were higher in 1978, indicating general improvement in water quality of the lower Bay from 1969 to 1978. In both 1978 and 1994, gradients of increasing pollution intolerant macroinvertebrate densities and relative abundances were observed along south to north and east to west axes of the lower Bay.

The primary factor affecting diving duck distribution on lower Green Bay appeared to be the density of preferred macroinvertebrate foods within the ducks' feeding depth range. Ice cover, wind and wave

conditions and possibly human disturbance influenced diving duck distribution to a lesser degree. Diving ducks appeared to selectively feed in areas less than 10m deep, where densities of preferred macroinvertebrate foods exceeded 2000 – 4000/m^2.

The dramatic increases in scaup and goldeneye numbers and use days and the increasing occurrence of diving duck concentrations on known zebra mussel beds, indicate that mussel-feeding diving ducks responded to this new food resource within two-three years. During 1994–97, goldeneye and scaup altered their spring and fall migration patterns to make greater use of lower Green Bay.

UNIVERSITY OF WISCONSIN SEA GRANT

The Littoral Zooplankton Community Along the Trophic Gradient in Green Bay, Lake Michigan

Kay E. Miller

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December 1998

Major Advisor: Paul Sager, Ph.D.

ABSTRACT

This study summarizes the littoral zooplankton community sampled in the summer of 1995 in four coastal wetlands along the trophic gradient in Green Bay, Lake Michigan. During the study, five orders, seventeen families and 33 genera were collected. The most abundant order collected was Cladocera. The order Cladocera also contained the most families as well as the most genera. The most abundant family was Bosminidae. *Bosmina, Chydorus, Brachionus, Polyarthrus* and *Keratella* were the most abundant genera collected.

The littoral zooplankton community varies in structure among the four coastal wetlands. Cladocerans tend to dominate the northern or upper bay sites while copepods and rotifers show their greatest abundances in the lower bay sites. Specifically, *Bosmina longirostris,* an indicator species of disturbance, appeared in greatest abundance in the northern most site where conditions are meso-oligotrophic with no clear explanation. Brachionus, Keratella and Polyarthra are rotifer indicator species of disturbance that appear in great abundance in the upper bay. These findings are not consistent with Richman et al. (1984) nor Gannon (1974). It appears that several taxa of the littoral zooplankton are not following the conditions of the pelagic zone in regards to the trophic gradient in Green Bay.

Total zooplankton abundance (per liter) was not significantly different among the sites from the northern bay to the lower bay. This is not consistent with Richman et al. (1984) and Gannon (1974) who report greatest abundances of pelagic zooplankton in the lower bay.

A factor analysis attempted to determine community structure for the four wetlands. Four factors or groupings were determined. These grouping have various relationships with environmental parameters that do not accurately explain why these species group together. The complexity and dynamics of the coastal marshes presents a window of opportunity for further research in these interesting and valuable areas.

UNIVERSITY OF WISCONSIN SEA GRANT

Brush Fences Fail to Prompt Growth of Submergent Aquatic Vegetation in Lacustrine Environment (Wisconsin)

Patrick J. Robinson

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Hallett J. Harris

University of Wisconsin-Green Bay, 2420 Nicolet Dr., Green Bay, WI 54311, 920/ 465-2371, Restoration & Management Notes 16:2 Winter 1998.

Unlike their successful use in shallow wetlands in Louisiana (Good, 1993), we found that, when used in a large body of water, brush fences failed to provide the environment necessary for the growth of submergent aquatic vegetation (SAV). It appears that the greater level of wave energy in large lakes simply overpowers these brush fences, propelling sediment and algal material through them with little apparent resistence or filtering. More over, brush fences, like those used in our study, have difficulty withstanding the effects of storms that produce long-duration, high-amplitude waves, and, therefore, need regular maintenance.

Our research into the potential of brush fences in lacustrine environments followed the structural model developed by the Louisiana Department of Natural Resources (Good, 1993). Supported by a research grant from the Wisconsin Department of Natural Resources, we designed a study to examine whether similarly designed brush fences would encourage the restoration of submerged aquatic vegetation in near-shore areas of lower Green Bay.

Green Bay is a long, shallow bay of Lake Michigan. Since the 1940s, its water quality and SAV populations have declined as human activity has increased throughout its watershed. To reverse this trend, the United States and Canada International Joint Commission, the organization responsible for the Great Lakes Water Quality Agreement, designated lower Green Bay as an Area of Concern in 1985. Three years later, the Wisconsin Department of Natural Resources adopted a Remedial Action Plan for the bay. The restoration of aquatic habitats, and specifically SAV, is one of the plan's objectives (Persson *et al.*, 1988).

To begin our experiment, we constructed three brush fences at sites where the water depth ranged from 0.5 m to 1.0 m (1.5 ft to 3 ft). Each brush fence consisted of a 2.0-m (6.5-ft) wide by 4.5-m (15-ft) long outer wall of snow fence and a 1.0-m (1.5-ft) wide by 3.5-m (11.5-ft) long inner wall of snow fence. We supported these fences by connecting them to 3.8-cm (1.5-in) diameter pipes that we drove 1.5 m (5 ft) into the sandy bottom sediments. Once we had constructed these walls, we filled the 0.5 m (1.5 ft) space between them with brush.

We then went to another site that has abundant SAV and, in a small area, took the top 14 cm (5.5 in) of sediment and propagules for use in our experiment. On June 1, 1995, we placed four 20 x 15 x 5-inch germination trays, each of which contained the sediment and a uniform number of propagules, inside each brush fence and in "open water" conditions. On a weekly basis, from June 8 to August 10, 1995, we measured chlorophyll a (Franson et al., 1985), light extinction, total suspended solids (Franson et al.,

1985), and ashed solids (Franson et al., 1985) both inside and outside the brush fences. We "harvested" the germination trays on July 25, 1995, and recorded the shoot densities.

The results of this study suggest that constructing brush fences of the type used in Louisiana is unlikely to promote SAV growth in larger water bodies such as Green Bay. Moreover, it seems to us that increasing the structural size and/or filtering capability of these units is not an option in high-wave energy, lacustrine environments. This study also emphasizes the need to consider the multitude of site-dependent factors in any restoration effort, and not to rely on the notion of universally-applicable restoration strategies.

UNIVERSITY OF WISCONSIN SEA GRANT

The Macroinvertebrate Community of the Littoral Zone: A Study of Four Coastal Wetlands in Green Bay, Lake Michigan

Patricia A. Schneider

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

August 1998

Major Advisor: Paul Sager, Ph.D.

ABSTRACT

The epiphytic macroinvertebrate community in the littoral zones of four coastal wetlands between Green Bay, WI and Escanaba, MI was examined. The study produced a taxonomic inventory of organisms at each site, a comparison of community structure between sites, and construction of food webs based on the stable isotopes of carbon and nitrogen.

Differences between sites were apparent in the proportion of organisms each order contributed to the total community, as well as in the relative abundance of organisms in the five functional feeding groups. The littoral zone of Portage Bay marsh had a larger proportion of shredders (mainly amphipods), a smaller proportion of collectors, and few zebra mussels. It had both a large proportion of scrapers (gastropods) and the greatest biomass of periphyton. The three remaining sites were similar to each other in their composition, with larger proportions of collectors and piercers than at Portage Bay marsh, fewer shredders, and a greater concentration of phytoplankton chlorophyll *a*.

Bray-Curtis ordination of samples based on common taxa, dominant taxa and functional feeding groups present illustrated a separation of Portage Bay marsh sample ordination scores from those of the three southern sites. Throughout all ordinations, there was a consistent correlation of an increased concentration of phytoplankton chlorophyll *a* with the distribution of ordination scores from Little Tail and Long Tail marsh, and an increased concentration of epiphytic algal chlorophyll *a* with the distribution of Portage Bay marsh ordination scores. This may indicate these variables have an influence on the community structure at these sites.

Food webs were constructed based on $\delta^{13}C$ and $\delta^{15}N$ signatures for primary producers, macroinvertebrates, and fish collected at the sites. The transport of carbon from algae and zooplankton through macroinvertebrates to higher trophic levels of the food web was illustrated at all sites. Macroinvertebrates seemed to exhibit less than the standard 3.4 o/oo accumulation of $\delta^{15}N$ per trophic level. Most macroinvertebrate primary consumers were dependent upon algae, zooplankton, and periphyton for dietary carbon. Lepidoptera larvae were the only invertebrates sampled that used submerged vegetation as a food source. A trichoptera larvae fed on filamentous algae. The carbon signature of zebra mussels was most similar to that of emergent vegetation, possibly indicating dependence on detritus from this source.

The food web at Portage Bay marsh was more depleted in $\delta^{13}C$ due to inputs of $\delta^{13}C$-depleted detrital carbon. More enriched $\delta^{15}N$ values for the primary producers at Portage Bay marsh and lower overall accumulations of ^{15}N within the food web were also seen. Possible reasons for the observed differences in the signature of dissolved inorganic nitrogen between sites and differences in realized trophic structure are discussed.

UNIVERSITY OF WISCONSIN SEA GRANT

Coastal Wetland Insect Communities Along a Trophic Gradient in Green Bay, Lake Michigan

Published: June 1999

Ryan S. King and John C. Brazner

Wetlands 19,426–437(1999)

ABSTRACT

Insects of Great Lakes coastal wetlands have received little attention in spite of their importance in food webs and sensitivity to anthropogenic stressors. We characterized insect communities from four coastal wetlands that spanned the length of a trophic gradient in Green Bay during spring and summer of 1995. We sampled flying insects using sticky traps in dense emergent, sparse emergent, and open water submergent vegetation zones within each wetland and estimated numerical abundance, biomass (mg dry weight) and taxonomic composition. We found that insect abundance and biomass were distributed differently among vegetation zones within wetlands along the gradient during both spring and summer. Insect abundance was highest at oligotrophic Portage Marsh during spring and lowest in wetlands toward the lower (southern), eutrophic end of the bay.

Biomass did not differ consistently along the trophic gradient but increased with increasing emergent vegetation cover in 3 of 4 wetlands during both seasons. Ordination revealed distinct gradients in community structure on both regional (i.e., upper, middle, and lower Green Bay) and local (vegetation zones within wetlands) scales. Wetlands sorted in order of trophic status during both seasons, primarily due to abundant small Chironomidae, such as trophic-sensitive Heterotrissocladius changi, in middle and upper bay wetlands. Chironomidae also were a dominant component of open water-submergent assemblages in all wetlands. Lower bay wetlands were characterized by fewer but larger Chironomidae (e.g.,Chironomus spp.), as well as Ceratopogonidac, Calliphoridae, and Ephydridae, which were most abundant in stands of emergent vegetation. Our results suggest that eutrophy in the lower bay may contribute to relatively poor foraging conditions for insectivorous fish and young waterfowl during spring, and they demonstrate the utility of using insect communities to assess environmental degradation, such as excessive nutrient loading, in coastal wetlands of the Great Lakes.

UNIVERSITY OF WISCONSIN SEA GRANT

Zebra Mussels *(Dreissena polymorphia)* Affect Submergent Aquatic Vegetation (Wisconsin)

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Ecological Restoration 18:2 Summer 2000.

The zebra mussel is a filter-feeding freshwater mollusc that has been a species of interest in the Great Lakes region ever since its accidental introduction from Europe to North America in 1986 (Hebert et al., 1991). Since 1991, when the species was first detected in Green Bay, it has colonized much of the available area in this shallow bay of Lake Michigan.

Despite much negative publicity concerning their ability to reproduce rapidly and clog water intake pipes, scientific studies have shown that zebra mussels have increased water clarity in some regions of the Great Lakes. Zebra mussels increase water clarity by feeding on phytoplankton, small zooplankton, and detritus from the water column (Reeders et al., 1993), and through the biodeposition of abiotic particulates in feces and pseudofeces (Griffiths, 1993). Leach (1993), for example, reported that secchi disk depth increased 52-85 percent in western Lake Erie between 1988 and 1990, when zebra mussels were first introduced in the lake. Many of these same researchers have documented a correlation between this increase in water clarity and an increased growth of submergent aquatic vegetation.

Our work in Green Bay produced different results. While looking into methods for restoring submergent aquatic vegetation in near-shore areas of lower Green Bay, we discovered that in some locations zebra mussels had attached themselves directly to submergent plants. We found that the presence of zebra mussels, which are estimated to have densities on the vegetation in lower Green Bay as high as 300 mussels per square centimeter, was associated with poor plant health and a high rate of mortality in submergent plant species, such as water celery *(Vallisneria americana)*, slender naiad *(Najas fiexilis)*, and coontail *(Cerato phyllum demersum)*. We suggest that this result is due in large part to the mucky silt or sand substrate on the west shore of Green Bay. Zebra mussels typically use rocky or gravelly substrate for attachment but, as illustrated by our findings, they will use submergent vegetation when these substrates are not available.

Recent attention has been focused on the ability of zebra mussels to promote submergent aquatic vegetation growth indirectly through improved water clarity. However, our observations in lower Green Bay suggest that the ability of zebra mussels to damage aquatic vegetation through attachment should also be considered and more closely evaluated, especially in those areas without a rock or gravel substrate.

UNIVERSITY OF WISCONSIN SEA GRANT

The Breeding Biology and Nesting Success of Marsh Wrens in Palustrine Marshes Adjacent to Green Bay, Lake Michigan

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

May 2001

Major Advisor: H.J. Harris, Ph.D.

ABSTRACT

The marsh wren *(Cistothoms palustris iliacus)* is an insectivorous bird that breeds and feeds in emergent marsh systems along Green Bay, Lake Michigan. The specific objectives of this study were to record the breeding biology and evaluate the reproductive performance of marsh wrens at two sites in Lower Green Bay, Lake Michigan: Peter's Marsh Wildlife Area and a 25-acre parcel of Ken Euers' Nature Area. Factors including predator-prey relationships, habitat quality, territorial area and PCB contamination were assessed to identify their role in the overall success or failure of marsh wren populations.

Polychlorinated biphenyls (PCBs) have been suggested as a causative agent in adverse effects observed in several Great Lakes fish and wildlife populations. PCBs are toxic, hydrophobic, refractory, lipophilic, stable and degrade slowly in the environment. PCBs are of particular concern since they are highly persistent in the environment and possess a high potential to bioaccumulate and impact wildlife populations. Numerous studies indicate that piscivorous birds associated with Lake Michigan environments are reproductively impaired and/or have biological dysfunctions due to PCB contamination. However, studies that either record nesting success and/or identify biological impairment for marsh birds eating contaminated insects are limited.

Hatching and fledging success varied but was always poorer at Ken Euers' ($p = 0.000, 0.029$, respectively) than at Peter's Marsh. Clutch size averaged 4.4 eggs per nest. Neither clutch size ($p = 0.068$) nor territorial area ($p = 0.460$) influenced hatchability. Twenty–three percent (23%) of all eggs in 1995 compared to 28% in 1996 fledged ($p = 0.297$), with an average of one bird fledging for all active nests. Territorial area did not influence fledging success ($p = 0.706$). There was no relationship between territorial area and the presence of a breeding nest ($p = 0.757$).

Fledging success at both sites was largely influenced by mortality during the egg stage due to predation. Reproductive performance was also impaired by predation during the nestling phase. It is my opinion that investigator-related-interference provided the mechanism for the predation of eggs and nestlings as nest visitation disturbed either marsh wren parent to an extent that they predated their own nest(s) or alerted other marsh wrens and/or other predators to nest locations.

Total PCB concentrations were only analyzed from Peter's Marsh, but nestlings did not exceed 0.4 ug/g. Intrinsically/extrinsically induced factors that have been linked to PCB contamination such as embryo toxicity, chick deformities, impaired growth, abnormal parental behavior and impaired reproductive performance, were not identified at Peter's Marsh. Given the small sample size, the study identifies emergent aquatic insects as providing a pathway for birds to accumulate PCB burdens at Peter's Marsh, but the levels of contaminants do not inhibit growth or reproductive capability of marsh wren populations at Peter's Marsh.

UNIVERSITY OF WISCONSIN SEA GRANT

Great Lakes Coastal Wetlands-Estuarine Systems: Invertebrate Communities, Particle Dynamics, and Biogeochemical Cycles

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Biological Sciences, University of Wisconsin–Milwaukee

Under the supervision of J.L. Kaster, Ph.D. and J. V. Klump, Ph.D.

May 2001

ABSTRACT

Benthic invertebrates, emerging insects, sedimentation patterns, and biogeochemical cycles were examined to determine the biological and physical function of three morphologically distinct, Great Lakes wetland-estuarine systems. These systems included a deltaic, riverine wetland, a drowned river valley wetland, and an impounded lake/wetland system.

Inundation of the deltaic wetland by the Peshtigo River resulted in a gradient of various physicochemical parameters (e.g., dissolved oxygen, temperature) across the wetland that suggested water from the wetland was mixing with riverine water creating wetland interior and wetland edge zones. Benthic invertebrate abundance, biomass, production, and diversity were greatest at the wetland edge. Similarly, emerging insect abundances and biomass were also greatest at the wetland edge. This was attributed to higher concentrations of dissolved oxygen, the presence of a diverse community of aquatic plants, and delivery of riverine organic matter (i.e. phytoplankton) and revealed the importance of this area to wetland organisms (i.e. birds, fish) that feed upon invertebrates.

Sedimentation patterns from ^{210}Pb and ^{137}Cs profiles in the three systems showed that the Muskegon Lake system, a combined impounded lake and wetland system, trapped approximately 30% of the material flowing through it while the wetland trapped an estimated 60%. The Kewaunee wetland proved to be the second most effective, trapping 20% of the annual river sediment load flowing through it. Finally, the Peshtigo was the least effective, trapping 4% of the material through it

The Peshtigo wetland was a minor sink for phosphorus, and was more likely transforming dissolved forms into particulate forms that were transported out into Green Bay. The Peshtigo wetland was also a source of carbon to Green Bay through exports of dissolved and particulate organic carbon. Finally, the Peshtigo wetland was a sink for nitrogen, removing an estimated 40% of nitrogen entering the system.

UNIVERSITY OF WISCONSIN SEA GRANT

Habitat and Landscape Associations of Breeding Birds in Great Lakes Coastal Wetlands

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

August 2003

Major Advisor: Robert Howe, Ph.D.

ABSTRACT

Although the relationships of birds to local habitat and larger-scale landscape variables have been the focus of many studies, surprisingly few investigations have focused on wetland systems, especially coastal wetlands. These wetlands are of particular concern because of the high degree of anthropogenic stress associated with coastal urbanization and residential development. I studied birds of the western Great Lakes Basin coastal wetlands as part of a larger study of environmental indicators in the U.S. Great Lakes. Coastal ecosystems are highly dynamic and the relationships between habitat and species distributions are often confounded by temporal change. I assessed the habitat and landscape associations using bird point counts, local habitat assessments, and landscape analysis acquired through Geographic Information System (GIS) databases. Bird associations with habitat and landscape cover types were assessed using principal components analysis. I used logistic regression analysis to identify the most influential scale and habitat/landscape characteristics for predicting the occurrence of several species of wetland birds. The local scale habitat variables were more effective in predicting bird occurrence, however several landscape characteristics were also effective. This suggests both the local habitat and landscape are influential to the avifauna of Great Lakes coastal wetlands. I also suggest that the habitat/landscape relationships are dependent on the amount of suitable habitat available to the birds. In highly dynamic systems such as the coastal wetlands, the amount of suitable habitat is frequently changing. This has crucial implications for management applications and conservation strategies.

UNIVERSITY OF WISCONSIN SEA GRANT

Anuran-Habitat in Coastal Wetlands of the Western Great Lakes

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

August 2003

Major Advisor: Robert Howe, Ph.D.

ABSTRACT

Amphibian-habitat associations are complex and influenced by the scale at which habitat variables are measured. Anthropogenic pressures and natural stressors greatly influence the Great Lakes coastal zone, yet no studies have focused on amphibian-habitat relationships in this area. I assessed anuran-habitat relationships by conducting anuran calling surveys and collecting habitat data at 63 coastal wetlands near the shores of Lake Michigan and Lake Huron during 2002. Habitat variables were acquired for specific anuran breeding sites and the surrounding landscape. Landscape variables at 3 spatial scales were derived from Landsat TM data, USGS National Land Cover data and digital orthophotographs. Wilcoxon rank-sum tests were used to compare habitat variables between occupied versus unoccupied wetlands for 7 anurans over the entire study area and for 2 anurans at the ecoregion scale. Stepwise logistic regression was used to identify important predictors for anuran species. Landscape-scale variables were more successful at predicting anuran wetland occupancy than breeding site variables. However, no single variable or spatial scale exhibited a consistent influence on all anurans. Furthermore, best predictive variables were different when ecoregions were analyzed separately. My results suggest that variables measured at the landscape scale are necessary to understand distribution patterns of anurans in coastal areas. Landscape habitat associations likely reflect 2 important aspects of amphibian ecology: 1) the need for non-breeding habitat adjacent to wetlands, and 2) the importance of metapopulation dynamics. Favorable landscape configurations are necessary for amphibian persistence in the coastal zone and appear to be corrupted by human-altered landscapes. In particular, anurans in the southern portion of the Great Lakes region may be stressed by the presence of urban cover classes.

UNIVERSITY OF WISCONSIN SEA GRANT

The Ecological Patterns of Benthic Invertebrates in a Great Lakes Coastal Wetland

Journal of Great Lakes Research

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ABSTRACT

Benthic macroinvertebrates were sampled in the summer of 1997 using a standard D frame kick net along a transect across the Peshtigo wetland, a river delta wetland on the coast of Green Bay, Lake Michigan, to describe the spatial and temporal dynamics of the invertebrate community. Various abiotic factors, including sedimentation rates determined from ^{210}Pb and ^{137}Cs as a proxy for delivery of riverine organic matter, were also measured to determine which factors influenced these dynamics. Significant decreasing gradients in dissolved oxygen and pH with distance from the river, coupled with trends in sedimentation rates, chloride, and sum nitrate (nitrate + nitrite), revealed that riverine water was mixing with wetland water up to 100 m from the wetland-river interface. Aboveground primary production and total invertebrate densities exhibited Weibull type distributions, with highest rates and numbers occurring 20 to 100 m from the Peshtigo River. Invertebrate densities were largely represented by *Asellus* sp isopods (12–53%) and exhibited the highest numbers in September. Invertebrate density at the genus level linearly decreased with distance from the river based on the Simpson's index of diversity (r^2 = 0.60, p less than 0.05) and the Shannon-Wiener function (r^2 = 0.73, p less than 0.01). Patterns observed suggest that there is an "optimal" zone for benthic invertebrates in the Peshtigo wetland 20 to 60 m from the Peshtigo River that is protected from high-energy events (e.g. storms, boating) in the Peshtigo wetland by a buffer zone (0 to 20 m) but is close enough to benefit from replenished levels of dissolved oxygen, nutrients, and organic matter delivered via the Peshtigo River.

UNIVERSITY OF WISCONSIN SEA GRANT

Invasive Plant Species in Diked vs. Undiked Great Lakes Wetlands

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DESCRIPTION

We compared the standing vegetation, seed banks, and substrate conditions in seven pairs of diked and undiked wetlands near the shores of Lake Michigan and Lake Huron, North America. Our analysis tested the null hypothesis that construction of artificial dikes has no effect on the vulnerability of Great Lakes coastal wetlands to non-native and native invasive species. Both the standing vegetation and seed banks in diked wetlands contained significantly more species and individuals of invasive plants. In addition, diked wetlands exhibited significantly higher levels of organic matter and nutrient levels, and significantly higher average pH. Two pervasive non-native invasive species in the Great Lakes region, *Lythrum salicaria* (purple loosestrife) and *Phalaris arundinacea* (reed canary grass) were significantly more abundant in diked wetlands. *Typha* spp. (cattail) also formed a much higher percent vegetation cover in the diked wetlands. Our results support the view that diking of shoreline wetlands modifies natural hydrologic regimes, leading to nutrient-rich aquatic environments that are vulnerable to invasion. The shallower, more variable water levels in non-diked wetlands, on the other hand, appear to favor another undesirable invasive species, *Phragmites australis* (common reed grass).

UNIVERSITY OF WISCONSIN SEA GRANT

Polychlorinated Biphenyl (PCB) Levels in Sediments, Aquatic Emergent Insects, and Marsh Wrens in a Green Bay, Lake Michigan Coastal Marsh

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

May 2005

Major Advisor: H.J. Harris, Ph.D.

ABSTRACT

Aquatic emergent insects are an important food resource for wetland avifauna, providing a link between the aquatic and terrestrial ecosystem. Besides providing a source of energy and nutrients to insectivorous birds, aquatic emergent insects may also serve as a vector for contaminants from the sediments. To investigate the potential for aquatic emergent insects to provide a biotic pathway for organochlorine contaminants, sediments, aquatic emergent insects, and marsh wrens were collected from a coastal marsh on Green Bay, Lake Michigan and analyzed for Polychlorinated Biphenyls (PCBs).

During 1992 aquatic emergent insects were collected in floating box traps at Peters Marsh and Sensiba Wildlife Area and analyzed for total PCBs. Insects collected at Peters Marsh had a mean total PCB concentration of 0.189 ug/g wet wt., and insects collected at Sensiba Wildlife Area had mean total PCB concentrations of 0.116 ug/g. While insect PCB concentrations at Sensiba Wildlife Area are lower, the difference between the two marshes was not statistically significant.

In 1993, floating box traps were placed within active nesting/feeding territories of marsh wrens *(Cistothorus palustris)* nesting along two channels at Peters Marsh, and aquatic emergent insects were collected and analyzed for total PCBs. Sediments, marsh wren eggs, and marsh wren nestlings were also collected and analyzed. Total PCB concentrations in sediments sampled at Peters Marsh ranged from 0.011 to 0.265 ug/g dry wt. with a mean concentration for 24 samples of 0.100 ug/g dry wt. Aquatic emergent insects collected at Peters Marsh had a mean total PCB concentration of 0.172 ug/g wet wt. There was a significant difference between insects collected in June and July versus August and September. Marsh wren eggs from Peters Marsh had a mean total PCB concentration of 1.97 ug/g wet wt. Marsh wren nestling total PCB concentrations ranged from 0.360 to 1.80 ug/g wet wt., and the PCB concentration was dependent upon the age of the nestling. Younger nestlings (4 and 5 day old) had a higher PCB concentration than older nestlings (14 day old).

A marsh wren PCB bioenergetic model was developed for 1 to 15 day old nestlings and the model predicted PCB concentrations to within 0.1 to 0.2 ug/g wet weight for three of the four marsh wren nestlings collected.

The eight highest sediment samples exceeded the high range for 11 of 18 potential injury thresholds listed in the Assessment Plan for the Natural Resources Damage Assessment (1996), although none of the sediment samples exceeded the maximum benthic threshold of 1 ug/g total PCB. Furthermore, 19 of the 22 aquatic emergent insect samples collected in this study exceeded the International Joint Commission Aquatic Life PCB Guideline of 0.100 ug/g.

UNIVERSITY OF WISCONSIN SEA GRANT

Vegetation Change in Great Lakes Coastal Wetlands: Deviation from the Historical Cycle

J. Great Lakes Res. 33:366–380 Internat. Assoc. Great Lakes Res., 2007

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ABSTRACT

Water-level change is integral to the structure and function of Great Lakes coastal wetlands, and many studies document predictable relationships between vegetation and water level. However, anthropogenic stressors, such as invasive species, land-use change, and water-level stabilization, interact to shift the historical cycle (of native vegetation migration up- and down-slope) toward dominance by invasive Typha species. Knowing from earlier studies that water-level stabilization alters the historical vegetation cycle, we asked if similar shifts can occur where water levels are not stabilized. Using historical aerial photographs of three coastal wetlands (in Lake Michigan's Green Bay, Wisconsin), we determined that habitat dominated by Typha species has expanded to eliminate wet meadow habitat. Between 1974 and 1992, linear regressions showed strong, significant relationships of both meadow area (R2 2′: 0.894: $p < 0.02$) and marsh area (R2 2 0.784; $p < 0.05$) to water level in all three wetlands. In 2000, meadow area was below that predicted by the historical pattern due to the landward advance of marsh habitat during a year of decreasing water levels. In the same period, land use in the wetland watersheds converted from agriculture to urban. Urbanization and the replacement of native Typha latifolia by the invasive hybrid *Typha xglauca* may have overwhelmed the beneficial impact of water-level fluctuation. The documentation of vegetation shifts, as herein, is an essential step in the process of preserving and restoring ecological integrity.

UNIVERSITY OF WISCONSIN SEA GRANT

Rapid Invasion of a Great Lakes Coastal Wetland by Non-Native *Phragmites australis* and *Typha*

J. Great Lakes Res. 33 (Special Issue 3):269–279 Internat. Assoc. Great Lakes Res., 2007

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ABSTRACT

Great Lakes coastal wetlands are subject to water level fluctuations that promote the maintenance of coastal wetlands. Point au Sauble, a Green Bay coastal wetland, was an open water lagoon as of 1999, but became entirely vegetated as Lake Michigan experienced a prolonged period of below-average water levels. Repeat visits in 2001 and 2004 documented a dramatic change in emergent wetland vegetation communities. In 2001 non-native Phragmites and Typha were present but their cover was sparse; in 2004 half of the transect was covered by a 3 m tall, invasive Phragmites and non-native Typha community. Percent similarity between plant species present in 2001 versus 2004 was approximately 19% (Jaccard's coefficient), indicating dramatic changes in species composition that took place in only 3 years. The height of the dominant herbaceous plants and coverage by invasive species were significantly higher in 2004 than they were in 2001. However, floristic quality index and coefficient of conservatism were greater in 2004 than 2001. Cover by plant litter did not differ between 2001 and 2004. The prolonged period of below-average water levels between 1999 and early 2004 exposed unvegetated lagoon bottoms as mud flats, which provided substrate for new plant colonization and created conditions conducive to colonization by invasive taxa. PCRIRFLP analysis revealed that Phragmites from Point au Sauble belongs to the more aggressive, introduced genotype. It displaces native vegetation and is tolerant of a wide range of water depth. Therefore it may disrupt the natural cycles of vegetation replacement that occur under native plant communities in healthy Great Lakes coastal wetlands.

UNIVERSITY OF WISCONSIN SEA GRANT

Monitoring Water Quality and Submergent Aquatic Vegetation of Lower Green Bay Wetlands and Influences of the Cat Island Chain Re-establishment Project

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

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Major Advisor: Patrick Robinson, Ph.D.

ABSTRACT

The loss of the Cat Island Chain (CIC) in Green Bay, Lake Michigan has been a suspected factor in the reduction and degradation of important aquatic habitat. The CIC re-establishment project wave barrier (completed in 2012) was designed, in part, to positively impact aquatic habitat by reducing wave-related stress and subsequently improving water clarity and promoting aquatic vegetation (AV) growth. The objectives of this study were to 1) quantify potential effects of the wave barrier on water quality, wave energy, light extinction, and abundance and distribution of AV; 2) assess the existing aquatic seed-bank on the lee side of the barrier; 3) and determine the survival and growth of transplanted AV propagules and *Schoenoplectus acutus* (hardstem bulrush) plugs on the lee and windward sides of the barrier. Our study found differences in water quality conditions between the windward and leeward sides of the wave barrier changed over time, with poorer water quality conditions varying between the windward and leeward sites based upon temporal changes in climatic variables; however, transplanted propagules and hard-stem bulrush plugs had greater growth and survivability on the leeward side of the wave barrier. Analysis of the existing AV distribution and seedbank also provided evidence of widespread propagule limitation in the leeside aquatic habitat. Overall, the results of the research suggest the potential for increased AV abundance due to the wave barrier, especially with some facilitated vegetation re-establishment efforts; however, further research is needed to better understand this potential and the possible effects of other factors, such as Lake Michigan water levels, sediment resuspension, and the impacts of tributary runoff.

UNIVERSITY OF WISCONSIN SEA GRANT

Standardized Measures of Coastal Wetland Condition: Implementation at a Laurentian Great Lakes Basin-Wide Scale

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ORIGINAL RESEARCH

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ABSTRACT

Since European settlement, over 50% of coastal wetlands have been lost in the Laurentian Great Lakes basin, causing growing concern and increased monitoring by government agencies. For over a decade, monitoring efforts have focused on the development of regional and organism-specific measures. To facilitate collaboration and information sharing between public, private, and government agencies throughout the Great Lakes basin, we developed standardized methods and indicators used for assessing wetland condition. Using an ecosystem approach and a stratified random site selection process, birds, anurans, fish, macroinvertebrates, vegetation, and physico-chemical conditions were sampled in coastal wetlands of all five Great Lakes including sites from the United States and Canada. Our primary objective was to implement a standardized basin-wide coastal wetland monitoring program that would be a powerful tool to inform decision-makers on coastal wetland conservation and restoration priorities throughout the Great Lakes basin.

UNIVERSITY OF WISCONSIN SEA GRANT

Breeding Birds and Anurans of Dynamic Coastal Wetlands in Green Bay, Lake Michigan

Erin E. Gnass Giese, Robert W. Howe, Amy T. Wolf and Gerald J. Niemi

Journal of Great Lakes Research, 2018–10, Vol. 44 (5), p. 950–959

SUMMARY

Breeding birds and anurans (frogs and toads) in coastal wetlands of Green Bay, Lake Michigan vary dynamically with changing water levels, habitat type, and geography. We describe species assemblages over a seven-year period (2011-2017) beginning with historic low water levels followed by an increase in average lake level of 0.85m. In general, species richness and abundance of marsh-obligate species responded to positively increasing water levels although several species of shallow wetlands (sandhill crane, sedge wren, swamp sparrow, and American toad) showed the opposite trend. Anuran assemblages were more diverse in the middle and upper bay. Three marsh-obligate bird species (black tern, sandhill crane, and sedge wren) were significantly more abundant in the middle or upper bay while sora, American coot, and common gallinule were more abundant in the eutrophic lower bay. Our findings have several important implications for conservation. Inland wetlands near the coast (including diked wetlands) might play a key ecological role by providing refugia for some species during low water years. However, the importance of shallow coastal wetlands and nearshore gradients of wetland habitat might be overlooked during low water years; when high water returns, these areas can become extremely productive and species-rich.

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Quantitative Restoration Targets for Fish and Wildlife Habitats and Populations in the Lower Green Bay and Fox River AOC

Robert W. Howe, Erin E. Gnass Giese and Amy T. Wolf

Journal of Great Lakes Research, 2018–10 Vol. 44 (5), p. 883–894

SUMMARY

The Lower Green Bay and Fox River Area of Concern (LGB&FR AOC) is one of the most ecologically diverse but demonstrably impaired AOCs in the Laurentian Great Lakes. We outline a transparent, quantitative process for setting targets to remove two fish and wildlife-related beneficial use impairments (BUIs). The method identifies important habitats and species/species groups and weights them according to ecological and socioeconomic criteria. These weights are paired with standardized estimates of current condition ranging from 0 (worst possible) to 10 (best possible). A weighted average of the condition scores gives an overall AOC condition for each BUI, creating a baseline for setting future restoration or BUI removal targets. Weighted averages for the LGB&FR AOC yielded a current condition of 3.60 for fish and wildlife habitats and 4.65 for species/species groups. Based on stakeholders, we propose removal targets of 6.0 for the "loss of fish and wildlife habitat" BUI. This quantitative approach illuminates multiple pathways for reaching restoration targets and facilitates informed discussions about cost effective restoration projects. According to our results, species and species groups in this AOC are generally in better current condition than habitats when compared on the same 1-10 scale. This suggests that many (though not all) desirable fish and wildlife populations in the LGB&FR AOC are able to survive in relatively degraded habitats or are able to use these habitats productively during part of their life cycle.

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Experimental Test of Abiotic and Biotic Factors Driving Restoration Success of *Vallisneria americana* in the Lower Bay of Green Bay

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Journal of Great Lakes Research, 2019–10 Vol. 45 (2), p. 340–349

SUMMARY

The eutrophication of aquatic habitats is a primary driver of ecosystem degradation, often culminating in a switch from a macrophyte-dominated clear water state to a phytoplankton-dominated turbid water state. While numerous studies have documented the ecological implications of this switch, subsequent reductions in nutrient and sediment loading do not consistently result in predictable reversals to macrophyte dominance. Re-introduction of rooted aquatic macrophytes at appropriate scales and species combinations may disrupt these negative feedbacks, although our current limited understanding of these complex mechanisms hinders the development of effective, targeted restoration strategies. We evaluated the potential for restoration of *Vallisneria americana* (wild celery) in the Lower Bay of Green Bay by altering restoration size and co-planting with the emergent species *Schoenoplectus acutus* (hardstem bulrush). Wild celery survival among all sites exceeded 90% in 2015 and 110% in 2016. However, in contrast to our expectations the effect of restoration size and interspecific facilitation on survival was either marginal or non-significant. Instead, various environmental effects focused largely on the interaction of water depth, substrate characteristics, and the abundance of unrestored floating macrophytes (i.e. *Lemna, Ceratophyllum,* and *Utricularia* spp.) drove variability in restoration success, suggesting that future work focus on identifying restoration methods that can withstand a highly dynamic environment. Our results provide insight into the factors continuing to limit the re-establishment of aquatic macrophytes in degraded systems, suggesting a more limited role of water quality and greater role of interspecific competition and propagule limitation or seedling establishment than previously recognized.

UNIVERSITY OF WISCONSIN SEA GRANT

Environmental Factors Influencing the Restoration of Northern Wild Rice *(Zizania palustris L.)* at Coastal Wetlands Within the Bay of Green Bay, Lake Michigan

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science and Policy, University of Wisconsin–Green Bay

August 2020

Major Advisor: Matt Dornbush, Ph.D.

DESCRIPTION

Green Bay has become a model ecosystem for the restoration of aquatic macrophytes in degraded freshwater systems. Countless ecosystem stresses challenge Green Bay today, with cultural eutrophication the principal driver of initial and sustained aquatic ecosystem degradation. In response, a significant amount of time and resolve has been invested into the state of Green Bay to improve conditions, namely through watershed level reductions in nutrients and sediment loading. Recent efforts have emerged to actively restore aquatic macrophytes in an attempt to disrupt the within-system positive feedbacks that may be perpetuating an algal dominated eutrophic state, with this study evaluating the restoration potential of northern wild rice *(Zizania palustris L.)*, a native annual grass once historically abundant within Green Bay and its tributaries.

The first objective of this study was to document variations in environmental conditions among nineteen potential wild rice restoration sites in Green Bay and to understand relationships among these variables and wild rice restoration success. In agreement with our expectations, principal components analysis suggested significant variation in environmental conditions existed among both wetland complexes and the restoration sites established within wetlands. Distinct environmental differences were driven primarily by differences in water clarity, sediment conditions, and non-restored aquatic vegetation. Furthermore, annual average wild rice cover appeared to be related to these environmental factors.

The second objective of this study was to evaluate the seasonal effects of abiotic and biotic factors on wild rice cover, with seasons paralleling discrete growth stages of wild rice. Contrary to our expectations, environmental factors were found to have little seasonality, with the ability of seasonal environmental conditions to predict wild rice cover inferior to or only marginally better than annual environmental conditions with the exception of late summer/ early fall. Late summer/ early fall environmental factors that best predicted wild rice cover included water clarity, submerged aquatic vegetation (SAV) cover, and sediment composition. In other words, restoration sites with greater wild rice cover had relatively greater water clarity, higher SAV cover, and sandy substrates. These results suggest that three simple metrics—water clarity, sediment composition, and SAV—may serve as valuable indicators for successful wild rice restoration sites within Green Bay and furthermore, that the success of a potential restoration site can be reasonably predicted by sampling for these three metrics in late summer/early fall.

UNIVERSITY OF WISCONSIN SEA GRANT

Prioritizing Coastal Wetlands for Marsh Bird Conservation in the U.S. Great Lakes

Joanna Grand, Sarah P. Saunders, Nicole L. Michel, Lisa Elliot, Stephanie Bielke, Annie Bracey, Thomas M. Gehring, Erin E. Gnass Giese, Robert W. Howe, Bradford Kasberg, Nathaniel Miller, Gerald J. Niemi, Christopher J. Norment, Douglas C. Tozer, Joanna Wu and Chad Wilsey

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SUMMARY

Human activity surrounding the Laurentian Great Lakes basin has significantly degraded coastal wetland habitats, resulting in severe marsh bird population declines and reduced coastal resilience to changing environmental conditions. Given the need to conserve remaining coastal wetlands for wildlife and people, we developed a spatial prioritization to identify the most important U.S. Great Lakes coastal wetlands for 14 marsh bird species. We modeled occurrence and relative abundance of each species using boosted regression trees, a machine learning algorithm to related standardized monitoring data to ten remotely sensed environmental covariates. We then used Zonation conservation planning software to rank every wetland cell based on its importance for the suite of marsh bird species. Evaluation of the drivers of marsh bird occurrence and abundance revealed that open water, herbaceous wetland, latitude, longitude, and impervious surface were the most important predictors across focal species. The high-priority wetlands for marsh birds (defined as grid cells ranked in the top 20%) occurred along the shores of eastern Lake Ontario, western Lake Erie/St. Clair, Saginaw Bay, Green Bay, northern lakes Michigan and Huron, and western Lake Superior. Overall, less than half (42%) of high-priority coastal wetlands across the Great Lakes basin are currently under some level of protection, with Lake Ontario priority wetlands being the least protected (25%). Our findings represent an opportunity to improve coastal wetland conservation in a region where wetland loss and degradation continue to threaten marsh bird populations and the integrity of one of the world's largest freshwater ecosystems.

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Influence of Lake Levels on Water Extent, Interspersion, and Marsh Birds in Great Lakes Coastal Wetlands

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Tara R. Hohman, Robert W. Howe, Douglas C. Tozer. Erin E. Gnass Giese, Amy T. Wolf, Gerald J. Niemi, Thomas M. Gehring, Greg P. Grabas and Christopher J. Norment

ABSTRACT

Coastal wetlands in the Laurentian Great Lakes undergo frequent, sometimes dramatic, physical changes at varying spatial and temporal scales. Changes in lake levels and the juxtaposition of vegetation and open water greatly influence biota that use coastal wetlands. Several regional studies have shown that changes in vegetation and lake levels lead to predictable changes in the composition of coastal wetland bird communities. We report new findings of wetland bird community changes at a broader scale, covering the entire Great Lakes basin. Our results indicate that water extent and interspersion increased in coastal wetlands across the Great Lakes between low (2013) and high (2018) lake-level years, although variation in the magnitude of change occurred within and among lakes. Increases in water extent and interspersion resulted in a general increase in marsh-obligate and marsh-facultative bird species richness. Species like American bittern *(Botaurus lentiginosus)*, common gallinule *(Gallinula galeata)*, American coot *(Fulica americana)*, sora *(Porzana carolina)*, Virginia rail *(Rallus limicola)*, and pied-billed grebe *(Podilymbus podiceps)* were significantly more abundant during high water years. Lakes Huron and Michigan showed the greatest increase in water extent and interspersion among the five Great Lakes while Lake Michigan showed the greatest increase in marsh-obligate bird species richness. These results reinforce the idea that effective management, restoration, and assessment of wetlands must account for fluctuations in lake levels. Although high lake levels generally provide the most favorable conditions for wetland bird species, variation in lake levels and bird species assemblages create ecosystems that are both spatially and temporally dynamic.