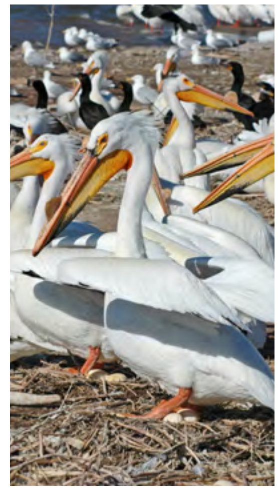
UNIVERSITY OF WISCONSIN SEA GRANT INSTITUTE

The State of the Bay

The Condition of the Bay of Green Bay/Lake Michigan 2013

SATELLITE IMAGERY, SEPTEMBER 8, 2002



TOM ERDMAN, UWGB

Twenty years have passed since the last State of the Bay Report. Many changes have occurred during this period. This edition presents new data on water quality, fish and wildlife populations, aquatic invasive species, beach conditions and contaminants status.

USEPA, REGION 5, GLNPO

Theresa Qualls, H.J. (Bud) Harris, Victoria Harris

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ACKNOWLEDGEMENTS

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ACRONYMS

AIS	Aquatic Invasive Species
ANOVA	Analysis of Variance
AOC	Area of Concern
BOD	Biological Oxygen Demand
Cl	Chloride
CPUE	Catch per unit effort
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
GBMBS	Green Bay Mass Balance Study
GBMSD	Green Bay Metropolitan Sewerage District
IJC	International Joint Commission
NOAA	National Oceanic and Atmospheric Administration
PCBs	Polychlorinated biphenyls
RAP	Remedial Action Plan
SWAT	Soil Water Assessment Tool
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSS	Total Suspended Solids
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
VHS	Viral Hemorrhagic Septicemia
VSS	Volatile Suspended Solids
WNDR	Wisconsin Department of Natural Resources
YOY	Young-of-the-year

EXECUTIVE SUMMARY

This is the third edition of the State of the Bay Report. The first edition, published in 1990, focused on the water quality and the condition of water-related resources and uses of Lake Michigan's Green Bay. The second, published in 1993, focused on the Fox-Wolf River Basin, a large drainage basin that covers a 6,640-square-mile area and contributes to the Fox River and Green Bay.

Each State of the Bay report identifies chemical, physical, biological, and social indicators of the "health" of the bay and assesses the current status and how it is changing. The reports are intended as easily understandable summaries of the overall health of the bay ecosystem. As the scope of information and organization has increased, subsequent reports have included additional topics.

Twenty years have passed since the last State of the Bay Report. Many changes have occurred during this period, and more information is available. This version presents new data on water quality, as well as data on fish and wildlife populations, aquatic invasive species, beach conditions and the status of contaminants in the region. The advantage of having data over such a long period of time is that it allows scientists and citizens to see if conditions are getting better, worse, or staying about the same.

AREAS OF PROGRESS

As shown in Table 1, progress has been made from earlier years (1970s and 1980s) in the Area of Concern (AOC) on levels of ammonia and dissolved oxygen found in the water. The decrease in ammonia is attributed to improved wastewater treatment at the Green Bay Metropolitan Sewerage facility. Dissolved oxygen levels are also generally good in large portions of the bay. Nevertheless, hypoxic areas ("dead zones") develop in isolated bottom waters during late summer.

Good news can be found for walleye populations. Green Bay supports a walleye trophy fishery, which remains unchanged. Their re-establishment serves as an example of a successful effort to restore the Fox River system. Spotted muskies are also faring well due to stocking efforts and hatchery production. Northern pike are holding their own and currently receiving considerable attention with spawning habitat restoration.

Beach closings due to bacterial contamination are at a fair level and seem to be decreasing at most sites as this new monitoring program progresses and communities work at identifying and controlling sources of the bacteria.

Coastal wetlands are currently considered in fair condition, but remain endangered due to development pressures and an increase in sediment in the water, which limits the amount of light available for the plants to grow.

AREAS NEEDING WORK

Phosphorus concentrations are known to be tied to harmful algal blooms. Until levels can be reduced, algal blooms can be expected to persist.

Nitrate and nitrite concentrations in the river have been increasing over time, likely a reflection of increased fertilizer use in the watershed.

The amount of "gunk" in the water in the form of suspended solids (things like algae, soil, decaying plant matter, and wastewater particles that can be caught on a filter) equal many dump-truck load equivalents every day in some parts of the bay and are considered excessive. These solids can limit the amount of light available in the water and make it hard for plants to grow. They can also decrease oxygen in the water and cause fish kills. Sediment delivered into the bay clogs shipping channels, which require dredging on a regular basis. Better land-use practices and other measures are needed for this factor to improve.

Levels of a crucial plant pigment called chlorophyll *a* are found in too great a quantity in water samples. This means there is excess growth of algae, including the potentially toxic blue-green kind, which can reduce water quality and causes a human health risk for people in direct contact with the water. Although levels have been reduced by the filtering activities of invasive zebra and quagga mussels, they remain higher than recommended.

The water clarity in Green Bay averages half a meter. To meet targets necessary for ecosystem health, it needs to be twice that. Suspended solids and phosphorus levels contribute to the lack of water clarity.

Levels of toxic chemicals in the bay, such as PCBs, dioxins, DDT, arsenic and mercury continue at unacceptable levels. These chemicals pollute fish, bay sediments, and pose health risks for wildlife and humans. They come from many sources and require coordinated, long-term cleanup efforts. However, dredging directed at removal of PCBs will undoubtedly remove other harmful chemicals, but increased monitoring efforts will be needed to demonstrate improvement and attainment of acceptable levels.

Aquatic invasive species can be considered a type of biological pollution. These unwanted and invasive plants and animals disrupt local ecosystems and make survival more difficult for native species. Although public outreach and education efforts have helped limit the spread of these species along with restoration efforts, they continue to take a toll on the health of the bay.

Bottom-dwelling animals in the bay, called benthic macroinvertebrates, are important food sources for fish and waterfowl and play a crucial role in keeping ecosystems healthy. Population levels of these bottom-dwellers are possibly due to a combination of factors, such as sediment ammonia concentration, low O_2 at sediment water interface and unconsolidated sediment structure.

WHAT CAN BE DONE?

Many groups and organizations are working to restore Green Bay with the goals of eliminating the toxicity of wastewater discharges, remediating contaminated sediments, protecting and restoring wetlands and ecological services, preventing further invasive species introductions, and reducing nutrients and the amount of solids. Continuing these efforts can only help with these issues, but it requires continued public and political support.

2012 GREEN BAY INDICATOR ASSESSMENT

Table 1: Status and trend assessments of Green Bay indicators

Indicator	Status	Trend
Total Phosphorus	Poor	Unchanging
Ammonia	Good	Unchanging
Nitrate	Fair to Good	Deteriorating
Total Suspended Solids	Poor	Unchanging
Chlorophyll *a*	Poor	Unchanging
Water Clarity (Secchi)	Poor	Unchanging
Dissolved Oxygen (DO)	Fair	Improving
Toxic Contaminants	Poor	Undetermined
Water Levels	Below Average	Declining
Beach Health	Fair	Undetermined
Aquatic Invasive Species	Poor	Deteriorating
Benthic Macroinvertebrates	Poor	Undetermined
Coastal Wetlands	Fair	Deteriorating
Walleye	Good	Unchanging
Yellow Perch	Mixed	Improving
Spotted Musky	Fair	Improving
Northern Pike	Fair	Unchanging
Lake Sturgeon	Recovering Population	Improving
Colonial Nesting Birds	Mixed	Improving to Deteriorating

Status Categories

Good: The state of the ecosystem component is presently meeting ecosystem objectives or otherwise is in acceptable condition.

Fair: The ecosystem component is currently exhibiting minimally acceptable conditions, but it is not meeting established ecosystem objectives, criteria, or other characteristics of fully acceptable conditions.

Poor: The ecosystem component is severely negatively impacted and it does not display even minimally acceptable conditions.

Mixed: The ecosystem component displays both good and degraded features.

Undetermined: Data are not available or are insufficient to assess the status of the ecosystem component.

Four Trend Categories

Improving: Information available shows the ecosystem component to be changing toward more acceptable conditions.

Unchanging: Information available shows the ecosystem component to be neither getting better nor worse.

Deteriorating: Information available shows the ecosystem component to be departing from acceptable conditions.

Undetermined: Data are not available to assess the ecosystem component over time, so no trend can be identified.

INTRODUCTION

Lower Green Bay and the Fox River have together been designated an Area of Concern (AOC) by the International Joint Commission (IJC) and the state of Wisconsin. One of 43 AOCs in the Great Lakes, the Lower Green Bay and Fox River area was designated because persistent pollution or degraded habitats have restricted many activities—such as fishing and consuming fish, using the water for drinking, and swimming and enjoying beaches. Remedial Action Plans (RAPs) have been developed for each Great Lakes AOC to prescribe actions needed to restore such beneficial uses.

The Lower Fox River and Green Bay AOC includes the Lower 11.2 km of the Fox River below the De Pere Dam and a 55 km2 area of southern Green Bay out to Point au Sable and Longtail Point. The Fox River drainage area encompasses portions of 18 counties in Wisconsin and 40 watersheds of the Upper Fox River, Wolf River, and Lower Fox River basins, including the largest inland lake in Wisconsin, Lake Winnebago and its pool lakes (Figures 1 and 2).

While water-quality problems and public use restrictions are most severe in the AOC, water resources of the entire basin are affected by runoff pollution from urban and rural areas, municipal and industrial wastewater discharges, and degraded habitats. Thirteen beneficial use impairments (Table 2) have been identified (two are listed as suspected) in the AOC, including degradation of benthos (bottom dwelling organisms), plankton (small plants or invertebrates in water column), and fish and wildlife populations; animal deformities or reproductive problems; over-enrichment with nutrients (eutrophication) or undesirable algae; restrictions on drinking water consumption due to public health risks or taste and odor problems; and beach closings due to bacterial contamination.

The Lower Green Bay and Fox River RAP was prepared in 1988 (the first RAP accepted by the IJC in the Great Lakes Basin) and updated in 1993. The plan recommends 120 specific actions to restore healthy fish and wildlife populations, provide for safe swimming and other recreational uses, and eliminate restrictions on fish consumption, water use, and dredging based on persistent contaminants. In 2011, the WDNR prepared a Stage 2 RAP update for the Lower Green Bay and Fox River AOC that provides a summary of each use impairment status and specific actions for reaching delisting targets.

ERSC, UW-MADISON

Satellite photo of Lower Green Bay on May 20, 2000, shows the hypereutrophic conditions in the Area of Concern and a distinct gradient of highly turbid water entering the southern bay from the Fox River to clearer water north of Little Sturgeon Bay. Source: ERSC, UW-Madison

Table 2: Beneficial Use Impairments in the AOC

USE IMPAIRMENTS IN THE AOC	PRESENT	ABSENT	SUSPECTED
Restrictions on Fish and Wildlife Consumption	TOX		
Tainting of Fish and Wildlife Flavor			TOX
Degraded Fish and Wildlife Populations	P/SS		
Fish Tumors or Other Deformities			TOX
Bird or Animal Deformities or Reproductive Problems	TOX		
Degradation of Benthos	TOX, P/SS		
Restrictions on Dredging Activities	TOX		
Eutrophication or Undesirable Algae	P/SS		
Restrictions on Drinking Water Consumption or Taste and Odor Problems	TOX		
Beach Closings	BAC		
Degradation of Aesthetics	P/SS		
Added Costs to Agriculture or Industry		X	
Degradation of Phytoplankton and Zooplankton Populations	P, TOX		
Loss of Fish and Wildlife Habitat	P/SS		

TOX: Toxic Substances **SS:** Suspended Solids **P:** Phosphorus **BAC:** Bacterial SOURCE: WDNR, 1993

The Fox River is the dominant influence on the overall water quality and ecology of Green Bay. However, other major and minor tributaries drain to the bay and are important in their own right (Figure 2). Since the Fox-Wolf Basin (Figure 1) has such a dominant influence on Lower Green Bay, much of the report that follows will focus on the AOC.

Figure 1: Map of the Fox-Wolf Basin.

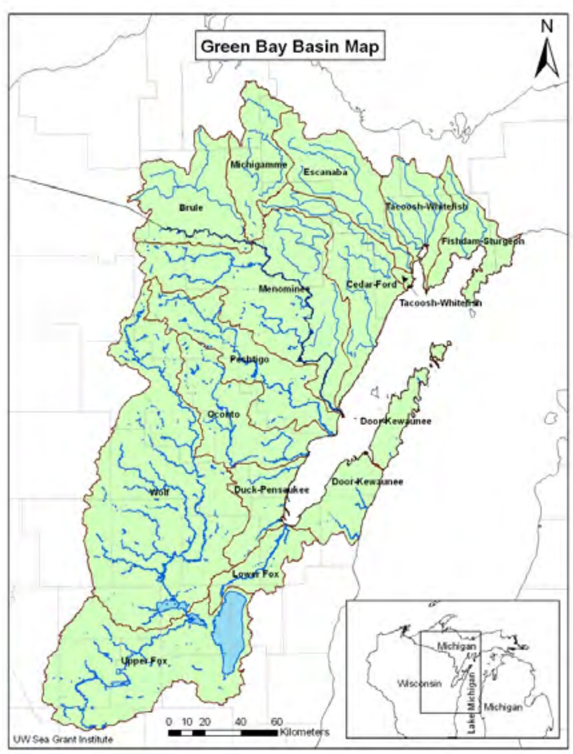


Figure 2: Map of the Green Bay drainage basin.

HISTORY OF REGION

To understand the current state of the bay and what the future may be, it is helpful to look at its past. The Fox River and Green Bay have long been used for transportation, commerce, energy, food and recreation, and this region has experienced centuries of exploitation and degradation (Figure 3). Water quality first became a public issue in 1920s, when the public complained of fish kills, pollution and odors in the Fox and East rivers. In 1938, results from Green Bay's first comprehensive water quality study showed oxygen depletion was related to paper mill discharges. The study also found "very large quantities" of blue-green algae and few burrowing mayflies. Bay Beach was permanently closed in 1943 because of high levels of bacteria. Environmental recovery began in the 1970s with the Clean Water Act and biological oxygen demand (BOD) waste load allocation.

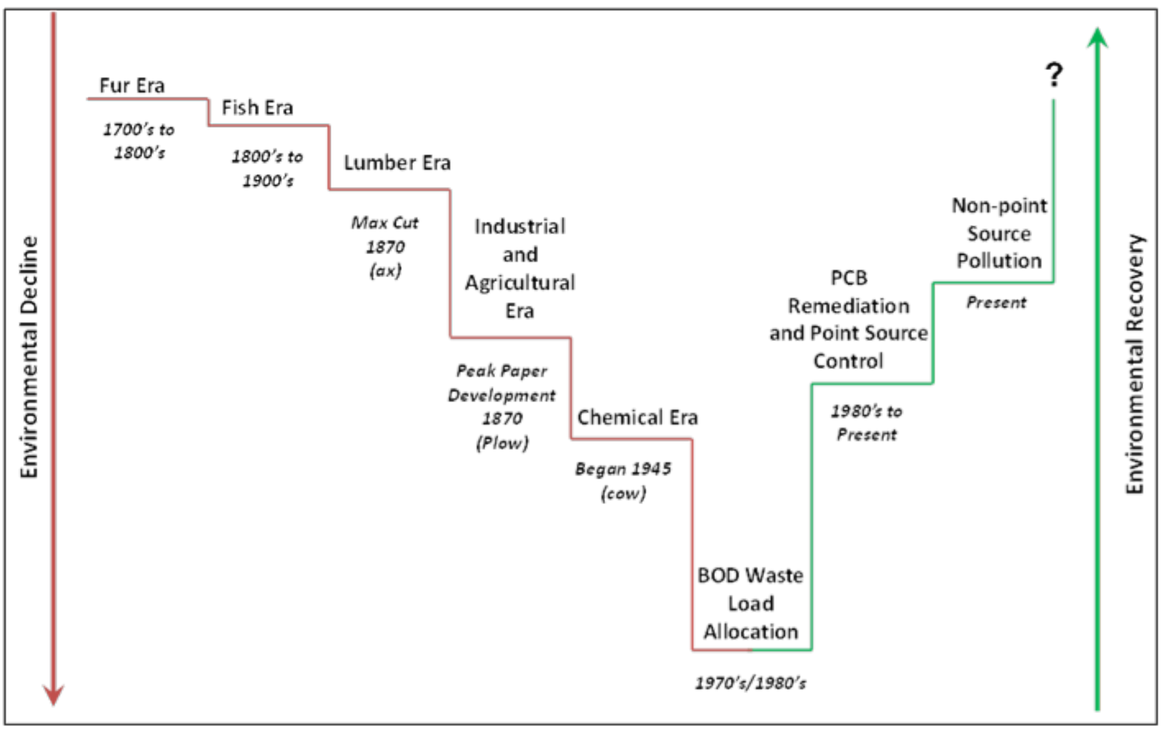


Figure 3: Timeline of environmental degradation and recovery in the Lower Fox River/Green Bay AOC.

WATER QUALITY INDICATORS

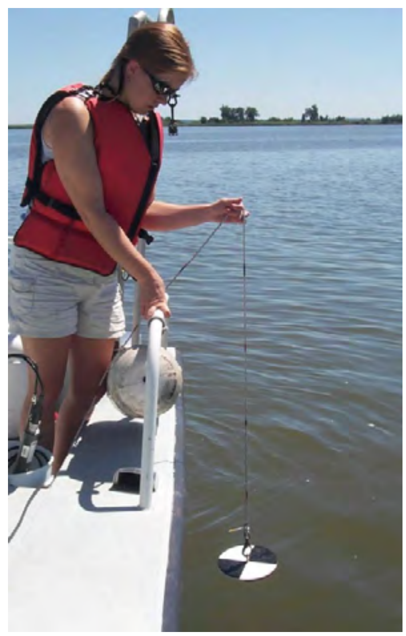
TROPHIC STATE INDICATORS

Eutrophication and Use Impairment

The majority of beneficial use restrictions in Green Bay as well as the Fox-Wolf Basin are due to hypereutrophic (super nutrient-rich) conditions. Eutrophication is a natural aging process in lakes caused by inputs of nutrients and sediments. This process is accelerated by excessive phosphorus, nitrogen, and suspended solids from agricultural and urban runoff. Combined with industrial and municipal discharges, these can cause frequent and extensive algae blooms. It is often called "cultural eutrophication."

STEVE SEILO, PHOTODYNAMIX

Aerial photo of the Lower Fox River mouth on April 12, 2011



GBMSD

Secchi disk sampling

In addition to suspended algae, suspended sediments from soil erosion in the Fox-Wolf Basin make the bay waters turbid, or cloudy. The algae and other suspended solids reduce light penetration to the bay bottom, limiting growth of rooted aquatic plants that are beneficial to fish and wildlife. Other problems caused by hypereutrophication include beach closings and degradation of fish and wildlife habitat. Reversing the hypereutrophic conditions in the river and bay and improving the underwater light conditions is a top priority for the Green Bay RAP.

Managers and scientists are monitoring the current trophic conditions in Green Bay by measuring the concentrations of specific important trophic state indicators. Concentrations of phosphorus, suspended solids, and chlorophyll *a* (a measure of phytoplankton abundance) in the water are measured from spring to fall. A simple measure of water clarity is the Secchi disc reading. A lake becomes more eutrophic as phosphorus, suspended solids, and chlorophyll *a* concentrations increase and Secchi depth decreases.

Standards and Projected Targets

Monitoring and research of Lower Green Bay over the past several decades has revealed that relationships exist between phosphorus concentrations, Secchi depth, total suspended solids, and chlorophyll *a* concentrations. Based on these relationships, preliminary targets or objectives for phosphorus, total suspended solids, and chlorophyll *a* were established in the Lower Green Bay and the Fox River RAP update (1993) with the objective of achieving sufficient water clarity (0.7 m) to provide the minimum light conditions required to support survival of a submergent rooted plant (water celery). More recently, the 2012 TMDL for the Lower Fox River Basin and Green Bay set numeric TP and TSS targets for the mouth of the Fox River with predicted results for Secchi depth in zones 1 and 2 (Table 3).

Table 3: TMDL targets for trophic state indicators

TP (mg/L) Mouth of Fox River	TSS (mg/L) Mouth of Fox River	Secchi (m) Predicted value in Zones 1 and 2
0.10	18	1.14 m

Under the federal Clean Water Act, states and authorized tribes are required to develop a total maximum daily load (TMDL) for all impaired waterbodies. Since the Lower Fox River Basin and Lower Green Bay are impaired by excessive phosphorus and sediment loading, a TMDL has been developed to improve water quality in this region. A TMDL is the total amount of a pollutant that a given waterbody can receive without violating water quality standards. The goal of the TMDL for the Lower Fox River and Green Bay is to set achievable limits that are protective enough to correct water quality impairments and meet water quality standards in the river and bay. The Lower Fox River and Green Bay TMDL was completed and approved by the U.S. Environmental Protection Agency (EPA) on May 18, 2012. For more information and to access the Lower Fox River and Green Bay TMDL, please refer to http://dnr.wi.gov/water/projectdetail.aspx?key=16084305.

Under the Lower Fox River and Green Bay TMDL, targets for total phosphorus (TP) and total suspended solids (TSS) were set for the tributary streams and main stem of the Lower Fox River. These targets were established by evaluating predicted improvements in water quality and littoral zone habitats in zones 1 and 2 (Figure 4) in Green Bay from simulated reductions in Lower Fox River TP and TSS concentrations.

Another TMDL measurement is an Epar score. Epar scores are inversely proportional measures of the ability of light to penetrate the water column. Low Epar scores reflect clearer water with deep light penetration, while high scores indicate turbid water with minimal light penetration. Using data collected by Green Bay Metropolitan Sewerage District (GBMSD), a multiple regression model was established relating Epar in Zones 1 and 2 to corresponding levels of TP and TSS in the Lower Fox River. An additional simple regression model was calculated to relate Epar to Secchi depth measurements.

The targets set by the TMDL for TP are a summer median concentration of 0.10 mg/L (100 µg/L) for the Fox River (from the outlet of Lake Winnebago to the mouth of Green Bay) and a summer median concentration of 0.075 mg/L (75 µg/L) for all of the tributary streams in the basin. The target for TSS for the outlet of Lower Fox River is a summer median concentration not to exceed 18 mg/L (includes an implicit margin of safety of 10%). These targets are expected to result in a mean Epar score of 1.5 m in zones 1 and 2, which by a series of regression models would lead to an estimated Secchi depth of 1.14 m. This would be 63% increase in water clarity from the baseline Secchi depth of 0.70 m. In addition, the TP and TSS concentrations for zones 1 and 2 are projected to be 0.06 mg/l and 15 mg/l respectively (TMDL Report 2012).

Data Collection and Monitoring

The GBMSD provided data for the trophic state indicators. Twelve stations were sampled in Lower Green Bay and four stations were sampled on the Fox River (Figure 4). Historically, the sampling area in Lower Green Bay is categorized into three zones. It is important to note that stations 23 and 25 were no longer sampled after 2006 due to low water levels and six new stations (60, 63, 65, 71, 72, and 75) were added in 2011 north of zone 3 (new stations are not shown on the map).

Typically, GBMSD collects water-quality samples weekly (depending on the weather) between May and October of each year and has done so since 1986. Water samples are collected at one-meter depths for stations less than 3 meters deep (stations 23, 25, and 26). For stations greater than 3 meters deep, samples are collected at a depth of 1 meter from the surface and 1 meter from the lake bottom (stations 5, 7, 13, 16, 22, 32, 41, 47, 48, 51, 55, 46, and 57).

For several of the stations (47, 48, 55 and 57), a composite of the top and bottom samples are combined during sampling and analyzed as a single sample. For the others, the top and bottom samples (stations 5, 7, 13, 16, 22, 32, 41, 51, and 56) are analyzed separately, but data are averaged for statistical analysis.

All samples are analyzed for several chemicals; however, the actual parameter list has evolved over the years. Beginning in 1986, the samples were analyzed for chloride (Cl), total phosphorus (TP), ammonia nitrogen (NH3), and dissolved oxygen. Sampling for chlorophyll *a* began in 1990, and sampling for suspended solids including total solids (TS), total suspended solids (TSS), and volatile suspended solids (VSS), in 1991. In addition, temperature, conductivity, and Secchi depth are measured.

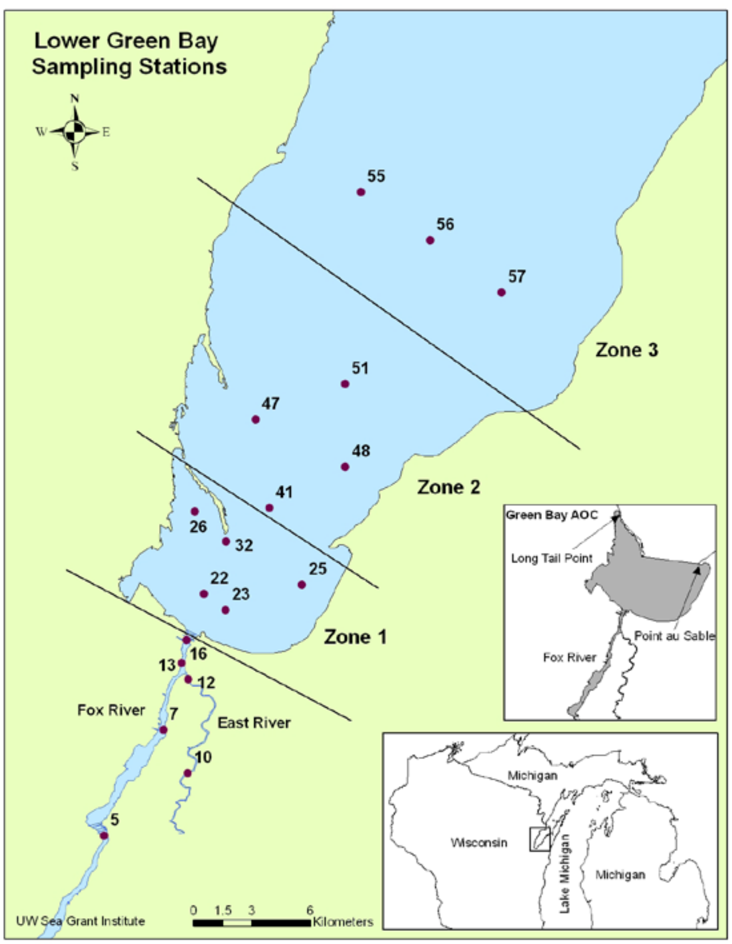
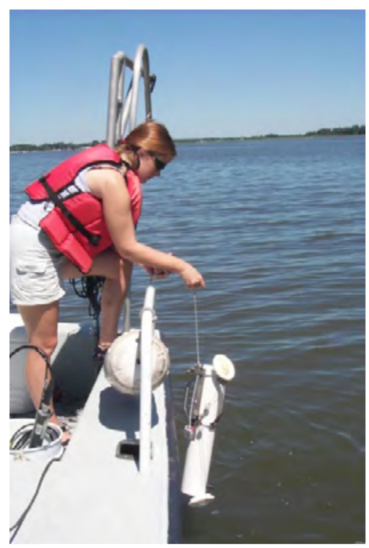


Figure 4: Lower Green Bay sampling stations.



GBMSD

Person water sampling on Green Bay

Because the stations are sampled from May to October, data spans three seasons (spring, summer, and fall). Seasonal weather conditions in some years prevent spring or fall sampling. In addition, the realities of environmental sampling and laboratory analysis—such as wind and wave conditions, equipment failure, time constraints, or human error—resulted in some missing data points. To compare data over all years, only data from June through September (summer) are used in the statistical analyses.

Statistical Analyses

Samples from stations with a top and bottom sample that were not mixed prior to chemical analysis (stations 5, 7, 13, 16, 22, 32, 41, 51, and 56) were analyzed as separate samples. However, after chemical analyses, data were averaged before statistical analyses were performed. Averaging the top and bottom samples simulates mixing, and samples can be compared to composite samples.

Summer averages were calculated for each year by zone and graphed in Microsoft Excel with error bars representing one standard deviation. Linear regression analyses were performed by zone to determine if parameters have changed over time. Regressions were performed using Excel and SAS. Alpha=0.05 was used as the probability level of significance.

Lake level data for Green Bay were obtained from the National Oceanic and Atmospheric Administration (NOAA). Daily lake levels were provided and lake level averages were determined only using the months June through September. It is important to note that 1996 lake level data was missing and 1997 lake level data was limited. Linear regressions of total phosphorus and chloride concentrations on lake levels were performed for each zone.

Analysis of variance (ANOVA) was performed for each zone to determine if changes occurred in nutrient concentrations pre- to post-zebra and quagga mussels for NH3, TSS, Secchi, chlorophyll *a*, and TP. 1993 was used as the cutoff year. This was determined using cluster analysis (Qualls 2003). Pre-zebra and quagga mussel years were 1986-1992 and post-zebra and quagga mussel years were 1993-2012. In SAS, PROC ANOVA was used. If significant differences were found, Duncan's multiple-range test was used to determine specifically which groups were different. All differences were evaluated at alpha=0.05.

Total Phosphorus

Status: Poor

Trend: Unchanging

Between 2006 and 2011, total phosphorus levels in the river approached TMDL target levels 0.1 mg/L. However, total phosphorus levels rebounded in 2012 to near all-time highs for the river. Erratic TP and TSS fluctuations since 2004 remain unexplained.

Phosphorus is one of the most important and controlling chemicals in the Green Bay ecosystem. Phosphorus is an essential plant nutrient needed to support growth of aquatic plants like algae that form the base of the aquatic food chain. In natural freshwater environments, phosphorus is generally present in such small amounts that plant growth is limited. Additional phosphorus coming into a lake will stimulate additional algae growth. In excess amounts, phosphorus promotes growth of massive algae "blooms." Algae, along with suspended sediment particles and other particulate matter, reduces water clarity. Phosphorus-stimulated algal blooms can also limit the light penetration needed to support rooted aquatic plants. When a large mass of algae dies and decays, bacteria numbers increase to break down the algae and use dissolved oxygen from the water. This can cause hypoxia, fish kills and other problems. A fundamental management issue is to identify where the phosphorus originates.

Considerable efforts both past and present have been made to estimate phosphorus loading from the Fox River Basin to Green Bay via the Fox River (Scheberle et al. 2005; TMDL Report 2012). Estimating loading is not a perfect science and variation in estimated loads is expected. Non-point source loads were calculated using the Soil and Water Assessment Tool (SWAT). The SWAT model is rigorously calibrated and validated. When combined with point source discharge estimates, it allows for phosphorus total load estimates. Mean annual TP loading in the Lower Fox River Basin is an estimated 249,865 kg/yr (Figure 5). Lake Winnebago is estimated to contribute an additional 325,888 kg/yr at its outlet, for a combined total mean annual TP loading of 565,753 kg/yr (Figure 6). However, 67% of the annual phosphorus load from Lower Fox River tributaries occurs in 14 days of loading (Grayczyk et al. 2012).

Phosphorus enters waterways primarily from two sources: non-point and point sources. Non-point sources are those that cannot be traced to one individual point of origin, such as agricultural and urban runoff or atmospheric deposition. Approximately 62% of the TP entering Green Bay from the Lower Fox River Basin comes from non-point source pollution (Figure5) (TMDL Report, 2012). If Lake Winnebago is included in the TP loading estimate, it contributes over half of the nutrient load to the bay, which originates mainly from non-point sources (Figure 6).

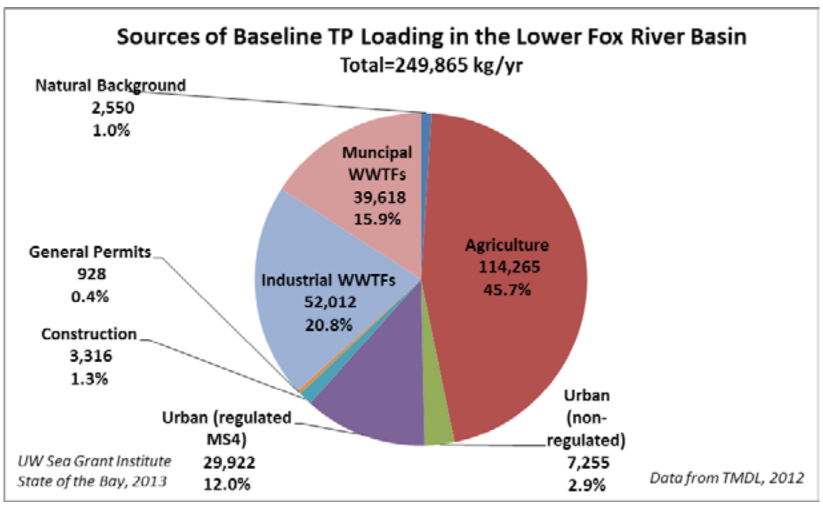


Figure 5: Total phosphorus loading for the Fox-Wolf Basin using modeled and observed data from the period 1977-2009. Data from TMDL report, 2012.

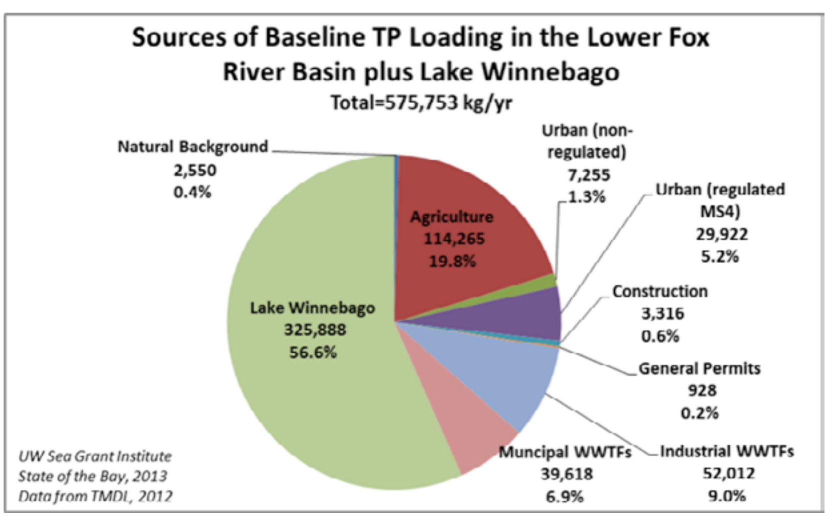


Figure 6: Total phosphorus loading for the Fox-Wolf Basin, including Lake Winnebago using modeled and observed data from the period 1977-2009. Data from TMDL report, 2012.

It is most instructive to know how phosphorus levels have changed in Green Bay over time. Because of the GBMSD monitoring program and research efforts at UW-Green Bay, a record of total phosphorus concentrations for more than 30 years in Green Bay is available. The 1993 RAP set the target for total phosphorus at 0.05 mg/l to 0.107 mg/l for the AOC. Although this concentration is still high enough to result in generally eutrophic conditions, it would allow zone 1 and the river (AOC) to support beds of rooted submerged vegetation and associated aquatic life and reduce the occurrence of nuisance algae blooms and periods of low dissolved oxygen. More recently, the TMDL set the total phosphorus target at 0.10 mg/L for the Fox River (from the outlet of Lake Winnebago to the mouth of Green Bay).

Total phosphorus concentrations exceeded the RAP target until recently and continue to exceed the TMDL target for the river. Phosphorus concentrations decreased in the 1970s following improved sewage treatment required by the Clean Water Act and a ban on phosphorus detergents (Figure 7). After that initial decrease, phosphorus concentrations changed very little during the 1990s. The time period from 2000 to 2005 saw higher than average total phosphorus concentrations. Then, beginning in 2006, total phosphorus concentrations began decreasing and reached a low in 2009, which would have satisfied the RAP target (Figure 7). Subsequently, phosphorus levels have rebounded in the following years. (Figure 7).

The graph uses measurements of total phosphorus (TP). Total phosphorus includes all forms of the phosphorus present in the water sample, only some of which is available as a nutrient. This can include phosphorus absorbed to other particles, particulate and dissolved organic phosphorus, and dissolved in-organic phosphorus. This is an inclusive measure of phosphorus and is commonly used by water chemists.

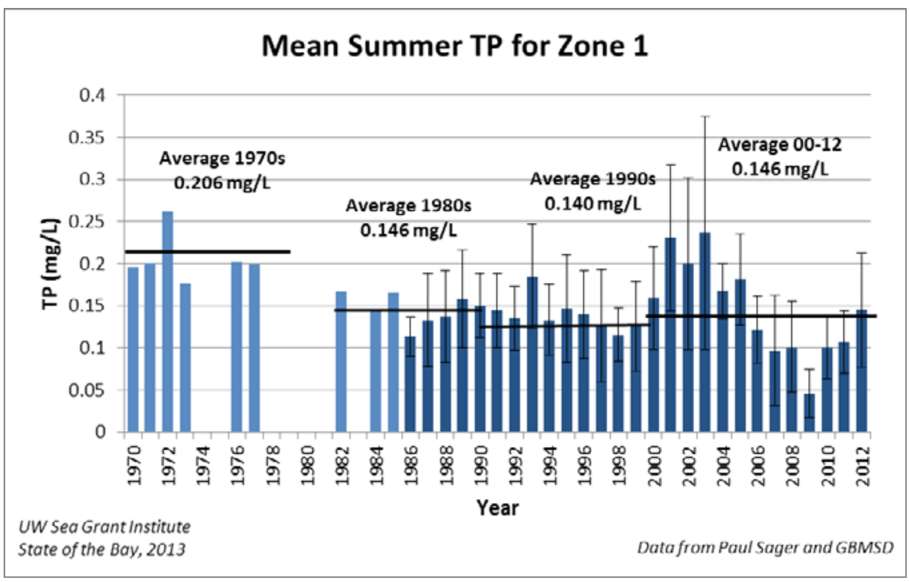


Figure 7: Graph of mean total phosphorus concentrations for zone 1. Error bars represent one standard deviation. Dr. Paul Sager (UW-Green Bay) provided data from 1970-1985 (light blue bars) and GBMSD provided 1986-2012 data (dark blue bars). The phosphorus in Green Bay varies not only over time, but spatially as well (Figure 8). Four major zones, including the river stations, have been identified through sampling. (Refer to Figure 4.)

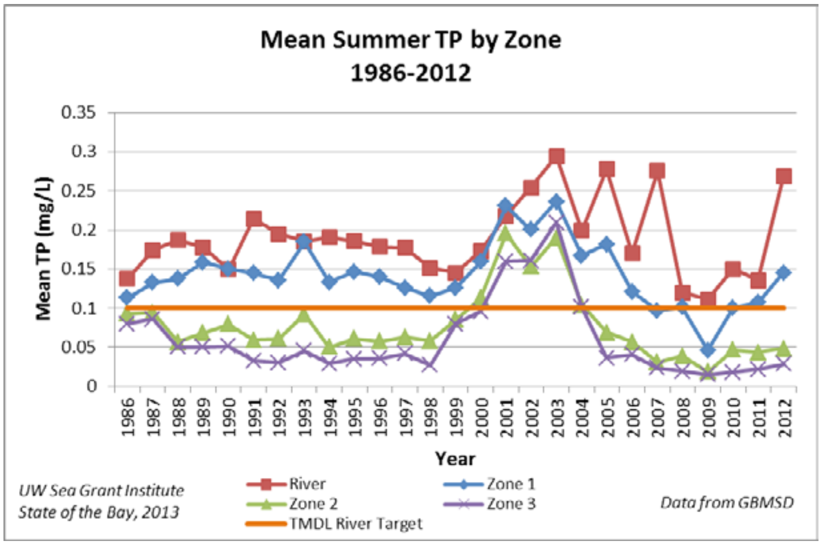


Figure 8: Graph of mean summer total phosphorus concentrations by zone.

See Appendix for standard deviations. The orange line indicates the approved TMDL target of 0.10 mg/l at the mouth of the Fox River. If river meets TMDL target, a predicted TP concentration of 0.06 mg/l in zones 1 and 2 combined is expected.

The three zones in Green Bay and the river stations are distinct, with the highest TP concentrations found in the river stations and the lowest TP concentrations found in zone 3 (Figures 8 and Table A-1). Mean summer TP concentrations in the river stations vary between 0.29 mg/l and 0.11 mg/l. In zone 1, mean summer TP concentrations vary between 0.24 mg/l and 0.05 mg/l. Zone 2 mean summer TP concentrations vary between 0.20 mg/l and 0.02 mg/l, and mean summer TP concentrations in zone 3 vary between 0.21 mg/l and 0.015 mg/l.

While phosphorus concentrations appear to decrease slightly between 1993 (a year of very high spring precipitation and record river flows) and 1999, concentrations began increasing steadily in 2000. However in recent years, TP concentrations are decreasing and 2009 had the lowest mean TP concentrations in all zones since 1986. Based on the results of the linear regressions, there is no significant relationship between TP concentrations and year in the river stations and zones 1, 2 and 3 ($p>0.05$).

It is unclear why TP concentrations increased in 2000-2003, and then decreased. The increase in TP concentrations beginning in 1999 may be due to a combination of lower water levels, introduction of zebra and quagga mussels, increased resuspension of sediments due to lower water levels and a change in prevailing wind direction. It is unclear why TP concentrations have decreased steadily in zones 1, 2, and 3 since 2003. The decreases in these zones and in the river since 2008 may be linked to dredging operations associated with PCB cleanup.

Water levels have varied significantly over the time the data were collected. Analysis of water levels and TP concentrations indicated no significant relationship between lake levels and TP ($p>0.05$).

When the impact of zebra and quagga mussels on TP in all zones is considered, the mean TP concentrations significantly increased from the period before zebra mussels to the period after them in the zone 1 ($p=0.0442$) and no significant changes in zones 2 and 3 ($p=0.6981$ and $p=.8293$ respectively). In zone 1, the mean TP concentration significantly increased 6% from 0.139 mg/l (pre zebra/quagga mussels) to 0.147 mg/l (post zebra/quagga mussels). In zones 2 and 3, the mean TP concentration increased after zebra mussels, but the increases were not significant. This relationship is explored further in the chlorophyll section.

The third factor that may influence phosphorus in the water column is resuspension of sediments by wind. The direction of summer winds over the Great Lakes including Green Bay has shifted since the 1990s. This shift is bound to influence sedimentation rates in shallow areas. An ongoing Sea Grant project is determining how wind direction affects Green Bay in terms of thermal structure, circulation, sediment retention and frequency of sediment resuspension. These factors may very well influence phosphorus levels in the water column (Waples and Klump, 2002).

An obvious fourth factor that could influence TP is loading from the Fox River. Based on the most recent USGS assessment using volume weighted concentration, the flux (phosphorus load) at the mouth of the Fox River has decreased by approximately 1.5 %/year 1988-2010 ($p<0.02$) (Dale Robertson USGS, personal communication). If we examine a similar relationship from 2002-2010, there was a significant decrease in flux (load) by 8.6%/year ($p<0.0002$) (Dale Robertson USGS, personal communication). When we examine the concentrations of mean TP below the dam as a function of TP concentrations in a single station above the dam, there is a significant relationship (Figure 9). This relationship, although not surprising, when taken together with the load outcome strongly implies that the variation in TP concentrations occurring in the bay is being driven by upstream variables, perhaps loading from Lake Winnebago.

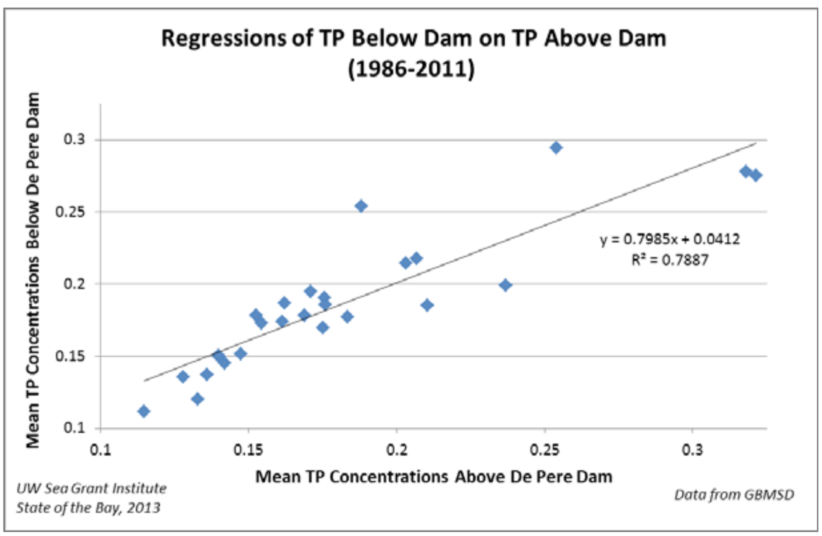


Figure 9: Graph of regression results of mean total phosphorus concentrations below De Pere dam on TP above De Pere dam.

In any event, it is clear that TP concentrations have been fluctuating over time. Even at these lower concentrations, Lower Green Bay remains a highly stressed hypereutrophic system at the southern end, grading to a mesotrophic condition by mid-bay and near oligotrophic state in the northern bay. This pronounced trophic gradient within Green Bay strongly influences the variation at different levels of lake productivity. For example, eutrophic conditions produce a dominance of growth of large-sized cyanobacteria (blue-green alage) and low grazing rate by microcrustaceans (Sager and Richman, 1991). The trophic state influences energy transfer efficiencies in the pelagic food chain with very high primary productivity in the southern bay with low transfer efficiencies and low productivity in the northern bay accompanied by higher transfer efficiencies (Sager and Richman, 1990; Smith and Magnuson, 1990). Trophic conditions also influences the littoral zone (near shore) submergent plant communities and their attendant invertebrate and aquatic insect composition (Schneider and Sager, 2007 and McLaughlin and Harris, 1990).

Nitrate (NO_3) and Nitrite (NO_2)

Status: Fair to Good
Trend: Deteriorating

Nitrogen is an important nutrient for plant and algae growth, and nitrate is an inorganic form of nitrogen that can be taken up by plants. Nitrate can be converted from other forms of nitrogen in water and soils by bacteria or it can enter surface waters directly through atmospheric deposition, runoff from industrial, residential, and agricultural sources, or from groundwater. When nitrate is limiting, some cyanobacteria (blue-green algae) have an advantage over other algae species, because these cyanobacteria can use ("fix") nitrogen directly from the atmosphere (see the chlorophyll section for a description of cyanobacteria). Harmful algal blooms are associated with low nitrogen to phosphorus ratios. When the ratio of nitrogen to phosphorus is less than 29:1, harmful algal blooms may occur (Smith 1983).

In the river and zone 1, nitrate and nitrite concentrations are higher than in zones 2 and 3 (Figures 10-11; Tables A-2 and A-3). In zones 2 and 3, the low nitrate concentrations may indicate that total phosphorus is adequately high and that there may be a shift to cyanobacteria. Nitrate and nitrite concentrations in the river have been increasing over time, with the exception of 2012. The decline in nitrate and nitrite is remarkable and may be related to the high phosphorus levels driving an increase in algal production (i.e. chlorophyll *a* levels), which could create a decrease in total nitrogen. Regression of nitrate and nitrite in the river since 1986 were positive and significant (p=.0035 and p=.0053 respectively).

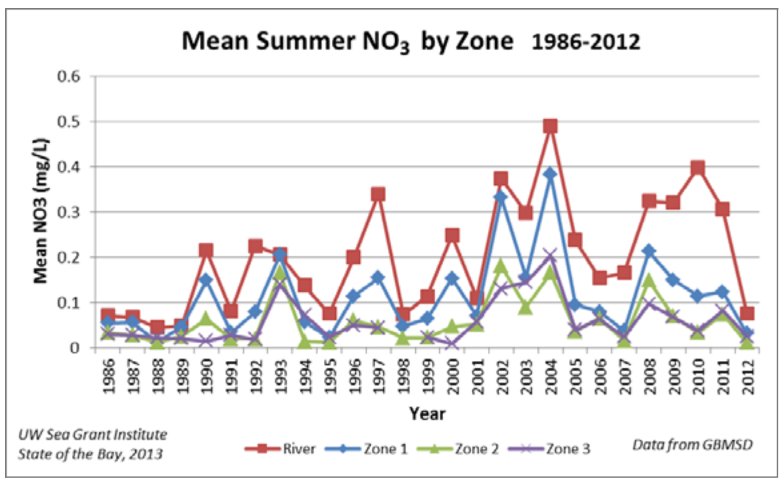


Figure 10: Graph of mean nitrate concentrations by zone.

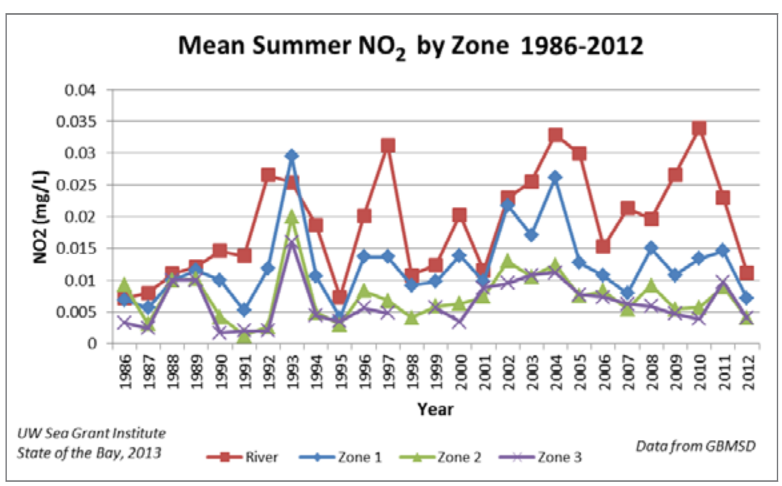


Figure 11: Graph of mean nitrite concentrations by zone.

Ammonia

Status: Good

Trend: Undetermined

Green Bay waters are safely meeting the state standards.

Ammonia (NH_3) is a nonpersistent toxic substance that has received increasing attention in Wisconsin. It is one form of nitrogen used by algae and other plants and can act as a fertilizer, contributing to algal blooms under certain conditions. Ammonia is released as bacteria decompose organic matter such as sewage, paper fibers, manure, and algae. Because of its chemistry, ammonia is often higher in water where dissolved oxygen is low. At higher concentrations of dissolved oxygen, bacteria oxidize ammonia to the nitrate form.

Alkaline (high pH) and warm water temperatures increase the toxicity of ammonia. Water quality criteria that account for pH and temperature have been developed for ammonia discharges in Wisconsin. These criteria provide different discharge limits for summer and winter seasons. Ammonia concentrations in the inner bay and the river (AOC) decreased beginning in 1993 (Figure 12; Table A-4). The decrease in ammonia is attributed largely to improved wastewater treatment at the Green Bay Metropolitan Sewerage facility beginning in 1992 to meet the then unionized ammonia criteria. Recently, these criteria have been changed based on numerous studies of ammonia toxicity to aquatic life. Based on these new criteria, maximum summer ammonia concentrations in zone 1 (inner bay) should not exceed 0.59 mg/l given average summer temperatures and pH (calculated by James W. Schmidt, WDNR). Under these criteria, Green Bay waters are safely meeting state standards.

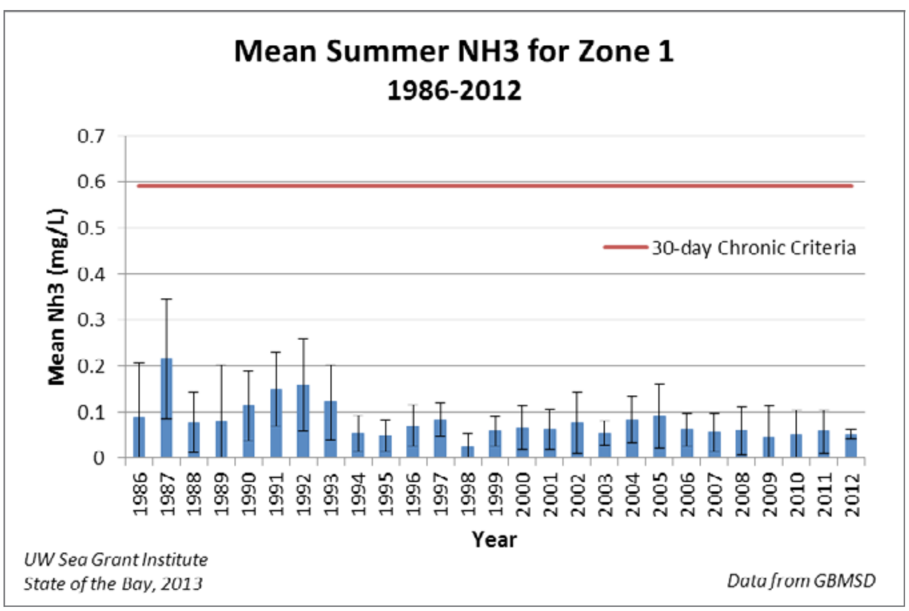


Figure 12: Graph of mean ammonia concentrations for zone 1 with error bars representing one standard deviation. The red line indicates the 30-day chronic criteria (0.59 mg/l) for the AOC.

Total Suspended Solids

Status: Poor
Trend: Unchanging
Suspended solids are above target levels.

Total suspended solids (TSS) are all of the particles in the water that can be trapped on a filter. TSS includes a wide variety of material, such as soil, algae, decaying organic matter, and particles discharged in wastewater. Volatile suspended solids (VSS), a component of TSS, are organic (biotic) solids derived from algae, decaying plant and animal material, and organic wastes from sewage and industrial discharges. The remainder and majority of TSS consist of inorganic solids like silt, clay, and fine sand.

Negative impacts of TSS include:

- Less sunlight to submerged vegetation
- Reduction of oxygen in water column
- Decreased visibility for fish and diving birds
- Fouling fish gills
- Covering fish eggs, fish nursery areas, invertebrate habitat
- Increased dredging and maintenance in shipping channels and harbors

STEVE SEILO, PHOTODYNAMIX

Suspended solids enter Green Bay mainly from the Fox River and its tributary streams. Suspended solids negatively affect tributary streams, Lake Winnebago, the Fox River, and Green Bay in a number of ways. TSS scatter and absorb sunlight, reducing the amount of light reaching submerged vegetation. In very murky, turbid water, photosynthesis is limited and submerged plants like water celery cannot survive. Reduced photosynthesis provides less oxygen to the water column and in combination with oxygen consumption by bacteria lowers dissolved oxygen. Occasional fish kills from depleted oxygen conditions have been reported in Green Bay. Decreased visibility caused by lowered water clarity can affect the ability of animals like fish and diving birds to find and capture food. Suspended solids foul gills and therefore increase stress in fish and invertebrates. As suspended solids settle to the bottom, they can bury fish eggs, fish nursery areas, and the micro-habitats used by invertebrates like amphipods and aquatic insects.

The suspended solids load at the mouth of the Fox River is 137,816 mt/yr -1 (151,915 tons/yr) (TMDL Report 2012). This amounts to 416 tons per day (378 mt/day) in an average year or the equivalent to 25 dump trucks per day of sediment deposited into Green Bay (Figure 13). However, approximately 60-70% of the load is delivered in a much shorter period of time (13-15 days), primarily in spring (Grayczyk et al. 2012).

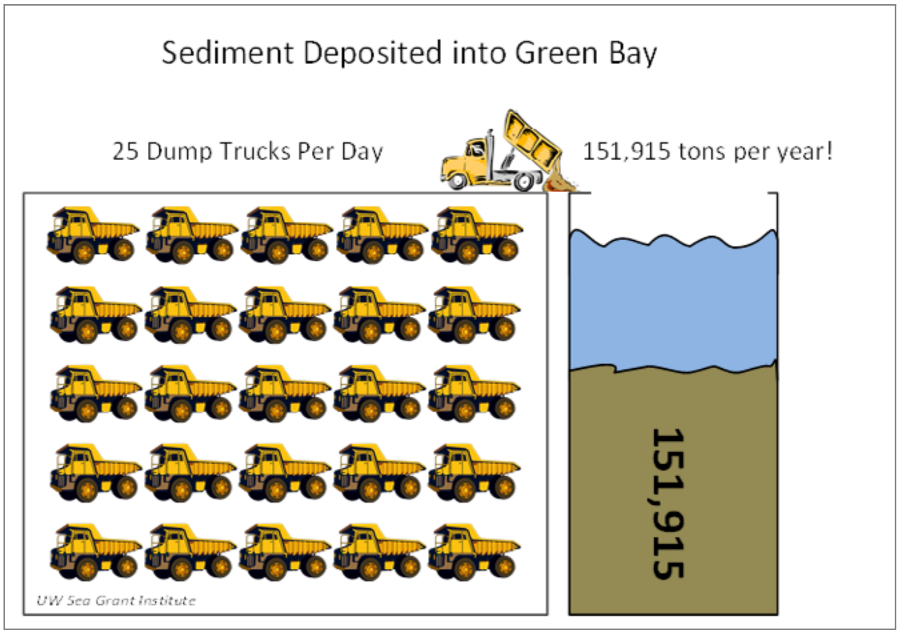


Figure 13: The total suspended solids load at mouth of Fox River in dump truck equivalents.

Suspended solids contribute to sediments settling into the shipping channels and harbors that are economically important to marina owners and the Port of Green Bay. The 137,816 metric tons (151,915 tons) of suspended solids delivered to the bay each year from the Fox River are not only grossly detrimental to the river and bay and represent loss of a critical resource (topsoil) but also necessitate a costly maintenance dredging program in the Green Bay harbor and shipping channels. From 1957 to 2010, a total of 16,462,152 cubic yards of sediment were dredged from Green Bay harbor at a cost of $50,600,860 (USACE 2011). Currently, 85,000 to 100,000 cubic yards of sediment are dredged every year from the Green Bay harbor by the Corps (Dean Haen, Port of Green Bay, Brown County Port and Solid Waste Department). Assuming that 100,000 cubic yards of sediment need to be dredged each year, the amount of sediment for disposal over 10 years is one-million cubic yards. At a cost of $17 per cubic yard (USACE 2011), the total cost for dredging and disposal over 10 years would be $17 million. Clearly, investment in best-management land-use practices has dividends beyond the conservation of soil.

The TMDL target for TSS is 18 mg/L for the outlet of the Lower Fox River. TSS concentrations are above this target level (Figures 14-18; Table A-5). Based on results of linear regressions, there are no significant changes in TSS concentrations over time (1991-2012) in the river stations and in zone 1 ($p>0.05$). In zones 2 and 3, TSS concentration significantly decreased over time ($p=0.0429$ and $p=0.0071$ respectively).

Mean TSS concentrations have been affected by the introduction of zebra and quagga mussels into Green Bay. In all zones, TSS concentrations decreased since the introduction of zebra and quagga mussels. In zone 1, there was a 14% decrease in mean TSS concentrations from 33.62 mg/l before zebra/quagga mussels to 28.83 mg/l after zebra/quagga mussels ($p=0.0006$). In zone 2, mean TSS concentrations decreased by 21% from 13.4 mg/l before zebra/quagga mussels to 10.5 mg/l after zebra/quagga mussels ($p=0.0003$). In zone 3, mean TSS concentrations decreased by 35% from 7.19 mg/l before zebra/quagga mussels to 4.7 mg/l after zebra/quagga mussels ($p<.0001$). However, these changes should be viewed cautiously since there are only two pre- zebra/quagga mussel years (1991 and 1992) for which TSS data are available.

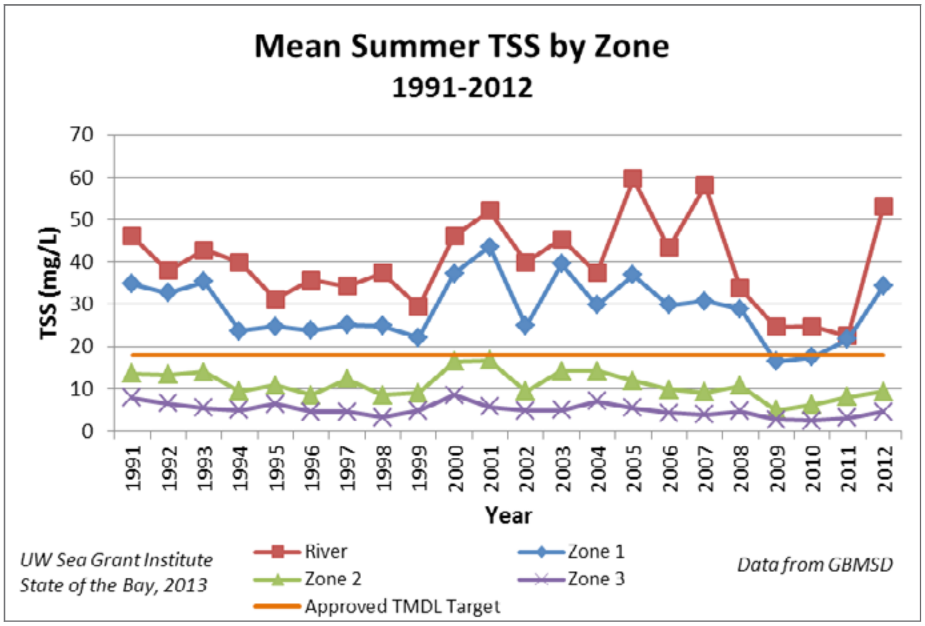


Figure 14: Graph of mean total suspended solids concentrations by zone. The orange line represents the TMDL target of 18 mg/L for the mouth of the Fox River.

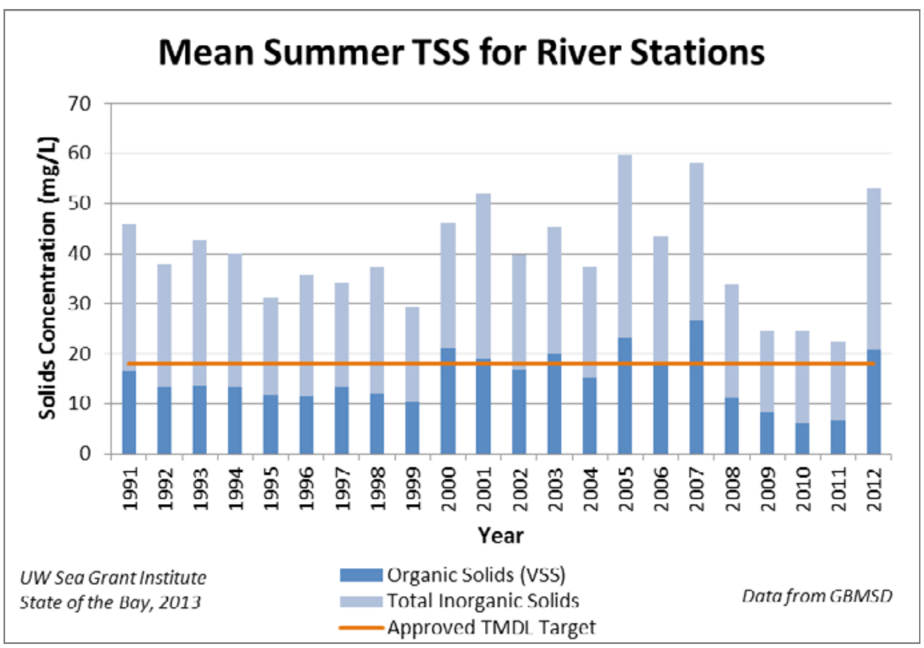


Figure 15: Graph of mean total suspended solids concentrations for the river stations. The orange line indicates the TMDL of 18 mg/l for the mouth of the Fox River.

Figure 16: Graph of mean total suspended solids concentrations for zone 1.

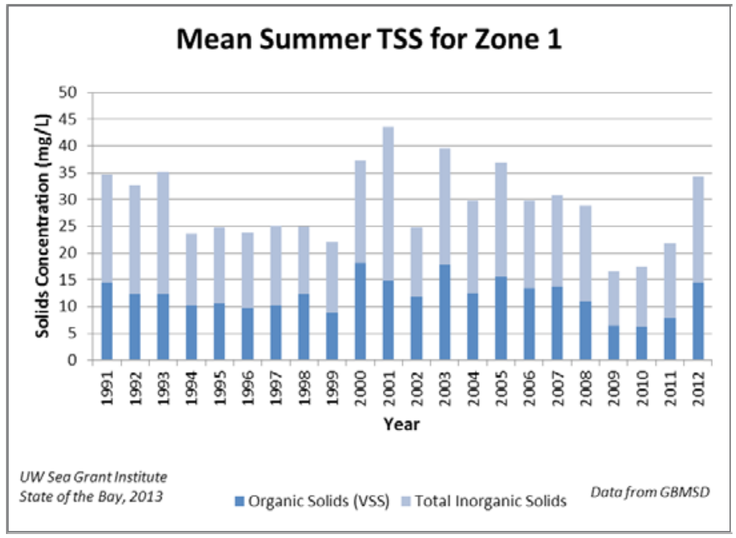


Figure 17: Graph of mean total suspended solids concentrations for zone 2.

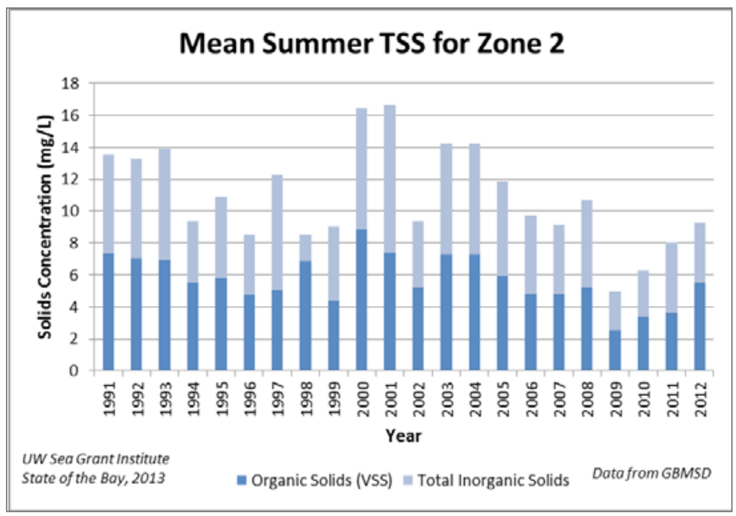
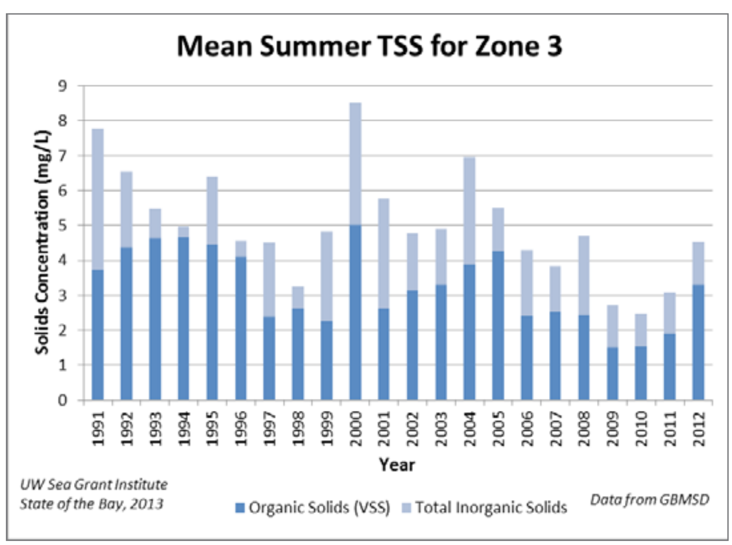


Figure 18: Graph of mean total suspended solids concentrations for zone 3.



Chlorophyll *a*

Status: Poor

Trend: Unchanging

Green Bay waters are currently not meeting the chlorophyll a *concentration standards set by the RAP.*

Chlorophyll *a* is a green pigment that plants use to convert sunlight, carbon dioxide, and water into sugars through photosynthesis. Therefore, chlorophyll *a* concentrations provide an indirect measure of the amount of living algae suspended in the water column. An increase in nutrients, especially phosphorus, stimulates an increase in algae production if sufficient light is available. Given an increase in phosphorus, algae populations will continue to increase, reducing water clarity and light penetration, since algae are solids suspended in the water. Algae blooms (abundant growths that cause the water to appear green or bluish green) can greatly reduce light penetration, and the decay of large amounts of algae can reduce dissolved oxygen concentrations.

Chlorophyll *a* concentration does not differentiate between the types or species of algae that are growing in a particular location. Cyanobacteria (blue-green algae) can become problematic under high phosphorus conditions. Some cyanobacteria are capable of fixing nitrogen directly from the air, unlike more desirable green algae, and so are limited only by the amount of available phosphorus. They readily use increased amounts of phosphorus and out-compete more desirable green algae that form the base of the bay food chain.

Many cyanobacteria have internal "flotation devices" that allow them to remain within the surface layer of the bay and form large floating mats or scums on the surface. This type of surface-level algae can severely limit light penetration and decrease the survival of more desirable algae species and other submerged plants, and also deter water recreationists. Decaying mats of cyanobacteria may accumulate along the shoreline and smell like sewage. Some species of cyanobacteria also release toxins that can harm or kill fish, other aquatic life, and even wildlife or pets that drink sufficient quantities of contaminated water. Invertebrate filter feeders do not readily utilize some cyanobacteria and in combination with high phosphorus levels allows cyanobacteria populations to grow exponentially creating a harmful algal bloom (HAB).

Chlorophyll *a* concentrations have only been measured in Green Bay on a routine monthly basis since 1990, but at present provide the best assessment of health risk from HABs. The other two measures, cell densities and microcystin LR, a cyanotoxin produced by a common genera of cyanobacteria (Microcystis), have only been monitored for one year. The TMDL does not set a target for chlorophyll *a*. The RAP target concentration for chlorophyll *a* of 13 ug/l to 32 ug/l is still being exceeded (Figures 19-20; Table A-6). In all zones, chlorophyll *a* concentrations have significantly decreased since zebra and quagga mussels were introduced into Green Bay ($p<0.0001$). In zone 1, average chlorophyll *a* concentration decreased by 28% from 69.44 mg/m3 before zebra/quagga mussels to 50.19 mg/m3 after zebra/quagga mussels. Zone 2 had a 36% decrease in the average chlorophyll *a* concentrations from 29.92 mg/m3 before zebra/quagga mussels to 19.1 mg/m3 after zebra/quagga mussels, and in zone 3 average chlorophyll *a* concentration decreased by 39% from 14.43 mg/m3 before zebra/quagga mussels to 8.8 mg/m3 after zebra/quagga mussels.

There is a well-established relationship between chlorophyll *a* and phosphorus. This relationship exists because phosphorus is a required nutrient for algal growth; if phosphorus concentrations decrease, then the amount of chlorophyll *a* in the system will also decrease. However, zebra and quagga mussels may impact this relationship through filter feeding and removing algae. This results in a decreased chlorophyll *a* concentration without a reduction in nutrients. An analysis of the data set by Qualls (2003) revealed that zebra and quagga mussels did not change the expected chlorophyll-phosphorus relationship in zones 1 and 2, but did change it in zone 3. It follows that any phosphorus reduction across all zones may not lead to an accompanying drop in chlorophyll *a* in zone 3, which would be apparent in zones 1 and 2.

A relationship between the relative biomass of blue-green algae (%BG) in phytoplankton of lakes in relation to TP concentrations was examined (Paul Sager, personal communication) (Figure 21). Currently blue-green algae make up over 70% of the phytoplankton in Lower Green Bay. The vertical lines in Figure 26 identify baseline TP in the LFR (180 µg/l), the TMDL target for the LFR (100 µg/l) and a predicted numeric level (60 µg/l-for Zones 1 and 2) when the TMDL target is achieved. The reduction in percent blue-green algae corresponding to the TP change is apparent and is likely one of the major benefits of the TMDL initiative because it will reduce the frequency of HABs.

HABs include different types of algae taxa such as dinoflagelates, diatoms, and cyanobacteria. Cyanobacteria are of special concern because of their potential impacts on drinking and recreational waters. Increasingly, the public have expressed concern about health risks and environmental quality deterioration from the HABs. In response, the state has developed the Wisconsin Harmful Algal Bloom surveillance program. Data obtained from the program is intended to document conditions that occur in conjunction with human and animal illnesses potentially related to harmful algal bloom exposure.

Because there are no federal recreational water guidelines for cyanobacterial cell densities or chlorophyll *a* concentrations, Wisconsin uses the World Health Organization (WHO) guidelines to determine risk to recreational water users (Table 4).

Based on one summer (2011) of sampling at two stations in the AOC, microcystin LR levels are within the low-risk category of the WHO recreational water guidance (WDNR 2011). However, chlorophyll *a* levels are in the moderate- to high-risk category. Further investigation is necessary to clarify the discrepancy between risk categories.

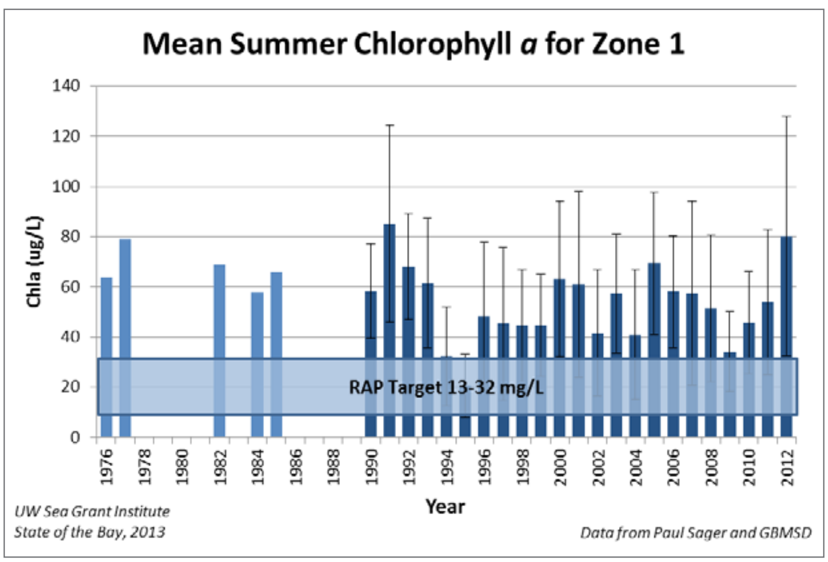


Figure 19: Graph of mean chlorophyll *a* concentrations for zone 1 with error bars representing one standard deviation. The blue box indicates the RAP target of 13-32 ug/l. Dr. Sager provided data from 1976-1985 (light blue bars), and GBMSD provided 1986-2012 data (dark blue bars).

Figure 20: Graph of mean chlorophyll *a* concentrations by zone.

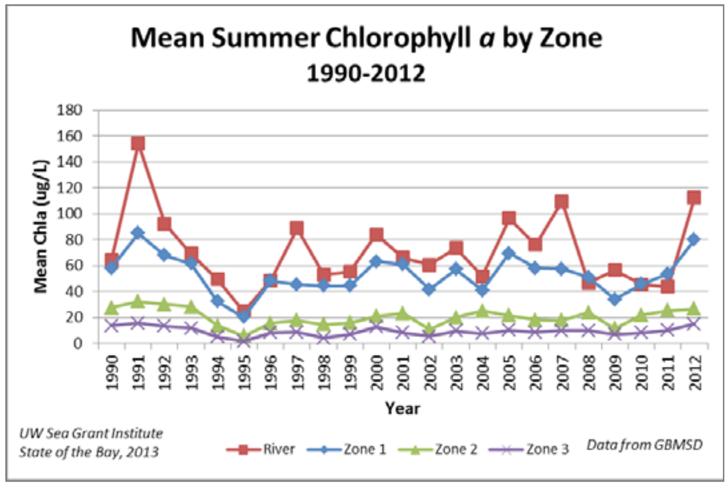


Figure 21: Predicting the relative biomass cyanobacteria in phytoplankton from total phosphorus level in lakes. (Trimbee and Prepas, 1987).

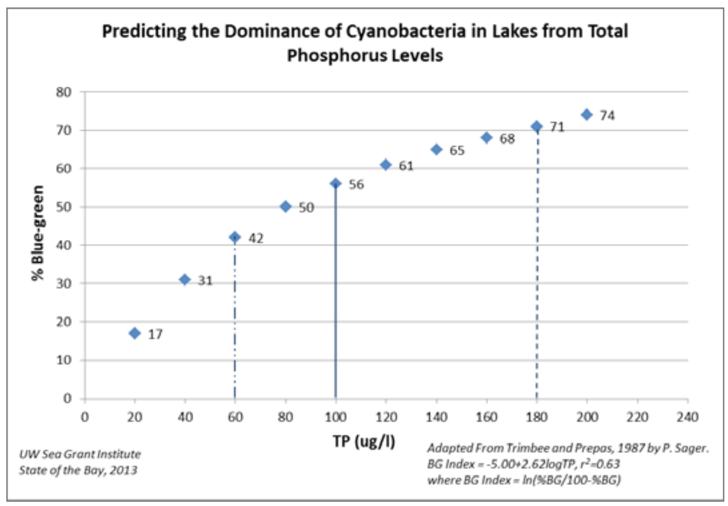


Table 4: World Health Organization for cyanobacteria risk to recreational water users.

Relatively Probability of Acute Health Effects	Cell Densities (cell/ml)	Chlorophyll *a* Concentration (ug/L)	Microcystin LR Concentration (ug/L)
Low	< 20,000	<10	<10
Moderate	20,000-100,000	10-50	10-20
High	100,000-10,000,000	50-5,000	20-2,000
Very High	>10,000,000	>5,000	>2,000

Table from the EPA: http://www2.epa.gov/nutrient-policy-data/cyanobacterial-harmful-algal-blooms-cyanohabs

Water Clarity (Secchi Depth)

Status: Poor
Trend: Unchanging

One simple measure of water clarity is Secchi depth. A Secchi disk is a black-and-white disk that is lowered into the water until it is no longer visible. It is then raised until it becomes visible. The Secchi depth is recorded as the mid-point between the two depths. However, most investigators use the depth at which the disk disappears as the Secchi depth, as was done and reported here. Higher Secchi depths indicate clearer water and lower Secchi depths indicate more turbid water. Water clarity is impacted by algae, soil particles, and other suspended particles. Using the relationships between TP, TSS, light extinction (Epar) and Secchi depth, the predicted Secchi depth in zones 1 and 2 is 1.14 meters if the TMDL target of TP and TSS are met. Studies conducted in the early 1990s (McAllister 1991) defined the relationship between water clarity, light availability, and the maximum depth at which a particular submergent plant can colonize and persist (Table 5). The predicted Secchi depth for zones 1 and 2 exceeds the minimum of 0.7 meters Secchi depth needed for survival and growth of wild celery.

In zone 1, mean summer Secchi depths have varied between 0.77 meters and 0.29 meters (Figures 22 – 24; Table A-7) since 1986. The long-term average Secchi depth in zone 1 is 0.51 meters. In zone 1, Secchi depths significantly <u>decreased</u> after zebra and quagga mussels (p=0.0064). For zone 2, between 1986 and 2011, mean summer Secchi depths varied between 2.08 meters and 0.85 meters, with a long-term average Secchi depth of 1.42 meters (Figure 22). In zone 2, there was an 11% improvement in mean Secchi depth after zebra and quagga mussels entered the bay (p=0.0017). Mean summer Secchi depths in zone 3 vary between 3.3 meters and 1.61 meters since 1986, with a long-term average of 2.4 meters (Figure 22). In zone 3, Secchi depths increased by 12% after zebra and quagga mussels (p=0.0009). Following the introduction of zebra and quagga mussels, Secchi depth appears to improve from 1994 until 1998 and has then declined steadily until recent years.

Table 5: Relation of water clarity as measured by Secchi disk to depth of colonization of *Vallisneria americana* (wild celery).

Secchi Disk (m)	Estimated maximum depth of colonization (Zc)
0.5	0.99
0.6	1.21
0.7	1.43
0.8	1.66
0.9	1.90
1.0	2.14

Values derived from McAllister 1991.

Figure 22: Graph of mean Secchi depths by zones. The orange line indicates the predicted Secchi value in zones 1 and 2 (1.14 m) if the TMDL targets for TP and TSS are met.

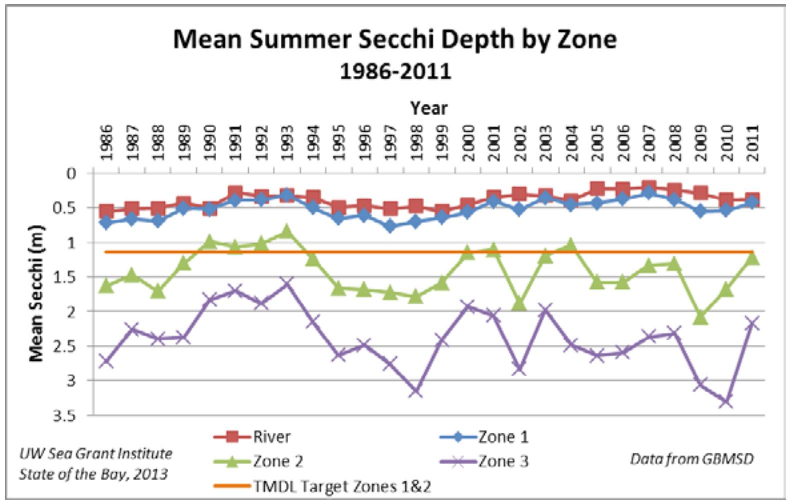


Figure 23: Graph of mean Secchi depths for zones 1 and 2 combined. The orange line indicates the predicted Secchi value in zones 1 and 2 (1.14 m) if the TMDL targets for TP and TSS (in the river) are met.

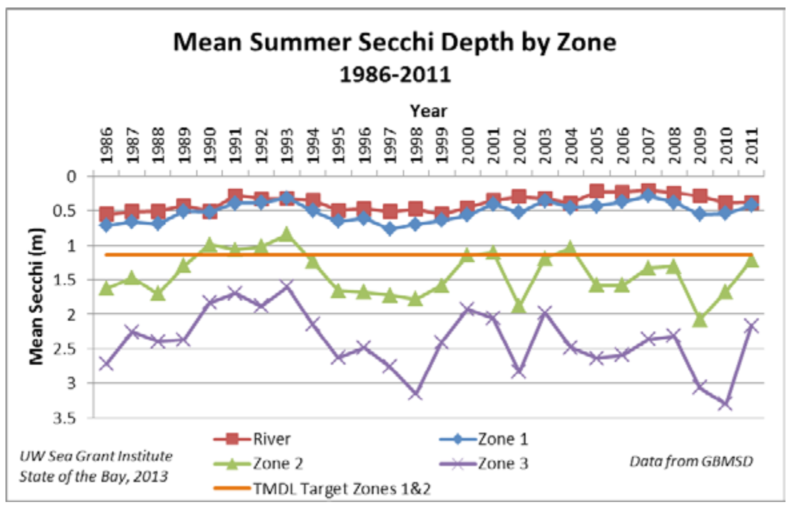
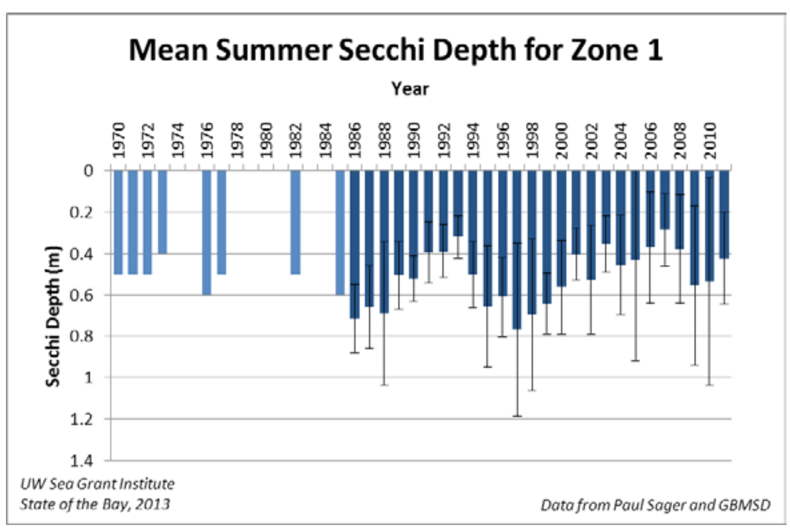


Figure 24: Graph of mean Secchi depths for zone 1. The error bars represent one standard deviation. Dr. Sager provided data from 1970-1985 (light blue bars) and GBMSD provided 1986-2011 data (dark blue bars).



Chloride

No substantial change in chloride concentrations for all zones or the river stations has occurred.

Most of the chloride dissolved in Green Bay water is derived from natural sources (NaCl) or anthropogenic (human) sources, including chemical fertilizers, manure, road salts, sewage, and industrial waste. According to research done by the EPA, anthropogenic inputs of chloride have resulted in increased chloride ion concentrations in the Great Lakes. In Lake Michigan, current concentrations are between 10-20 mg/l and continue to increase at a slow rate of about 0.1 mg/l/year. In outer Green Bay, chloride concentrations are similar to Lake Michigan, but for the inner bay and the river (AOC), chloride is slightly higher—although still below limits for toxicity to most organisms. Models suggest that continued use of road salts will result in increasing chloride in the Great Lakes for the next 500 years (GLNPO 2012).

Based on statistical tests, there has been no significant change in chloride concentrations over time (1986-2012) for all zones or the river stations ($p>0.05$) (Figure 25; Table A-8).

Analysis of water levels and chloride concentrations suggests a significant negative relationship between chloride concentrations and lake levels only in zone 1 ($p=0.0019$) (Figure 26). For zones 2 and 3, the regressions of Cl concentration on lake levels were not significant at alpha=0.05. Based on the regression results, in zone 1, Cl concentrations are decreasing with increasing lake levels. In other words, Cl concentrations are higher with lower lake levels. However, the r2 value suggests lake level is not the only factor that causes variations in Cl concentrations.

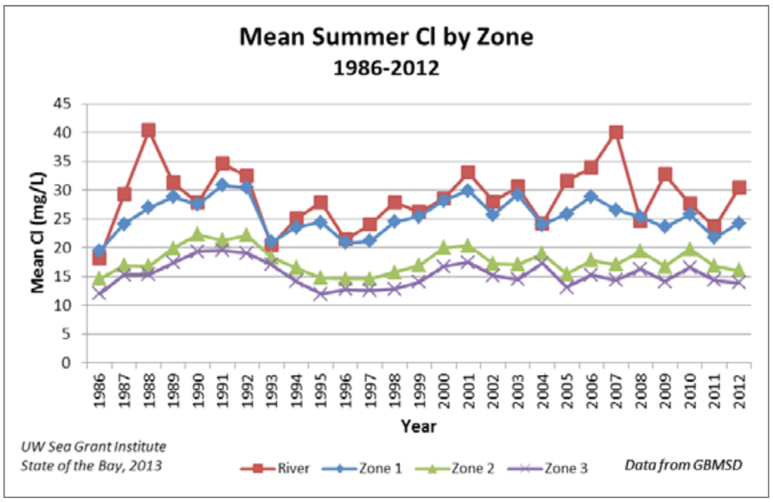


Figure 25: Graph of mean chloride concentrations for river stations and zone 1, 2, and 3.

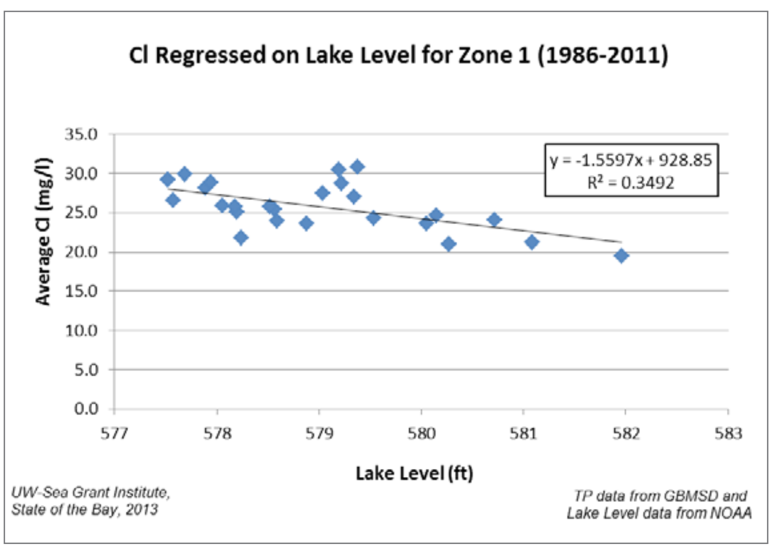


Figure 26: Chloride regressed on lake level for zone 1. There is a significant negative relationship between chloride concentrations and lake levels in zone 1 (p=0.0019).

Dissolved Oxygen

Status: Fair

Trend: Improving

Mean dissolved oxygen (DO) concentrations meet warmwater fishery criteria. Minimum DO concentrations are below 5 ppm.

The amount of oxygen dissolved in lake water depends on wave action, water flow into the bay, water temperature, water depth, and photosynthesis by phytoplankton and aquatic plants. It also depends on the biological oxygen demand (BOD). BOD is the amount of oxygen consumed by all organisms living in the lake, including algae and plants, bacteria, invertebrates like insects, and vertebrates like fish. Photosynthesis by phytoplankton and rooted aquatic plants releases oxygen into the water during the daylight. However, at night oxygen concentrations decline because animals, plants, and bacteria continue to consume oxygen, but no photosynthesis can occur in the dark. This is particularly evident in waters near the bottom because of bacterial activity breaking down rich organic and nutrient laden sediments. This process is referred to as sediment oxygen demand. Levels of dissolved oxygen (DO) remain a specific measure of water quality and an indicator of ecosystem health. The level of dissolved oxygen needed to maintain a quality warmwater sport fishery is generally accepted as a minimum of five milligrams per liter or parts per million (ppm).

Since the control of BOD organic wastes from sewage and industrial facilities in the 1970s and 80s, average dissolved oxygen levels in the inner bay and the river (AOC) have generally met the desired standard of five ppm. A simple regression of mean DO concentration over the years reveals a significant increase in DO ($p=0.0001$) in all zones. There are times, however, when the measured minimum concentration drops below this level (Figure 27-30).

Averages tell something, but as far as the organisms are concerned, extreme conditions make survival difficult. For example, there are many instances in which the measured minimum oxygen concentration in all zones falls below the 5 ppm DO standard, while the average concentration remains above the standard (Figures 27-31). Because of the high level of photosynthesis and the generation of oxygen, DO levels may approach saturation (the maximum amount of DO that the water can hold). Benthic organisms, because they are mostly immobile, are subject to these extreme fluctuations. Other benthic organisms, such as round gobies, may also be affected by periodic decreases in bottom DO.

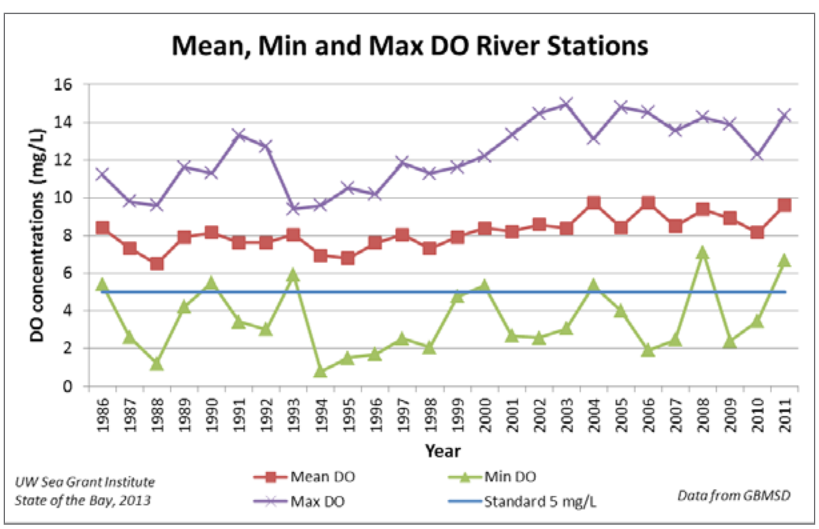


Figure 27: Mean, minimum, and maximum dissolved oxygen concentrations (mg/l) for river stations. The blue line indicates the minimum dissolved oxygen standard of 5 ppm.

Figure 28: Mean, minimum, and maximum dissolved oxygen concentrations (mg/l) for zone 1. The blue line indicates the minimum dissolved oxygen standard of 5 ppm.

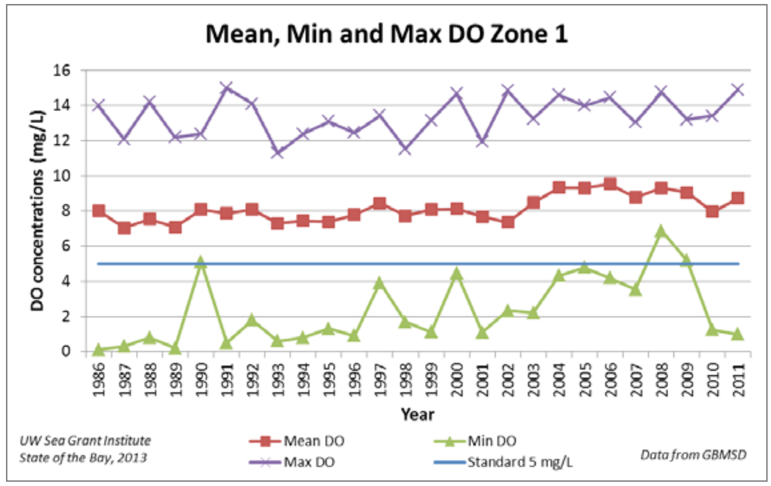


Figure 29: Mean, minimum, and maximum dissolved oxygen concentrations (mg/l) for zone 2. The blue line indicates the minimum dissolved oxygen standard of 5 ppm.

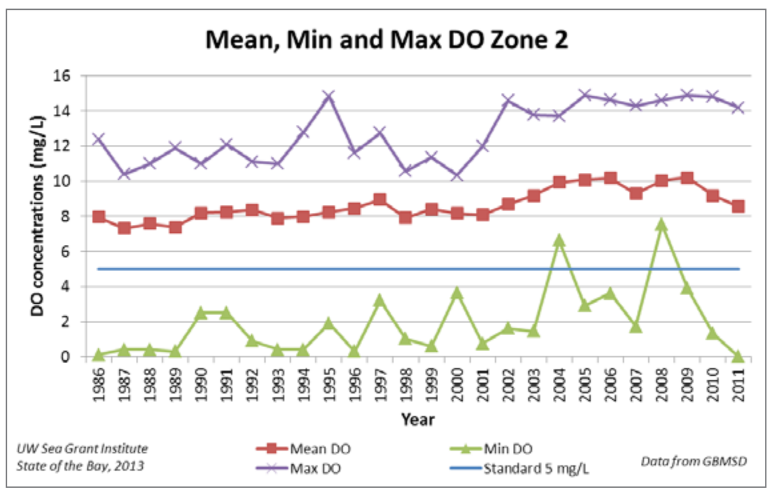
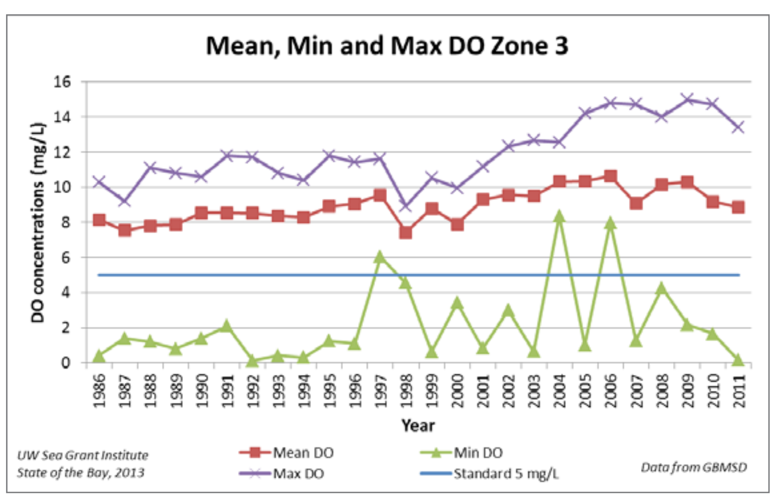


Figure 30: Mean, minimum, and maximum dissolved oxygen concentrations (mg/l) for zone 3. The blue line indicates the minimum dissolved oxygen standard of 5 ppm.



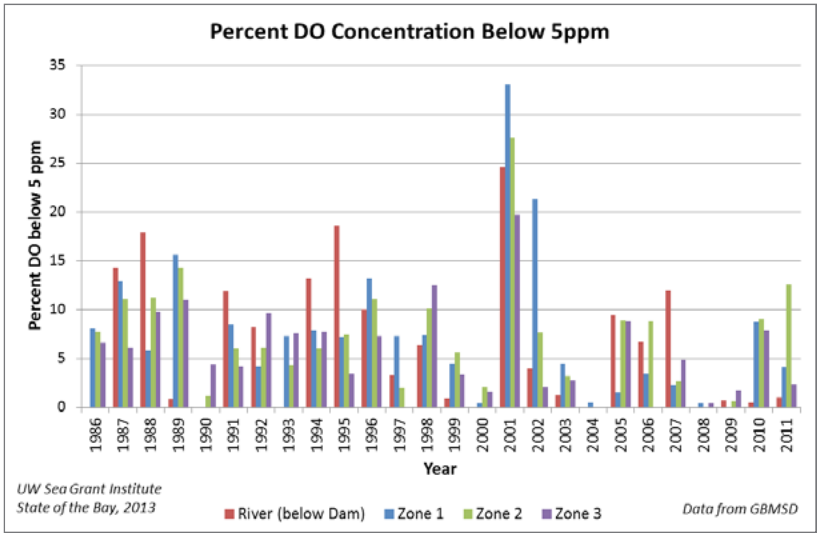


Figure 31: Percent dissolved oxygen concentrations that are below 5 ppm by zone and year.

Such an event apparently occurred in August 2005. Mr. Paul Peeters, Wisconsin Department of Natural Resources (WDNR), responded to a call reporting hundreds of thousands of dead and dying small fish lying on the shore near Bayshore County Park. Once on the scene, he discovered tens of thousands of little fish lethargically hanging around. They were 99% round gobies. From the eyewitnesses account, earlier in the day this went on along the shoreline for a great distance and the fish were actually trying to come up out of the water. Peeters measured the DO at 3 ppm and the temperature at 61.1 degrees F, both much lower than what would be expected for this region at this time of year. Peeters speculated that, "sometime overnight, for whatever reason, we had a cold upwelling of cold anoxic water in this immediate area. The cold anoxic water traveling along the bottom actually herded the bottom-dwelling gobies right to shore and pinned them there."

Previous work has documented distinct water mass movements in central Green Bay, which are likely influenced by large intrusions of lake water. Evidence of cold oxygen deficient water masses (hypolimnetic intrusion) apparently moving from the northern extents to the southern bay and even penetrating into the Fox River was documented by Kennedy in 1986, via *in situ* vertical profile data from the lower bay (Kennedy et al. 1987). An even more dramatic intrusion was documented in 1988 by continuous monitors in Green Bay and the Fox River and by *in situ* vertical profiles (Kennedy et al. 1987). The continuous monitors show a distinct influx of cold, nearly anoxic water in the lower water column. Temperature plots clearly show the southward migration of the water mass. Characteristics of this water mass included temperature <10 degree C, DO <2 mg/l, and conductivity of 200-240 umhos/cm (Kennedy et al. 1987).

The large variation in oxygen levels likely reflects the cumulative effects of upstream organic waste and algal production, sediment oxygen uptake, and bay water interactions. So while the general oxygen picture looks good, available data reveal it can be marginal at times. Once again, high phosphorus loads and excess algae production contribute to these occasional problems. A major study is now under way examining hypoxia (DO <2 ppm) in Green Bay.

With a history of excessive nutrient inputs and hypereutrophication, the waters of southern Green Bay have experienced recurring summertime hypoxia for decades. A multidisciplinary, collaborative project is being undertaken to quantify the interactions among oxygen biogeochemistry, organic carbon cycles,

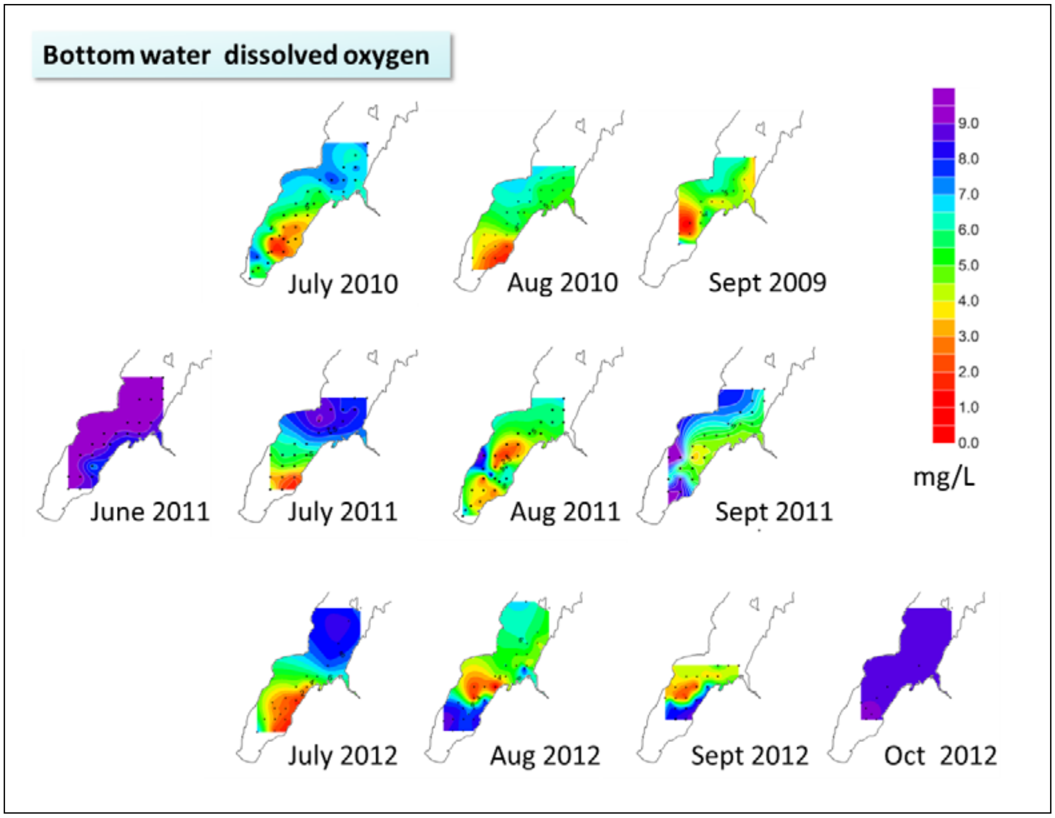


Figure 32: Bottom water dissolved oxygen in Green Bay, 2010-2012. From, "Drivers of Seasonal Hypoxia in Green Bay, Lake Michigan," Klump et al. (a presentation to the Association for the Sciences of Limnology and Oceanography (ASLO) 2013).

hydrodynamics, and nutrient loading. The areal extent of hypoxia varies, but stations in the southern portion of the bay experience concentrations < 2 mg/L over 50% of the stratified period (Figure 32). The onset and duration of hypoxia is driven by the interactions among sediment oxygen demand, thermal stratification, and cool Lake Michigan bottom water intrusions. Water mass mixing and stratification are driven largely by the wind shear and the prevailing wind field conditions. These appear to have shifted basin-wide in the last two decades altering circulation and increasing particle trapping and retention in the bay. This has the potential to impact hypoxia both by increasing the rapid deposition of labile organic matter and increasing rates of sediment oxygen demand, and by altering the water mass mixing, changing thermal stratification and bottom water temperatures by up to 10°C (Klump et al. 2013).

Temperature

Mean water temperatures in the bay are highest in July and August and in the river stations (Figure 33). The maximum water temperatures are important because of the relationship between temperature and dissolved oxygen and their effects on metabolic processes. Colder water can hold more dissolved oxygen than warmer water. As water becomes warmer, the amount of dissolved oxygen it can hold decreases. Therefore, during the summer months, when the water temperature is warmer, temperature may limit the total amount of oxygen present.

An examination of mean water temperatures (June-September) over the period of 1986-2011 reveals no obvious changes during that period (Figure 34). An analysis of maximum water temperature over the same period also reveals no changes.

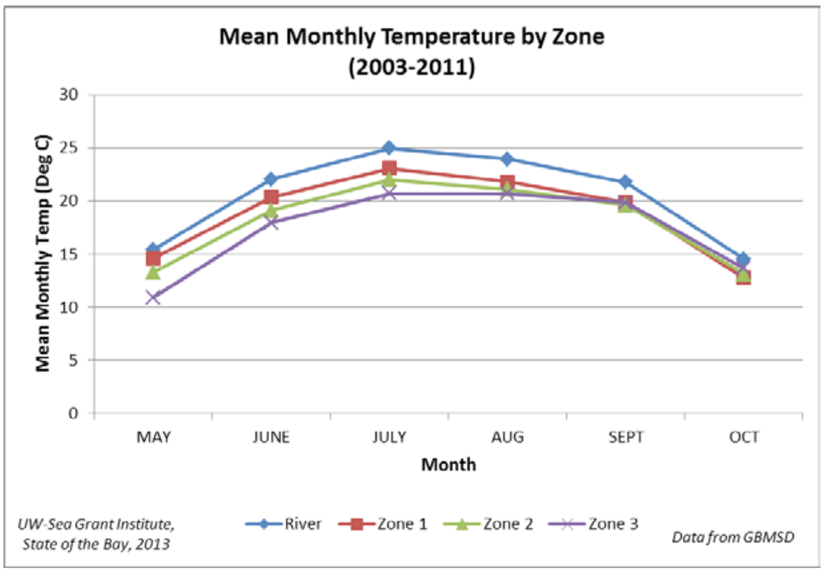


Figure 33: Mean monthly temperatures by zone.

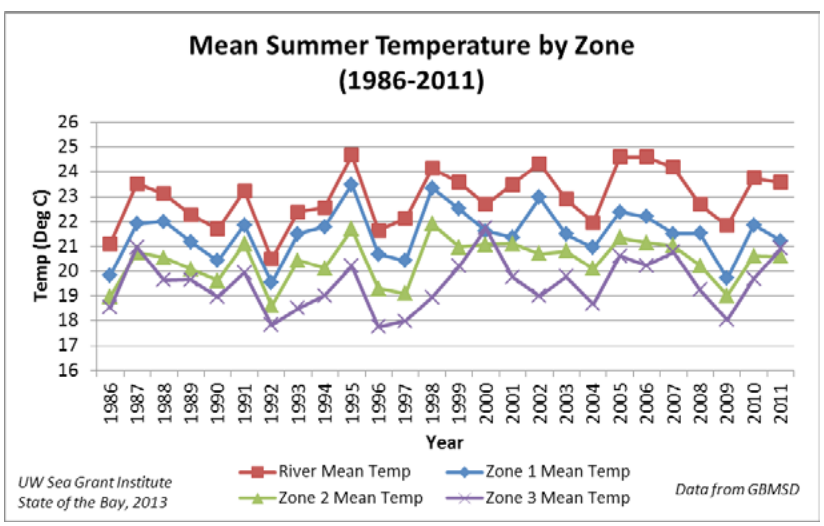


Figure 34: Mean summer water temperature by zone.

While there has been no apparent change in temperature for the data sets representing the lower portion of Green Bay, this may not be true for mid and upper bay waters as reflected by the number of days of 90% ice cover (Figure 35). The data set was developed by the Great Lakes Environmental Research Laboratory from satellite imagery of ice cover on mid and Upper Green Bay. This analysis reveals a significant decline (five days per decade) in the number of days of 90% ice cover, which implies warming conditions of the waters of the mid and upper bay.

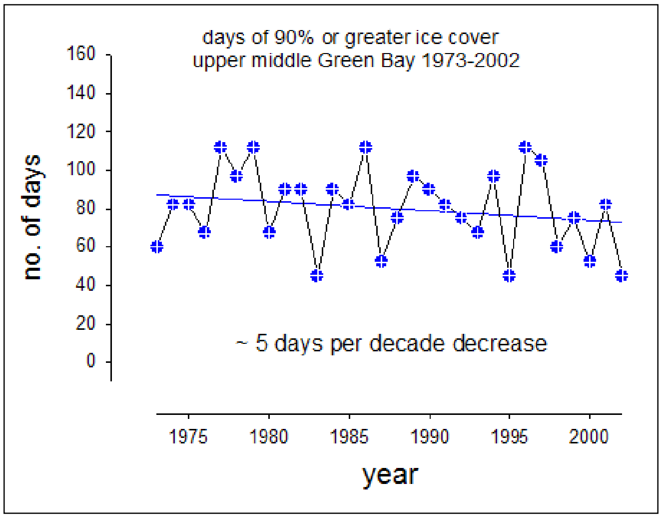


Figure 35: Days of 90% or greater ice cover in Upper Middle Green Bay. Data from GLERL

The apparent contradiction between the temperature data set collected from 1986-2011 and the ice duration data may reflect the difference in the methods used to detect temperature changes and/or seasonal or regional differences. Consistent with ice cover for Mid and Upper Green Bay, Lake Superior has experienced a 70% loss in ice cover over the last 40 years, and in 2012, Lake Superior had the highest surface water temperature ever recorded (71° F) (Superior Watershed Partnership, 2013). The implication for climate change in the Great Lakes is a significant issue.

Climate Change Impacts on Water Quality

Over the next 100 years, climate change will have significant impacts in the Great Lakes Region of North America. Long-term predictions for the Great Lakes include both warmer and wetter conditions, with mean summer temperatures in Wisconsin increasing by 4.7° – 6.5° F by the middle of the 21st century and an increase in precipitation during winter and spring months. In addition to warmer and wetter conditions, scientists expect an increase in the frequency of heavy rainfall events. By mid-century the probability of an April rainfall event larger than one inch in Green Bay is predicted to be 0.523. This is 12% higher than the current probability. By the end of the century, the probability of exceeding the one-inch rainfall threshold is 0.613 (WICCI, 2011).

Based on previous experience, the Green Bay working group of the Wisconsin initiative on Climate Change Impacts (WICCI) assessed the potential consequences of climate change by evaluating the risk posed to the Green Bay ecosystem from regional shifts in temperature, precipitation, and storm events.

Climate experts agree that runoff is the most significant impact associated with climate change. Consequently, further effort to quantify the magnitude of runoff under climate change conditions is warranted. Evidence to-date reveals that nutrient and suspended solids loading to tributaries and the bay is event-driven. A significant change in future climate will likely affect the amount and timing of TP and TSS flux into Green Bay. Scientists from the University of Wisconsin-Milwaukee and the University of Wisconsin-Green Bay are collaborating with WICCI in a project funded by the National Oceanic and Atmospheric Administration to use downscaled climate data generated by the Climate Working Group in a computer runoff model (the Soil and Water Assessment Tool) to predict the impacts of climate change on TP and TSS inputs to Lower Green Bay. The overall goal is to evaluate and develop methods to address the effect of climate change on phosphorus runoff and TSS inputs to Lower Green Bay as well as changes in runoff.

References

The Cadmus Group (Cadmus). 2012. *Total Maximum Daily Load and Watershed Management Plan for Total Phosphorus and Total Suspended Solids in the Lower Fox River Basin and Lower Green Bay*. March 2012. Prepared for Wisconsin Department of Natural Resources (WDNR), U.S. EPA, WDNR and Oneida Tribe of Indians of Wisconsin. http://dnr.wi.gov/water/projectdetail.aspx?key=16084305

Grayczyk, D.J., D.M. Robertson, P.D. Baumgart, P.D., and K.J. Fermanich, K.J. 2012. *Hydrology, Phosphorus, and Suspended Solids in Five Agricultural Streams in the Lower Fox River and Green Bay Watersheds, Wisconsin, Water Years 2004–06: U.S. Geological Survey Scientific Investigations* Report 2011–5111, 28 pp.

Kennedy, J.A., P.E. Sager, and S. Weber. 1987. *Evidence of a Hypolimnetic Intrusion in Southern Green Bay, Lake Michigan*. International Association for Great Lakes Research, Michigan. Oral Presentation.

Klump, V.J. et al. 2013. *Drivers in Seasonal Hypoxia in Green Bay, Lake Michigan*. Association for the Sciences of Limnology and Oceanography (ASLO). Poster Presentation

McAllister, L.S. 1991. *Factors Influencing the Distribution of Submerged Macrophytes in Green Bay, Lake Michigan: A Focus on Light Attenuation and Vallisneria americana*. M.S. Thesis. University of Wisconsin-Green Bay.

McLaughlin, D.B. and H.J. Harris. 1990. Aquatic Insects Emergence in Two Great Lakes Marshes. *Wetlands Ecology and Management*. 1(2): 111-121.

Qualls, T.M. 2003. *Analysis of the Impacts of the Zebra Mussel, Dreissena polymorpha, on Nutrients, Water Clarity, and the Chlorophyll-Phosphorus Relationship in Lower Green Bay, Lake Michigan*. M.S. Thesis. University of Wisconsin-Green Bay. 104 pp.

Sager, P.E. and S. Richman. 1991. Functional Interaction of Phytoplankton and Zooplankton Along the Trophic Gradient in Green Bay, Lake Michigan. *Can. J. Fish. Aquat. Sci.* 48: 116-122.

Sager, P.E. and S. Richman. 1990. Patterns of Phytoplankton-Zooplankton Interactions Along a Trophic Gradient in Green Bay: I. Production and Utilization. *Verh. Internat. Verhein. Limnol.* 24: 393-396.

Scheberle, D., H.J. Harris, M, Finney, J. Potter, S. Oldenburg, and P. Dessart. 2005. *Toward a Total Maximum Daily Load (TMDL) for Phosphorus and Suspended Solids: The Lower Fox River Basin and Green Bay Area of Concern*. University of Wisconsin Green Bay Archives.

Schneider, P. and P.E. Sager. 2001. Structure and Ordination of Epiphytic Invertebrate Communities in Four Coastal Wetlands in Green Bay, Lake Michigan. *J. Great Lakes Res.* 33(2): 342-357

.

Smith, D.L. and J.J. Magnuson. 1990. Biomass Size Structure and Energy Transfer Efficiency Across the Productivity Gradient in a Freshwater Estuary – Green Bay, Lake Michigan. *Verh. Internat. Verhein. Limnol.* 24: 406-410.

Smith, V.H. 1983. Low Nitrogen to Phosphorus Ratios Favor Dominance by Blue Green Algae in Lake Phytoplankton. *Science* 221: 669-671.

Superior Watershed Partnership. 2013. *Lake Superior Climate Adaptation, Mitigation and Implementation Plan.*

Trimbee A.M. and E.E. Prepas. 1987. Evaluation of Total Phosphorus as a Predictor of the Relative Biomass of Blue-green Algae with Emphasis on Alberta Lakes. *Can. J. Fish Aquati.Sci.* 44:1387-1342.

U.S. Army Corps of Engineers. 2011. *Annual Report/Contract Dredging Report*, Detroit District, Operations Office.
http://www.lre.usace.army.mil/who/operationsofficehomepage/dredginginformation/dredginginformation-inwisconsin/ (Accessed 2/21/2013).

Waples J.T. and J.V. Klump. 2002. Biophysical Effects of a Decadal Shift in Summer Wind Direction over the Laurentian Great Lakes. *Geophysical Research Letters*. 29 (8): 43-1-43-4.

WDNR. 1993. *Lower Green Bay Remedial Action Plan Update*. Wisconsin Department of Natural Resources. Madison, WI. 152 pp.

Wisconsin Initiative on Climate Change Impacts. 2011. *Wisconsin's Changing Climate: Impacts and Adaptation*. Nelson Institute for Environmental Studies, University of Wisconsin-Madison and the Wisconsin Department of Natural Resources, Madison, Wisconsin.

Links

Trophic State of the Great Lakes:
http://www.epa.gov/glnpo/glindicators/water/trophicb.html

Information on Clean Water Act:
http://www2.epa.gov/laws-regulations/summary-clean-water-act

Information on Lower Green Bay and Fox River Area of Concern
http://dnr.wi.gov/topic/greatlakes/greenbay.html

Information of Blue-Green Algae in Wisconsin Waters:
http://dnr.wi.gov/lakes/bluegreenalgae

DRINKING WATER

Status: Poor

Trend: Unchanging

Status is rated as poor because waters of the AOC are deemed unsuitable as a source of drinking water.

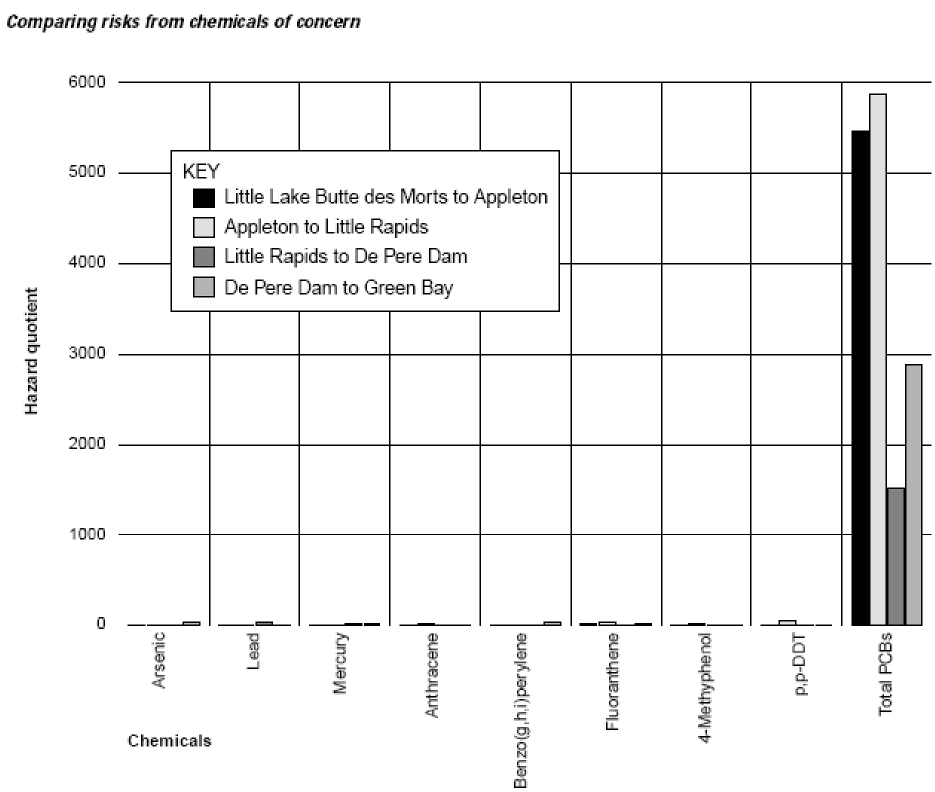
The city of Marinette (population 11,000) is the only city in Wisconsin that gets its drinking water from Green Bay. No communities use water from within the AOC as a source of drinking water. The 1996 amendments to the Safe Drinking Water Act required states to complete source water assessments for all public drinking water systems. The purpose of the assessments is to determine how susceptible public drinking water systems are to contamination. The WDNR completed a source water assessment for the City of Marinette in 2003.

Information on water quality, contaminant and monitoring violations, and potential health effects created by any violations is available in the Consumer Confidence Report (CCR). The CCR for Marinette Waterworks is available on the WNDR website: http://dnr.wi.gov/topic/DrinkingWater/CCR.html#accessing.

As of 2012, there were no MCL (Maximum Contaminant Level) violations. MCLs define the highest level of a contaminant allowed in drinking water. However, even though there were no violations, several contaminants were detected. In addition, in 2002 the Marinette Water Utility replaced all of the filter media in all of the filter beds, including the filter sand and carbon overlay used to control taste and odor.

SYSTEM CONTAMINANTS

Several contaminants have been identified as chemicals of potential concern (COPC) in the Lower Fox River and Green Bay. These chemicals include Polychlorinated biphenyls (PCBs), several types of dioxins, DDT and its metabolites (DDD and DDE), dieldrin, arsenic, lead, and mercury. Of all the chemicals in the Lower Fox River, a risk assessment determined that PCBs in the sediment pose by far the greatest threat to human health and wildlife (WDNR 1999) (Figure 36).



Calculated risk from PCB-contaminated river sediments is approximately 100 times higher than from any other chemical pollutant found in the Lower Fox River. Hazard quotient is the ratio of measured PCBs to the concentration at which PCBs are toxic in the environment.

Figure 36: Relative risk comparison for several contaminants of concern in the Fox River. Figure from Draft Studies Completed on Cleanup of PCBs in Lower Fox River Sediments, WDNR, 1999.

PCBs and other Organochlorine Contaminants

Status: Poor

Trend: Improving

Fish contamination remains unacceptable for some species and sizes. Areas of completed remediation show marked improvement.

BACKGROUND

PCBs are the toxic substance of greatest concern in Green Bay and the Fox River. PCBs are chemical compounds that were used in commercial and industrial applications. From 1954-1971, paper mills in the Lower Fox Valley manufactured and recycled carbonless copy paper containing PCBs. The Fox River-Green Bay system was contaminated with an estimated 110,000 pounds of PCBs, with approximately 80-85% of this amount in the Fox River (UW Sea Grant Institute).

PCBs are a persistent toxic substance, which means they remain in the environment for a long time. The level of PCBs measured in the Fox River during 1994 and 1995 reached 70 ng/l (ppt) (EPA 2004). This level is 500 to 600 times the Wisconsin Water Quality standard to protect wildlife (0.12 ng/l). In addition, PCBs bioaccumulate in organisms and biomagnify (increase in potency) as they are passed up the food chain. So they may negatively affect fish and wildlife at the top of the food chain.

The Green Bay Mass Balance Study (GBMBS) conducted in 1989-1990, produced the first complete large-scale model of the sources, movement, and fate of PCBs in an aquatic ecosystem (EPA 1992). Based on the GBMBS, scientists estimated the total amount of PCBs in the Fox River sediments to be 93,500 pounds, which is about five times greater than the amount in sediments in the bay at the time (UW Sea Grant Institute). In addition, scientists created a map of PCB deposits in Green Bay, which showed that the Fox River was essentially the only significant source of PCBs (UW Sea Grant Institute).

ECOLOGICAL EFFECTS

PCBs can have toxic impacts on benthic invertebrates, fish, amphibians, birds, and mammals and can impair reproductive success.

Studies have shown significant effects on some amphibians, fish, and birds. One study of leopard frog (*Rana pipiens*) eggs in Green Bay and the Fox River during 1995 concluded that there were significantly more spinal deformities in frogs from PCB-contaminated eggs than from uncontaminated eggs (Kersten 1997).

A study measuring PCBs in young-of-the-year fish at sites in lower, middle, and Upper Green Bay found that PCB concentrations exceeded the International Joint Commission Aquatic Life Guidelines of 100 ng/g (ppb) in all of the lower bay samples, in five of the nine middle bay samples, and in one upper bay sample (Brazner and DeVita 1998). The level of PCBs (approximately 500 ng/g wet weight) in the young-of-the-year fish may have effects on organisms higher in the food chain since young forage fish are a food source of several species of waterbirds and predator fish (Brazner and DeVita 1998). Consequently, fish-eating birds such as the Forster's tern and double-crested cormorant are vulnerable to contamination.

BUD HARRIS

Paper mills along the Fox River

Studies conducted on Forster's terns nesting in 1983 and 1988 found that the bird's reproductive success was significantly impaired by PCBs in 1983, but less so in 1988 (Kubiak et al. 1989; Harris et al. 1993). The median PCB concentration in eggs from the earlier study was 22.2 ug/g while the median level in eggs from the later study was 7.3ug/g. The 1988 study suggested that the apparent reduced impact in 1988 was related to lower PCB concentrations in the eggs and much reduced river flows (Harris et al. 1993). There have been no further studies on the Forster's tern since 1988.

Field studies on cormorants were conducted in 1994 and 1995 (Custer et al. 1999). Nesting success was measured at Cat Island. Of 1,570 eggs laid, 32% did not hatch and 0.4% had deformed embryos. The mean PCB concentration of sample eggs from clutches with deformed embryos and dead embryos did not differ from nests where all eggs hatched (12.1 ug/g). A logistic regression of hatching success identified DDE and not dieldrin or PCBs as a significant risk factor. Five other organochlorine contaminants (hepachlor epoxide, oxychlorodane cis-nanochlor, Mirex, hexochlorobenzene) were not at levels to be considered a risk.

Fish-eating birds (such as the Forster's Tern and cormorant) have higher levels of PCBs in their eggs and chicks than insect-eating birds (such as the Yellow-headed Blackbird, Red-winged Blackbird, Tree Swallow and Marsh Wren). The level of PCBs found in the eggs and young of tree swallows (2-4 ppm) are an order of magnitude higher than the level found in Red-winged and Yellow-headed Blackbirds (Ankley et al. 1993; Rattray 1997). This is likely due to the source of insects eaten by the birds. Tree Swallows forage on insects emerging from the river or bay sediments, and Yellow-headed Blackbirds forage on insects emerging in sediments from coastal marshes.

A study conducted in the summers of 1995 and 1996 in Green Bay found low levels (20 to 502 ng/g (ppb)) of PCB contamination in Yellow-headed Blackbird eggs and chicks (Rattray 1997). No obvious impairments or deformities were observed. However, at two of the sites in 1996, there was an unbalanced sex ratio of approximately three female chicks to each male chick. PCBs and other contaminants may potentially disrupt normal sexual development. PCBs may not have detrimental effects on all bird species in the Lower Fox River-Green Bay area because of different exposure routes.

The importance of prey and contaminant sources are clearly delineated in a 1994/1995 study of Tree Swallows nesting in Green Bay and a contaminated area of the Fox River compared to a clean reference site (Custer et al. 1998). Eggs and newly hatched young at the contaminated sited had a mean PCB level of 3.01 ug/g. Reference site young emerging from eggs and nestlings had a mean level of 0.26 ug/g PCB. There was no difference in reproductive success as measured by hatching success between contaminated and reference sites.

A study of Marsh Wrens nesting in two marshes in Lower Green Bay in 1992 and 1993 revealed how PCBs move from sediments to emergent aquatic insects to marsh wren eggs and young (Palmer 2005). The Marsh Wren egg PCB levels found in this study were one order of magnitude higher than the emergent aquatic insects upon which they fed. In a comparison of the mean aquatic emergent insect PCB concentration to the mean marsh wren PCB concentration, the calculated bioaccumulation factor was 12.0. This is a clear indication that as the PCBs move up the food chain from the aquatic emergent insects to the Marsh Wren, the chemical is biomagnified (Figure 37).

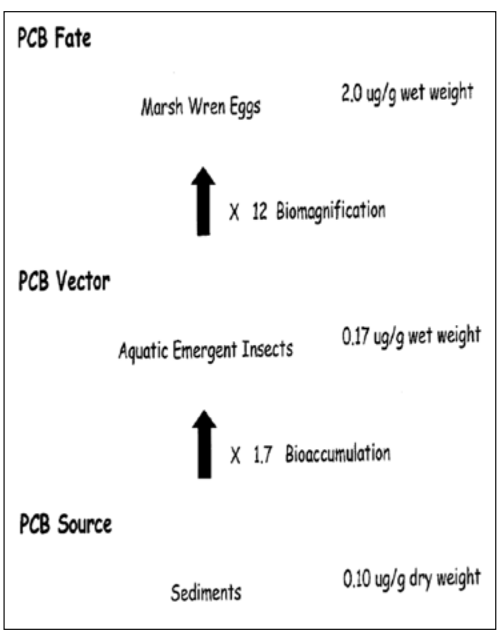


Figure 37: PCB food chain model for Peters Marsh (PCB values are means). Figure from Palmer 2005.

HUMAN HEALTH EFFECTS

PCBs are a human health concern. They are a probable human carcinogen (cancer-causing agent) and can affect reproductive function and the immune system. In addition, infants and children of women who have frequently eaten contaminated fish may have lower birth weights and developmental problems. Once PCBs are consumed, they are deposited in body fat and can accumulate in the body over time.

Consumption of fish produces the greatest risk of PCB exposure for humans. Fish absorb PCBs primarily from food sources but also from sediments suspended in the water. The amount of PCBs in fish varies depending on species, age, size, fat content, and diet (Figure 38). In pooled data covering the years 1984-2004, in walleyes less than 21 inches collected in the Fox River below the De Pere dam, PCB concentrations are decreasing (Figure 39; $r2=0.172$, $p<0.0001$). Although it is encouraging to see decreasing concentrations of PCBs over time, the fact remains that there is considerable variation among fish (Figure 38). WDNR fish advisories take this into account by suggesting limitations on intake related to species and size of the fish (Table 6).

Figure 38: Mean PCB concentrations in several fish species in the Fox River and Green Bay. Error bars represent one standard deviation. Data from Baseline Monitoring Data Report, 2009 (submitted to the WDNR).

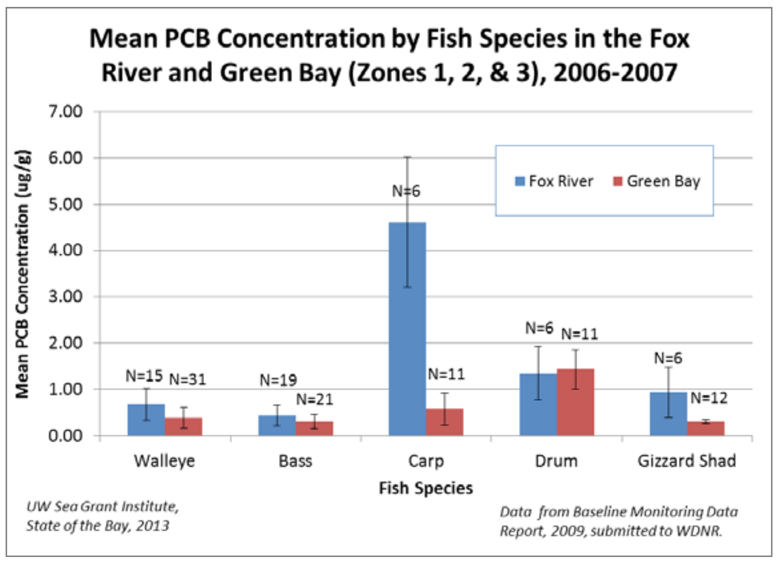


Figure 39: PCB concentrations in walleye less than 21 inches at the Fox River below the De Pere dam. Data provided by Candy Shrank, WDNR and from Baseline Monitoring Report, 2009 (submitted to the WDNR).

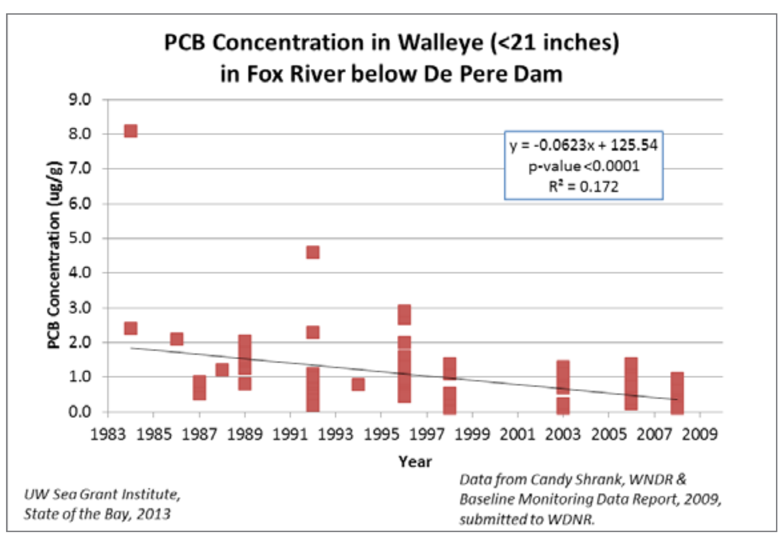


Table 6: Fish consumption guidelines for Area of Concern.

Waterbody/ Species	Unrestricted	No more than 1 meal a week	No more than 1 meal a month	No more than 1 meal every 2 months (6 meals/ year)	Do Not Eat
Fox River from De Pere Dam downstream to mouth					
Bigmouth Buffalo					All sizes
Black Crappie			All sizes		
Bluegill			All sizes		
Carp					All sizes
Channel Catfish					All sizes
Lake Whitefish			All sizes		
Northern Pike			Less than 33''	Larger than 33''	
Rock Bass			All sizes		
Sheepshead			Less than 19''	19-23''	Larger than 23''
Smallmouth Bass			All sizes		
Walleye			Less than 21''	21-25''	Larger than 25''
White Bass					All sizes
White Perch				All sizes	
White Sucker			All sizes		
Yellow Perch			All sizes		
Green Bay south of Marinette and its tributaries (except the Lower Fox) including the Menominee, Oconto, and Peshtigo Rivers from their mouth up to the first dam					
Brown Trout			Less than 28''		Larger than 28''
Burbot		All sizes			
Carp					All sizes
Channel Catfish				All sizes	
Chinook Salmon			Less than 30''	Larger than 30''	
Lake Whitefish			All sizes		
Musky				Larger than 50''	
Northern Pike			All sizes		
Rainbow Trout			All sizes		
Sheepshead			All sizes		
Smallmouth Bass		Less than 17''	Larger than 17''		
Sturgeon					All sizes
Walleye			All sizes		
White Bass					All sizes
White Perch				All sizes	
White Sucker		All sizes			
Yellow Perch		All sizes			

Source: Choose Wisely: A Health Guide for Eating Fish in Wisconsin. WDNR 2012.

Mercury

Status: Fair

Trend: Undetermined

While total mercury concentrations are high, methyl mercury concentration are relatively low, resulting in lower bioaccumulation factors.

BACKGROUND

Mercury is a contaminant of concern worldwide; Wisconsin is no exception. Mercury is an element that occurs naturally in the environment and is also released through human activity (anthropogenic sources). Natural sources of mercury include volatization from soils and rocks, volcanic activity, vaporization from aquatic systems, and biological activity (National Academy of Sciences 1978). Atmospheric anthropogenic sources of mercury include coal-fired power plant emissions, cinnabar mining, and other industrial processes. Sources of inorganic mercury to aquatic ecosystems include atmospheric deposition and industrial and municipal effluents.

Mercury exists in both inorganic and organic forms, and its chemistry in the environment is complex. The organic form, methylmercury, has the greatest significance in aquatic ecosystems because it is more toxic than inorganic forms, is soluble and mobile, enters aquatic food chains quickly, and biomagnifies in aquatic ecosystems.

The methylmercury content in atmospheric deposition is quite low, only 1-2% of the total amount deposited (Hurley 1995), while the level in fish tissues is high. It is known that inorganic mercury is biotransformed in aquatic environments to methylmercury, a process called methylation. Methylation is the result of microbial activity of anaerobic sulfur-reducing bacteria and aerobic bacteria and fungi that thrive in acidic conditions. The capacity of aquatic ecosystems to produce methylmercury is directly related to various physical and biological conditions. These include amount of CO2 production, pH, redox potential, humic acid content, organic carbon content, temperature, relation with other elements, and concentration of inorganic mercury present. Consequently, the risk associated with mercury toxicity is not going to be the same in all aquatic ecosystems. However, once mercury enters rivers and lakes it accumulates up the food chain; therefore, large predator fish can contain high amounts of mercury, over 85% methylmercury.

WHAT IS KNOWN ABOUT MERCURY IN THE GREEN BAY ECOSYSTEM?

Redman (1993) consolidated information from a number of studies of mercury contamination in Fox River and Green Bay sediments. This information has been summarized by Wenzel (1996) (Table 7).

Table 7: Studies showing mercury sediment concentrations of the Fox River and Lower Green Bay.

Site	Location	Hg Conc., (mg/kg, dry wt.)	Source
Above the De Pere Dam	Kaukauna Dam	3.3	Konrad 1971
	De Pere Dam	3.6	Konrad 1971
	Fox River	0.05-3.48	Pezzetta and Iskandar 1975
Below the De Pere Dam to the Mouth of Green Bay	Mason St. Bridge	2.5	Konrad, 1971
	Below De Pere Dam	7.4	Redman 1993
	Fort Howard	6.2	Redman 1993
	Dousman St. Bridge	3.6	Redman 1993
	Between East River and Mouth of Bay	3.48	Redman 1993
Lower Green Bay	400 yards NE off Red Bank	0.25	Konrad 1971
	Lower Green Bay	0.03-2.72	Pezzetta and Iskandar 1975
	Lower Green Bay	<0.2-2.0	Redman 1993

Table adapted from Wenzel 1996.

Because analytical methods have improved since 1990, earlier values may not be comparable. Even so, the data reveal that sediments in the Fox River contain elevated levels of mercury. It is likely that mercury loading associated with sediments in the Lower Fox River and Green Bay are the result of contributions from numerous sources. Those sources include industrial discharges, atmospheric deposition, municipal effluent discharges, and nonpoint source pollution associated with stormwater runoff (Hill, personal communication).

In 1994 and 1995, sediment samples were collected from Lake Michigan and Green Bay for the purpose of developing a contaminant Mass Balance for Lake Michigan (EPA 2004). Mercury concentrations in Fox River sediments (2-7 mg/kg) are at least an order of magnitude higher than sediments for Lake Michigan (0.002-0.260 mg/kg) (EPA 2004). This suggests the primary source of mercury to Green Bay is contaminated Fox River sediments. This conclusion is supported by data for total and dissolved mercury concentrations in Lake Michigan tributaries (Figure 40). The mean total mercury concentration for the Fox River was 28.9 ng/l, the highest for any tributary (EPA 2004), and the particulate fraction (total minus dissolved) was very large. Interestingly, the Fox River did not have the highest methylmercury concentration (Figure 41). Several other tributaries had higher methylmercury concentrations, particularly in the dissolved phase. These results suggest that conditions promoting methylation are not as favorable in the Fox River as they are in some other tributaries. A team of scientists studied the transport and partitioning of mercury in the Fox River from April 1994 to October 1995 (Hurley et al. 1998). Unfiltered mercury concentration in the Fox River during the study period ranged from 1.8 to 182 ng/l, with a median concentration of 24.8 ng/l, predominantly (93.6%) in the particulate phase. Transect sampling reveal progressively increasing water column mercury concentrations and mercury particulate enrichment downstream, which were consistent with trends in sediment levels in the river. Resuspended sediments are likely the predominant source of mercury from the Fox River into Green Bay. Despite elevated total mercury concentrations, methylmercury concentrations were relatively low, suggesting limited bioavailability of mercury associated with sediments.

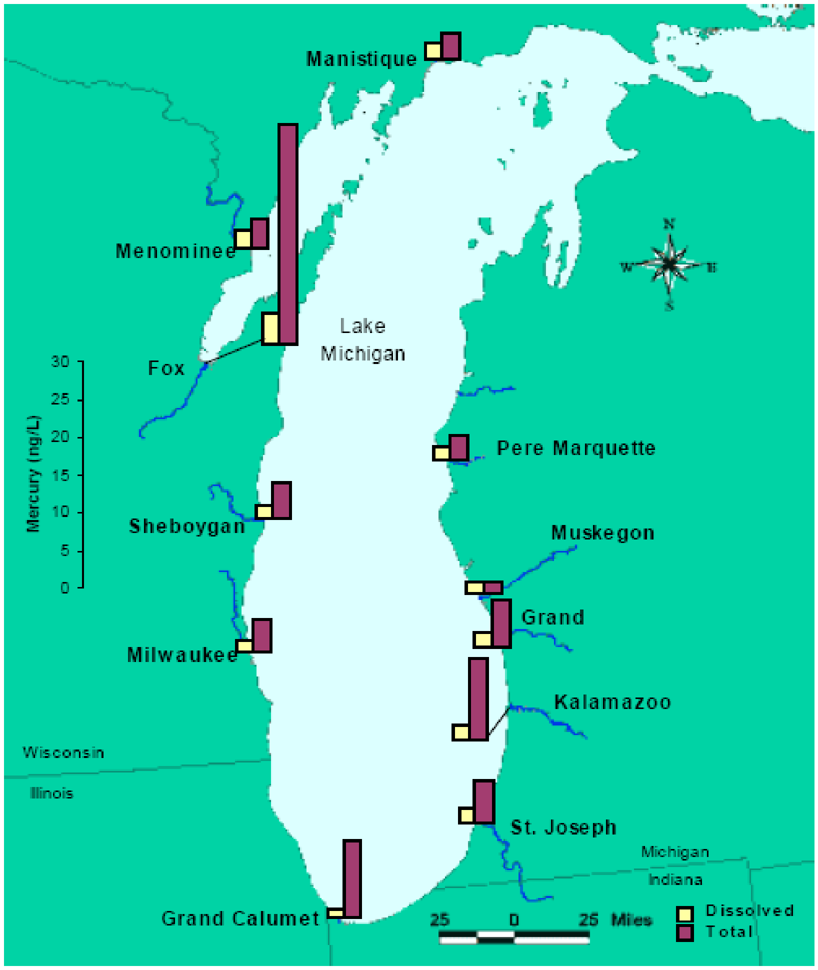


Figure 40: Mean total and dissolved mercury concentrations measured in Lake Michigan tributaries (map from the EPA 2004).

We might expect that the highest total mercury concentrations in the Fox River would lead to the highest concentrations of mercury in the open water column of Green Bay compared with the rest of Lake Michigan. This apparently is not the case, with several stations from Lake Michigan equaling or exceeding the total mercury concentration of Green Bay. However, the highest mean particulate mercury value (0.017 ng/l) was in Green Bay (EPA 2004). While particulate mercury concentrations were slightly higher in Green Bay than other sampling sites, there were no significant differences among sites in particulate mercury concentrations, based on a one-way analysis of variance (ANOVA) model using log-transformed results (p=0.1685).

In a separate study on mercury in surface-layer sediments of Green Bay collected from 74 different sites in 1987 and 1990, the surface sediments had a mean mercury concentration of 0.36 mg/kg (Rossmann and Edgington, 2000). The sediment mercury concentrations were highest along the eastern shore between the cities of Green Bay and Sturgeon Bay. The authors concluded the Fox River is the dominant contributor of mercury to Green Bay and the majority of the total mercury load to the bay is delivered by tributary rivers and not the atmosphere.

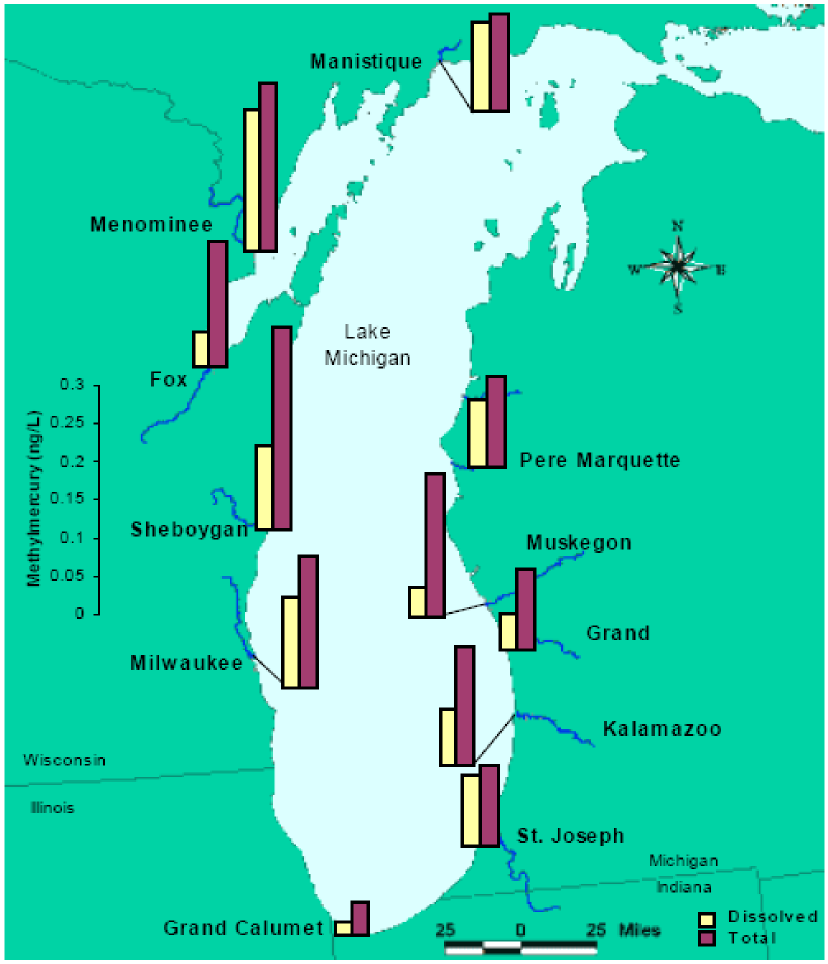


Figure 41: Mean total and dissolved methylmercury concentrations measured in Lake Michigan tributaries (map from the EPA 2004).

ECOLOGICAL EFFECTS

The high level of total mercury in the sediments of the Fox River exceeds the Ontario Sediment Quality Guidelines for "lowest effect level" (0.2 ug/g (ppm)) by 10 to 35 times (Figure 42). The concentration of total mercury in Fox River water exceeds the Wisconsin Water Quality Standard (2ng/l (ppt)) by 14 times. How do these levels in the river influence levels in sediments and organisms in the bay?

Total mercury levels in Lower Green Bay marsh sediments have been measured at 41 to 155 ng/g (ppb) (Wenzel 1996). Emergent insects captured from these marshes had total mercury concentrations ranging from 32 to 138 ng/g (ppb), which is no higher than in the sediments (Figure 42). Forage fish collected in proximity to Lower Green Bay marshes (Brazner and DeVita 1998) had levels no higher than those found in the emergent insects. Consequently, the bioaccumulation factor from sediments to forage fish is very low (0 to less than 1). Somewhat more expected is the level of total mercury found in walleye less than 16 inches (0.074 ug/g (ppm)) captured from the Fox River below the De Pere dam from 1984 to 1998 (Figure 42). The bioaccumulation factor for this group of fish based on mercury concentrations in Fox River water is 2.5 x 102. For walleye greater than 16 inches, the bioaccumulation factor is 1.4 x 103. One reason for these relatively low bioaccumulation factors may be the high acid neutralizing capacity of

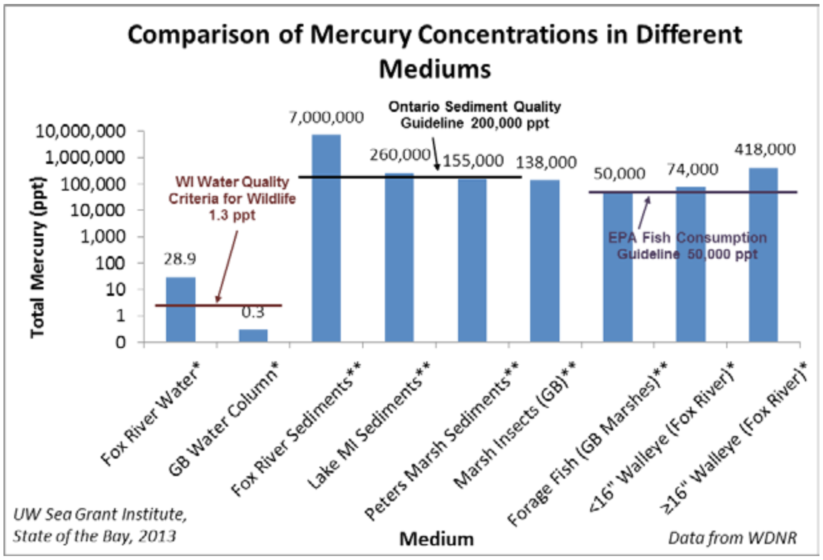


Figure 42: Mercury concentrations found in different mediums. Mercury concentration data for Fox River Water, Fox River sediments, and Lake Michigan sediments from Lake Michigan Mass Balance. Mercury concentration data for Peters Marsh sediments and marsh insects in Lower Green Bay marshes from Wenzel 1996. Mercury concentration data for Green Bay water column from Green Bay Mass Balance. Mercury concentration data for forage fish for Lower Green Bay marshes from Brazner and De Vita 1998. Mercury concentration data for walleye found in Fox River below De Pere dam from Candy Shrank, WDNR.

*Mercury concentrations are reported as mean values.

**Mercury concentrations are reported as highest measured value.

the water in this portion of the river and bay (Lathrop et al. 1991). Even so, the levels of mercury found in the biota and fish constitute a health risk—if not to the fish themselves (EPA 1997) then certainly to organisms higher on the food chain.

HUMAN HEALTH EFFECTS

Mercury is a human health concern, and contaminated fish are the main source of mercury in human diets. Studies have found that low levels of mercury can affect the nervous system of developing fetuses. In adults, low levels of mercury can affect the cardiovascular and immune systems. High levels of mercury can affect the human nervous system causing numbness, slurred speech, loss of coordination, and vision problems. Mercury accumulates in the muscle of fish, rather than in the fat like PCBs. Also, unlike PCBs, mercury can be slowly eliminated from your body over time. Fish advisories for the Fox River are based on PCBs, not mercury. Even though mercury is present in most Wisconsin fish, PCBs in the Fox River and Green Bay at this time pose a greater health risk.

Atrazine
Status: Fair
Trend: Undetermined

Atrazine is a commonly used herbicide in the United States that controls broadleaf weeds on corn and sorghum fields. It is estimated that atrazine is the most heavily used herbicide in the United States and approximately 64-75 million pounds of it are applied each year in the U.S. (EPA 2001).

Atrazine can enter surface waters through runoff, spray drift, discharge of contaminated groundwater to surface water, or atmospheric deposition in precipitation, vapor, or particulate phases. For human health protection, the EPA has set a maximum contaminant level of 3ug/l in drinking water. To protect aquatic life, the EPA has set draft ambient aquatic life criteria of 350 ug/l for protection from acute toxicity and 12 ug/l for protection from chronic effects. However, a recent study found that atrazine may cause reproductive abnormalities in amphibians at doses as low as 0.1 ug/l (Hayes et al. 2002).

The Lake Michigan Mass Balance (LMMB) study measured atrazine and its metabolites in atmospheric, tributaries, and open water column samples collected from 1994-1995. Samples were collected from 11 tributaries including the Fox and Menominee Rivers. Looking at atrazine loads for tributaries to Lake Michigan, the Fox River has one of the largest (Figure 43). Atrazine concentrations from tributary samples were below EPA standards for human health and ambient aquatic life criteria (Figure 44). The mean atrazine concentrations for the Fox and Menominee Rivers were 59 ng/l and 5.3 ng/l respectively (EPA 2001). Overall, the tributaries with the highest mean atrazine concentrations are located where agriculture is the greatest, and those tributaries with the lowest mean atrazine concentrations are located in more forested areas (Figure 44).

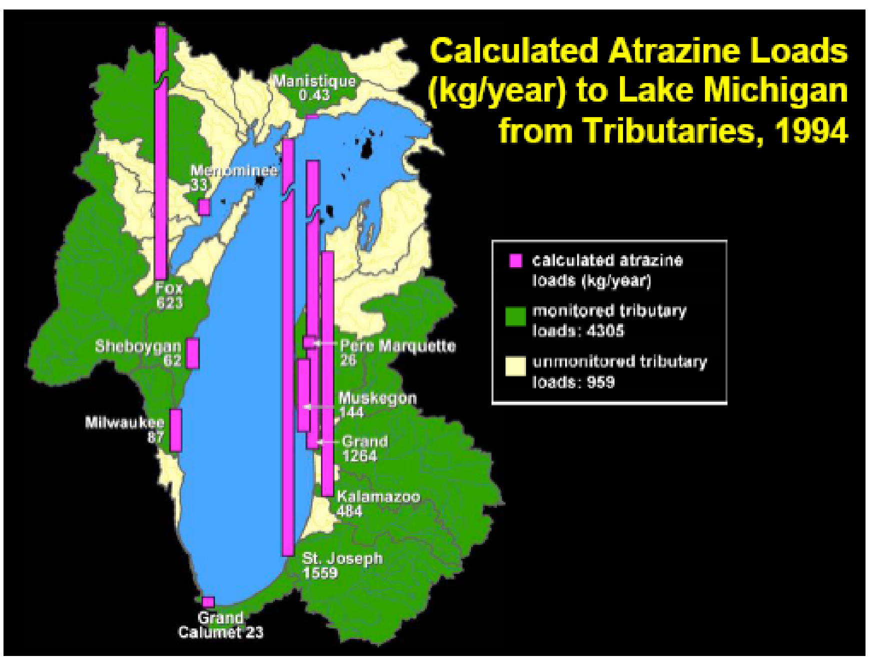


Figure 43: Atrazine loads (kg/yr) in Lake Michigan tributaries (map from Ken Rygwelski, Lake Michigan Atrazine Modeling presentation).

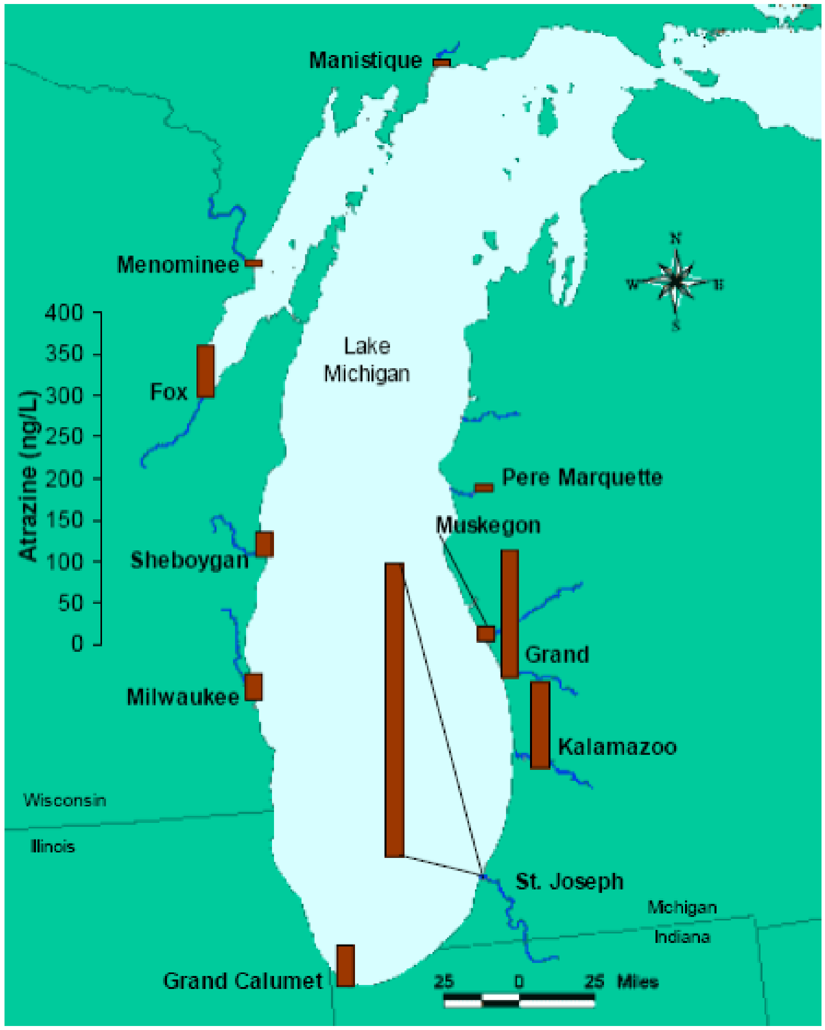


Figure 44: Mean atrazine concentrations measured in Lake Michigan tributaries (map from the EPA 2001).

References

Ankley, G.T., G.J. Niemi, K.B. Lodge, H.J. Harris, D.L. Beaver, D.E. Tillitt, T.R. Schwartz, J.P. Giesy, P.D. Jones, and C. Hagley. 1993. Uptake of Planar Polychlorinated Biphenyls and 2, 3, 7, 8-Substituted Polychlorinated Dibenzofurans and Dibenzon-p-dioxins by Birds Nesting in the Lower Fox River and Green Bay, Wisconsin, USA. *Archives of Contamination and Toxicology*. 24: 332-344.

Brazner, J. and W. DeVita. 1998. PCBs, DDE, and Mercury in Young-of-The-Year Littoral Fishes from Green Bay, Lake Michigan. *Journal of Great Lakes Research*. 24(1): 83-92.

Custer, T.W., C.M. Custer, R.K. Hines, S. Gutreuter, K.L. Stromborg, P.D. Allen, and M.J. Melancon. 1999. Organochlorine Contaminants and Reproductive Success of Double- Crested Cormorants from Green Bay, Wisconsin, USA. *Environmental Toxicology and Chemistry*. 18(6): 1209-1217.

Custer, C.W., T.M. Custer, P.D. Allen, K.L. Stromborg, and M.J. Melancon. 1998. Reproduction and Environmental Contamination in Tree Swallows Nesting in the Fox River Drainage and Green Bay, Wisconsin, USA. *Environmental Toxicology and Chemistry*. 17(9): 1786-1798.

Environmental Protection Agency (EPA). 1992. *The Green Bay/Fox River Mass Balance Study Management Summary: Preliminary Management Summary*. Prepared by: Robert F. Beltran. The Green Bay/Fox River Mass Balance Study Management Summary: http://www.epa.gov/glnpo/monitoring/data_proj/gbmb/mgmtsummary.html

Environmental Protection Agency (EPA). 1997. *Draft Wisconsin Mercury Sourcebook: Wildlife Health*. The Draft Wisconsin Mercury Sourcebook: http://infohouse.p2ric.org/ref/04/03851/section1.pdf

Environmental Protection Agency (EPA). 2001. *Results of the Lake Michigan Mass Balance Study: Atrazine Data Report*. Prepared by: R.N. Brent, J. Schofield, and K. Miller. Lake Michigan Mass Balance Study Atrazine Data Report: http://www.epa.gov/glnpo/lmmb/results/atra_final.pdf

Environmental Protection Agency (EPA). 2004. *Results of the Lake Michigan Mass Balance Study: Mercury Data Report*. Prepared by: H.B. McCarty, K. Miller, R.N. Brent, J. Schofield, and R. Rossman. Lake Michigan Mass Balance Study, Mercury Data Report: http://www.epa.gov/glnpo/lmmb/results/mercury/lmmbhg.pdf

Environmental Protection Agency (EPA). 2004. *Results of the Lake Michigan Mass Balance Study: Polychlorinated Biphenyls and trans-Nonachlor Data Report*. Prepared by: H.B. McCarty, J. Schofield, K. Miller, R.N. Brent, P. Van Hoof, and D. Eadie. Lake Michigan Mass Balance Study, PCB Data Report: http://www.epa.gov/glnpo/lmmb/results/pcb/lmmbpcb.pdf

Harris, H.J., T.C. Erdman, G.T. Ankley, and K.B. Lodge. 1993. Measures of Reproductive Success and Polychlorinated Biphenyl Residues in Eggs and Chicksof Forster's Terns on Green Bay, Lake Michigan, Wisconsin-1988. *Archives of Contamination and Toxicology*. 25: 304-314.

Hayes, T., K. Haston, M. Tsui, A. Hoang, C. Haeffele, and A. Vonk. 2002. Feminization of Male Frogs in the Wild. *Nature*. 419: 895-896.

Hurley, J. 1995. Watershed Effects on Background Mercury Levels in Rivers. In *National Forum on Mercury in Fish: Proceedings*, U.S. EPA Office of Water, June 1995. EAA 823-R-95-002.

Hurley, J., S.E. Cowell, M.M. Shafer and P.E. Hughes. 1998. Partitioning and Transport of Total and Methyl Mercury in the Lower Fox River, Wisconsin. *Environ. Sci. Technol.* 32: 1424-1432.

Kersten, S.M. 1997. *The Effects of PCB-Contaminated Environments on the Leopard Frog (Rana pipiens)*. M.S. Thesis. University of Wisconsin-Green Bay.

Konrad, J.G. 1971. Mercury Content of Various Bottom Sediments, Sewage Treatment Plant Effluents and Water Supplies in Wisconsin. *Research Report #74*, Department of Natural Resources, Madison, WI.

Kubiak, T.J., H.J. Harris, L.M. Smith, T.R. Schwartz, D.L Stalling, J.A. Trick, L. Sileo, D.E. Dockerty, and T.C. Erdman. 1989. Microcontaminants and Reproductive Impairment of the Forster's Tern on Green Bay, Lake Michigan- 1988. *Archives of Contamination and Toxicology*. 18: 706-727.

Lathrop, R.C., P.W. Rasmussen, and D.R. Knauer, 1991. Mercury Concentrations in Walleyes from Wisconsin (USA) Lakes. *Water, Air, and Soil Pollution*. 56: 295-307.

National Academy of Sciences (U.S.). 1978. *An Assessment of Mercury in the Environment*. National Academy of Sciences, Washington, D.C. 185 pp.

Palmer, K.A. 2005. *Polychlorinated Biphenyl (PCB) Levels in Sediments, Aquatic Emergent Insects, and Marsh Wrens in a Green Bay, Lake Michigan Coastal Marsh*. M.S. Thesis. University of Wisconsin-Green Bay.

Pezzetta, J.M. and I.K. Iskandar. 1975. Sediment Characteristics in the Vicinity of the Pulliam Power Plant, Green Bay, Wisconsin. *Environmental Geology* 1: 155-165.

Rattray, K.J. 1997. The Nesting Success and PCB Burdens of Yellow-Headed Blackbirds Found in Diked Marshes along Green Bay, Lake Michigan. M.S. Thesis. University of Wisconsin-Green Bay.

Redman, S. 1993. *Preliminary Evaluation of Mercury in the Sediments of the Fox River and Lower Green Bay (Draft)*. Planning and Policy Section, Bureau of Water Resources Management. Wisconsin Department of Natural Resources.

Rossmann, R. and D.N. Edgington. 2000. Mercury in Green Bay, Lake Michigan Surficial Sediments Collected between 1987 and 1990. *J. Great Lakes Res*. 26(3): 323-339.

UW Sea Grant Institute. PCBs in Green Bay Fact sheet. http://aqua.wisc.edu/publications/pdfs/PCBsInGreenBay.pdf

Wenzel, A.D. 1996. *Determination of Total Mercury Using Microwave Digestion on Emergent Insects Collected from two Coastal Marshes of Green Bay, Lake Michigan*. M.S. Thesis. University of Wisconsin-Green Bay.

Wisconsin Department of Natural Resources (WDNR). 2004: Bureau of Integrated Science Services. April, 2004. *Wisconsin Wildlife Surveys: Conservation of Endangered, Threatened and Nongame Birds, Performance Report, 1 July 2002 to 30 June 2003*. pp. 120-134.

Wisconsin Department of Natural Resources (WDNR). 1999. *Draft Studies Completed Cleanup of PCBs in Lower Fox River Sediments: Draft Remedial Investigation, Risk Assessment and Feasibility Study Available for Public Review*

Wisconsin Department of Natural Resources (WDNR). 2002. *Final Baseline Human Health and Ecological Risk Assessment: Lower Fox River and Green Bay, Wisconsin Remedial Investigation and Feasibility Study*. Prepared by: The RETEC Group, Inc. Risk Assessment Reports: http://ua.dnr.wi.gov/topic/ImpairedWaters/FoxRiver/original/riskassessment.html

Wisconsin Department of Natural Resources (WDNR). 2012. *Choose Wisely: A Health Guide for Eating Fish in Wisconsin*. http://dnr.wi.gov/topic/fishing/documents/FishAdvisoryweb2012low.pdf

Links

Lower Fox River PCB Cleanup:
http://ua.dnr.wi.gov/topic/ImpairedWaters/FoxRiver/original/

PCB Fact Sheet, UW Sea Grant Institute:
http://aqua.wisc.edu/publications/pdfs/PCBsInGreenBay.pdf

Fish Consumption Advisory for Wisconsin:
http://dnr.wi.gov/topic/fishing/consumption/index.html

Fish Advisory Information, U.S. EPA:
http://www.epa.gov/waterscience/fish

Fish Consumption Information in the Great Lakes:
http://www.great-lakes.net/humanhealth/fish/index.html

Information on Mercury:
http://dnr.wi.gov/topic/Mercury/Overview.html#tabx2

Green Bay/Fox River Mass Balance Study:
http://www.epa.gov/glnpo/monitoring/data_proj/gbmb/mgmtsummary.html

WATER LEVELS

Status: Below Average
Trend: Declining (since 2000)

Water levels in Green Bay reached a record low in December 2012 and January 2013 from the previous low set in 1964.

Low water levels in Green Bay have concerned many residents of Northeastern Wisconsin since the late 1990s. Although low water can be a problem for shoreline property owners, boaters, duck hunters and others, such fluctuations are a natural part of the system dynamics and have contributed to biodiversity in Green Bay, especially in coastal marshes. The water level of Green Bay can change dramatically. The U.S. Army Corps of Engineers has recorded water levels for Green Bay since the late 1800s, and it is clear that water level varies on several time scales, including daily, annually, and on roughly 10- to 20-year cycles. The difference between the all-time high water levels and the all-time low is six feet.

GARY FEWLESS, UWGB

Low water level on Green Bay east shore due to low lake wide levels in conjunction with an outgoing seiche.

SHORT-TERM LEVELS (SEICHE)

A seiche is a wave of water that oscillates back and forth in a basin, like water sloshing in a bathtub. The long narrow shape of the bay and its north-south orientation allow wind to drive water away from the mouth of the Fox River out toward Lake Michigan. The windblown water piles up on the windward side. When the wind dies, the water flows back. In the absence of significant wind, water will continue to move back and forth in the basin much like water in a shallow pan continues to move back and forth after the pan has been moved and then placed at rest.

In Green Bay, the seiche is highly variable, but consists of approximately 11-hour cycles (from high to low and back to high again). The magnitude of the seiche also varies depending on the strength, duration, and timing of the winds; changes in atmospheric pressure, and the location of the measurement. In Lower Green Bay, the average seiche is about 6-12 inches. Occasionally, the seiche is strong enough that large areas of lakebed are exposed. The resulting return of water down the bay can reverse river flow.

ANNUAL LEVELS

Water level depends on a balance between water input from rain, snow and evaporation. In winter, there is less total precipitation and almost no runoff of water from the land. Evaporation is greatest in warm winters when the lake does not freeze over. In spring, the bay generally receives a large input of melt water from the watershed, and the amount of monthly precipitation increases. By mid-summer, the runoff contribution from the watershed has diminished, and warm, sunny (and windy) days contribute to falling water levels. Each year, water levels rise to a high in about July (the result of spring runoff of snow melt and substantial spring and early-summer rains) and usually fall to a low in February or March. Differences in annual water levels are about one foot.

LONG-TERM LEVELS

In addition to the short-term changes, water levels can rise and fall over a period of years in response to varying climatic conditions. Water levels vary by as much as one meter above or below the long-term average on a 30-year cycle. These long-term water level changes are a natural part of the hydrology of Lake Michigan and Green Bay.

Evaporation and precipitation are the major contributors to long-term water level changes in the Great Lakes. Evaporation increases in warm years, especially those with warm winters, and decreases in cold years. Open water evaporates quickly without ice cover, even during years with normal snowfall. In the last few years, La Niña and El Niño conditions have resulted in warmer temperatures and lower precipitation in the Great Lakes. Since 1997, water levels have dropped two meters to historically low levels and have remained at relatively low levels since the large drop.

Water levels can be important for water-quality indicators because some chemicals (such as phosphorus and chloride) change due to water levels. During times of low water, increased mixing from wind can re-suspend buried phosphorus from the lake bottom and increase phosphorus concentrations. During times of high water levels, phosphorus contributions from the Fox River watershed will be diluted.

LINKS

Great Lakes Water Level Observations: Includes a link to the interactive Great Lakes Water Level Dashboard
http://www.glerl.noaa.gov/data/now/wlevels/levels.html

Great Lakes Water Level Data: Provides current and historical water levels for stations in the Great lakes (including Green Bay)
http://tidesandcurrents.noaa.gov/map/index.shtml?type=VerifiedData&region=Lake%20Michigan

RECREATIONAL USE INDICATORS

BEACH ADVISORIES AND CLOSINGS

Status: Fair

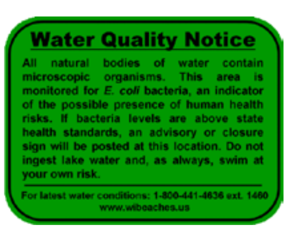
Trend: Undetermined

Numerous swimming beaches are located along the Green Bay shoreline (Figure 45). Beach closings have occurred at several of these beaches, primarily those in Door County (Figure 46) and these closings negatively affect tourism and recreation. These beach closings have occurred due to elevated bacteria levels, however the source of bacterial contamination is not completely known.

Wisconsin County Beaches

The state of Wisconsin received grants from the federal BEACH (Beaches Environmental Assessment and Coastal Health) Act of 2000 for monitoring beaches. The BEACH Act requires all coastal states to adopt beach water-quality standards and to develop monitoring programs. Each beach is assigned a priority ranking for monitoring based on several factors, including how many people use each beach and its environmental status. In 2011, high-priority beaches were monitored at least four times a week (down from five times a week in 2009), medium-priority beaches were monitored at least two times a week, and low-priority beaches were monitored once a week or only occasionally. Only beaches located in Brown and Door counties were given priority rankings; beaches located on Green Bay in Kewaunee County and beaches in Oconto and Marinette counties were not monitored (Table 8).

Wisconsin issues both closings and advisories and beaches are typically monitored from Memorial Day weekend through Labor Day weekend. Advisory signs are posted at monitored beaches to notify the public about beach water quality based on *E. coli* testing. A green informational sign is posted at monitored beaches when water tests are below the EPA standard for *E. coli*. Local health departments also have the choice to post a blue "good" sign with the green sign. A yellow "caution" sign is posted when the EPA health standard is exceeded for *E. coli* (235 cfu/100ml), and a red "closed" sign is posted when beaches are closed (*E. coli* exceeds 1000 cfu/100ml). It is important to note that the results from *E. coli* tests can take 18 to 24 hours. Therefore, an advisory for a given day is based on the results of samples taken the previous day. As a result, the posted advisory sign may not reflect the actual condition of the water. After rain events, elevated *E. coli* concentrations were found at most sampled beaches. So since 2005, wet weather advisories are posted at select Door County beaches within 24 hours of rain events of ¼ inches for 24 hours.



NICOLE FAHY

Sister Bay Beach, Door County

2010 was the eighth season of full implementation of the Wisconsin coastal beach program. During the 2010 beach season, *E. coli* levels exceeded the advisory limit 17 times and the closure limit five times at Door County beaches on Green Bay (Table 10). In addition, 20 wet weather advisories were issued at three Door County Beaches. Since beach monitoring began in 2003, it is difficult to say if bacterial levels are worse now than in previous years.

In the AOC, there have been no public swimming beaches since 1938 when Bay Beach closed due to excessive bacterial contamination; however several areas are used as unofficial swimming beaches. In Brown County, three beaches are being monitored about once a week: Bayshore Park beach, Communiversity Park beach, and Longtail beach (Table 8). These beaches have been in excellent condition during the last eight years of monitoring. There have only been two advisories and one closure at Bayshore Park beach, four advisories and three closures at Communiversity Park beach and no advisories or closures at Longtail Beach (Table 11).

Michigan County Beaches

Michigan issues both closings and advisories. Beaches are typically monitored from May through October. In Michigan, beach advisories are issued if samples exceed either a one-day geometric mean of 300 *E. coli* organisms per 100 ml of water or a 30-day geometric mean of 130 *E. coli* organisms per 100 ml of water. Two Michigan counties (Delta and Menominee) are the home to several beaches located along Green Bay (Figure 45 and Table 9). In 2010, there were no exceedances at beaches in Delta County and one exceedance at Menominee County beaches (Table 12).

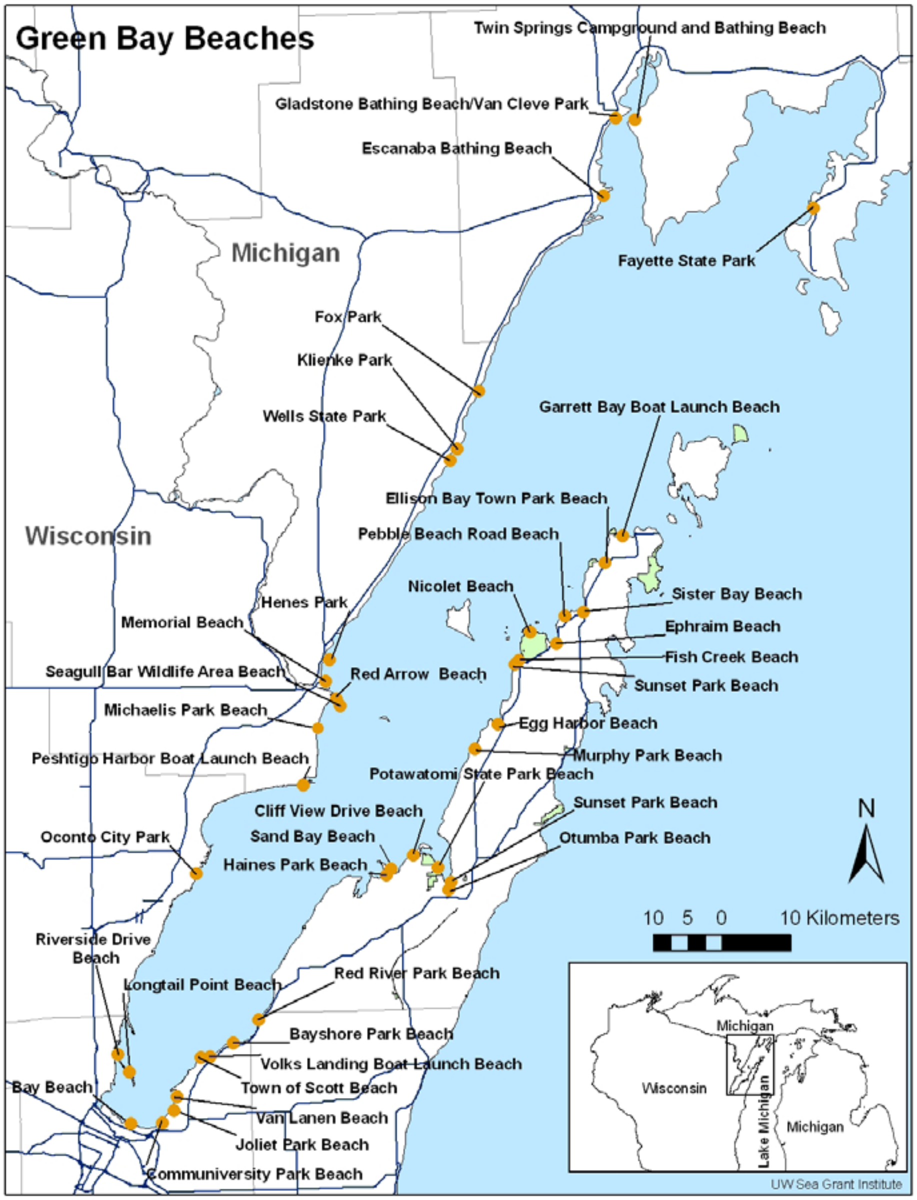


Figure 45: Locations of Green Bay beaches.

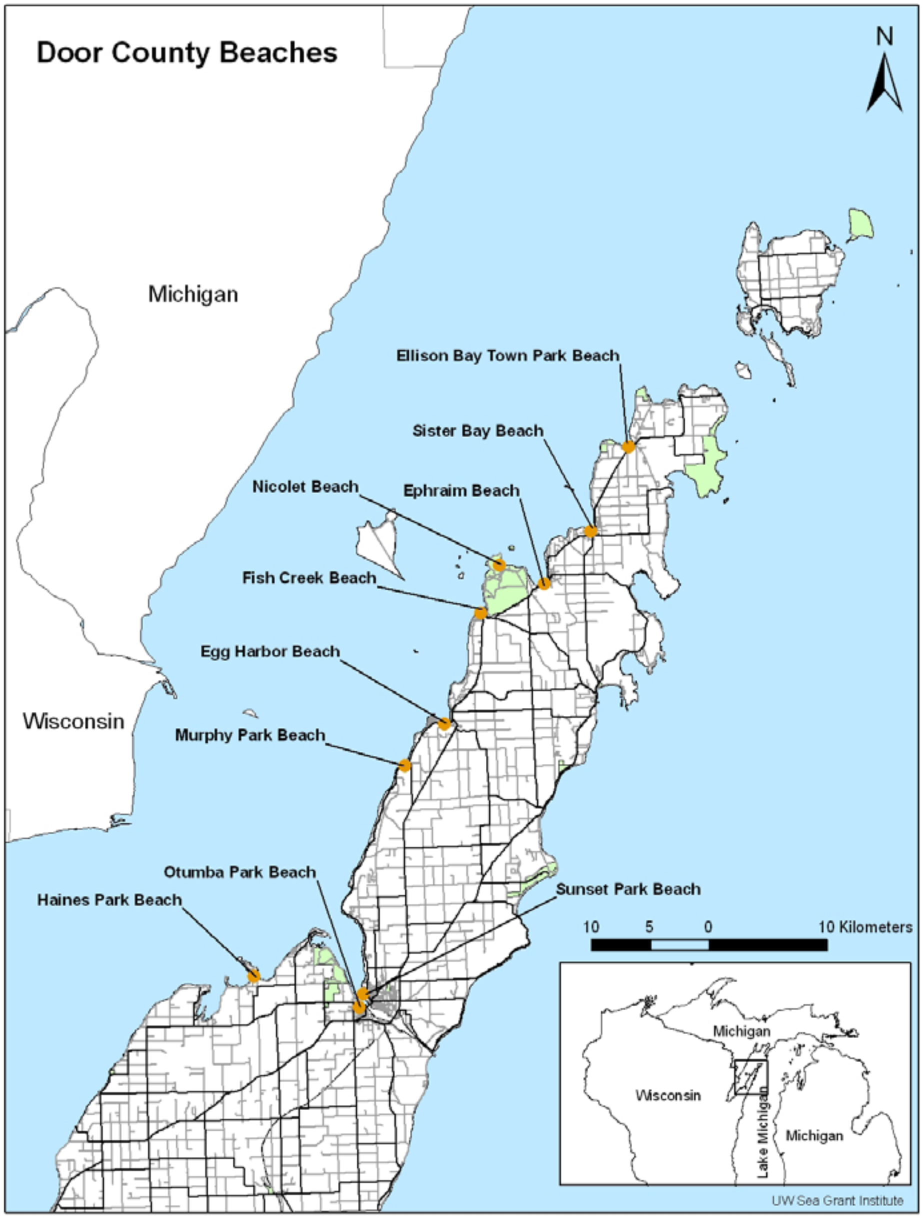


Figure 46: Locations of monitored Green Bay beaches in Door County.

Table 8: Monitoring priority of Wisconsin Green Bay beaches (2011).

County	Beach	Monitoring Priority
Brown	Bay Beach	Not Sampled
	Bayshore Park Beach	Low
	Communiveristy Park BeachLow	
	Joliet Beach	Not Sampled
	Long Tail Point Beach South	Low
	Long Tail Point Beach North	Low
	Riverside Drive Beach	Not Sampled
	Town of Scott Park Beach	Not Sampled
	Van Lanen Beach	Not Sampled
	Volks Landing Boat Launch	Not Sampled
Door	Egg Harbor Beach	High
	Ellison Bay Town Park Beach	High
	Ephraim Beach	High
	Fish Creek Beach	High
	Murphy Park Beach	High
	Nicolet Bay Beach	High
	Otumba Park Beach	High
	Sister Bay Beach	High
	Sunset Park Beach - Sturgeon Bay	High
	Haines Park	Medium
	Cliff View Drive Beach	Not Sampled
	Garrett Bay Boat Launch	Not Sampled
	Pebble Road Beach	Not Sampled
	Potawatomi State Park	Not Sampled
	Sand Bay Beach	Not Sampled
	Sunset Beach Fish Creek	Not Sampled
Kewaunee	Red River Park	Not Sampled
Oconto	Oconto City Park Beach	Not Sampled
Marinette	Michaelis Park	Not Sampled
	Peshtigo Harbor Boat Launch	Not Sampled
	Red Arrow Beach #1	Not Sampled
	Red Arrow Beach #2	Not Sampled
	Red Arrow Beach #3	Not Sampled
	Seagull Bar Wildlife Area	Not Sampled

Table 9: Monitoring status of Michigan Green Bay beaches (2010).

County	Beach	Monitoring Status
Delta	Big Bay De Noc/Fishdam River Public Access	No
	Escanaba Bathing Beach	Yes
	Fayette State Park	No
	Fuller Park	No
	Gladstone Bathing Beach/Van Cleve Park	Yes
	Little Bay De Noc Public Beach Access	No
	Public Shoreline Beach – East Wilsey Bay	No
	Public Shoreline Beach – Fishdam River	No
	Public Shoreline Beach – Indian Point	No
	Public Shoreline Beach – Indian Town Lake USFS	No
	Public Shoreline Beach – Jacks Bluff	No
	Public Shoreline Beach – Martin Bay	No
	Public Shoreline Beach – Nahma	No
	Public Shoreline Beach – North of Stonington	No
	Public Shoreline Beach – Ogontz Bay	No
	Public Shoreline Beach – Peninsula Point	No
	Public Shoreline Beach – Portage Peninsula	No
	Public Shoreline Beach – St. Vital's Island	No
	Public Shoreline Beach – USFS West Wilsey Bay	No
	Sac County Park (Point)	No
	Sac County Park (West)	No
	Twin Springs Campground and Bathing Beach	No
Menominee	Airport Park	No
	Fox Park	No
	Henes Park	Yes
	Klienke Park	No
	Memorial Beach	Yes
	Public Shoreline Beach – Cedar River	No
	Public Shoreline Beach – Fox Village	No
	Wells State Park	No

Table 10: Door County beach closings/advisories for years 2003-2010.

Beach	Year	# Samples	# Advisories	# Closures	% Advisories	% Closures	# Wet Weather Advisories
Egg Harbor	2003	87	3	0	3	0	NA
	2004	57	8	1	14	2	NA
	2005	56	2	1	4	2	0
	2006	57	2	0	4	0	8
	2007	57	2	1	4	2	0
	2008	61	6	1	10	2	0
	2009	58	5	3	9	5	0
	2010	56	2	1	4	2	0
Ellison Bay	2003	89	3	1	3	1	NA
	2004	58	5	1	9	2	NA
	2005	57	3	0	5	0	0
	2006	56	0	0	0	0	0
	2007	57	1	0	2	0	0
	2008	59	2	0	3	0	0
	2009	56	0	0	0	0	0
	2010	57	1	0	2	0	0
Ephraim	2003	86	0	1	0	1	NA
	2004	56	0	0	0	0	NA
	2005	56	2	1	4	2	0
	2006	56	0	0	0	0	8
	2007	57	1	1	2	2	10
	2008	65	7	0	11	0	7
	2009	60	8	5	13	8	3
	2010	60	2	1	3	2	9
Fish Creek	2003	88	3	1	3	1	NA
	2004	57	5	1	9	2	NA
	2005	57	3	3	5	5	0
	2006	58	1	2	2	3	8
	2007	57	1	1	2	2	10
	2008	64	3	0	5	0	7
	2009	57	4	1	7	2	2
	2010	60	0	1	0	2	9
Haines Park	2003	18	0	0	0	0	NA
	2004	16	2	0	13	0	NA
	2005	14	0	0	0	0	0
	2006	13	0	0	0	0	0
	2007	28	0	0	0	0	0
	2008	30	0	0	0	0	0
	2009	33	2	6	6	18	0
	2010	30	1	0	3	0	0

Beach	Year	# Samples	# Advisories	# Closures	% Advisories	% Closures	# Wet Weather Advisories
Murphy Park	2003	86	0	1	0	1	NA
	2004	59	7	5	12	8	NA
	2005	57	4	2	7	4	0
	2006	56	5	0	9	0	8
	2007	58	1	2	2	3	0
	2008	59	2	0	3	0	0
	2009	56	1	1	2	2	0
	2010	57	0	0	0	0	0
Nicolet	2003	86	1	0	1	0	NA
	2004	58	4	2	7	3	NA
	2005	56	5	1	9	2	0
	2006	57	1	0	2	0	0
	2007	57	1	0	2	0	0
	2008	60	2	0	3	0	0
	2009	56	0	0	0	0	0
	2010	57	1	0	2	0	0
Otumba Park	2003	92	5	2	5	2	NA
	2004	60	6	2	10	3	NA
	2005	57	4	2	7	4	4
	2006	57	11	1	19	2	7
	2007	57	3	1	5	2	9
	2008	66	8	0	12	0	10
	2009	60	6	2	10	3	7
	2010	61	7	1	11	2	2
Sister Bay	2003	85	4	0	5	0	NA
	2004	55	3	1	5	2	NA
	2005	57	3	0	5	0	0
	2006	56	0	0	0	0	0
	2007	57	3	1	5	2	0
	2008	60	3	0	5	0	0
	2009	57	3	0	5	0	0
	2010	58	1	0	2	0	0
Sunset Park Beach Sturgeon Bay	2003	91	9	1	10	1	NA
	2004	58	12	1	21	2	NA
	2005	58	8	4	14	7	4
	2006	59	10	2	17	3	8
	2007	29	1	0	3	0	10
	2008	63	6	0	10	0	10
	2009	61	2	1	3	2	7
	2010	57	2	1	4	2	0

Beach	Year	# Samples	# Advisories	# Closures	% Advisories	% Closures	# Wet Weather Advisories
Total (All Green Bay Door County Beaches)	2003	808	28	7	3	1	NA
	2004	534	52	14	10	3	NA
	2005	525	34	14	6	3	8
	2006	525	30	5	6	1	47
	2007	514	14	7	3	1	39
	2008	587	39	1	7	0.2	34
	2009	554	31	19	6	3	19
	2010	553	17	5	3	1	20

Data from Wisconsin Beach Health, http://www.wibeaches.us

#Advisory is the number of times the E. coli *level is >235 and <1000 cfu/100 ml*

 # Closures is the number of times the E. coli *level is >1000 cfu/100 ml*

Wet weather advisory is an advisory posted within 24 hours after all rain events of ¼ inches for 24 hours

Table 11: Brown County beach closings/advisories for years 2003-2010.

Beach	Year	# Advisories	# Closures
Bayshore Park Beach	2003	0	0
	2004	0	1
	2005	1	0
	2006	0	0
	2007	1	0
	2008	0	0
	2009	0	0
	2010	0	0
Communiversity Park Beach	2003	0	0
	2004	0	0
	2005	0	0
	2006	0	0
	2007	0	1
	2008	0	0
	2009	3	0
	2010	1	2
Longtail Beach	2003	0	0
	2004	0	0
	2005	0	0
	2006	0	0
	2007	0	0
	2008	0	0
	2009	0	0
	2010	0	0

Data from Wisconsin Beach Health, http://www.wibeaches.us

Table 12: Green Bay Michigan beach closings/advisories for years 2004-2010.

County	Beach	Year	# Advisory/Closure
Delta	Escanaba Bathing Beach	2004	0
		2005	0
		2006	0
		2007	0
		2008	0
		2009	0
		2010	0
	Gladstone Bathing Beach/Van Cleve Park	2004	1
		2005	0
		2006	0
		2007	1
		2008	0
		2009	0
		2010	0
Menominee	Henes Park	2004	0
		2005	2
		2006	0
		2007	8
		2008	0
		2009	0
		2010	1
	Memorial Beach	2004	0
		2005	1
		2006	0
		2007	0
		2008	0
		2009	0
		2010	0

Data from Michigan Department of Natural Resources and Environment, http://www.deq.state.mi.us/beach

Links

Wisconsin Beach Health:
http://www.wibeaches.us

U.S. EPA:
http://www.epa.gov/waterscience/beaches/

BEACON – Beach Advisory and Closing On-line Notification (U.S.EPA):
http://iaspub.epa.gov/waters10/beacon_national_page.main

Natural Resources Defense Council-Testing the Waters:
http://www.nrdc.org/water/oceans/ttw/titinx.asp

Great Lakes Beach Association:
http://www.great-lakes.net/glba/

BeachCast:
http://www.great-lakes.net/beachcast

Wisconsin Beach Program-WDNR:
http://dnr.wi.gov/topic/beaches

Michigan Department of Environmental Quality - Beach Water Monitoring:
http://www.michigan.gov/deq/0,1607,7-135-3313_3686_3730---,00.html

Michigan BeachGuard System:
http://www.deq.state.mi.us/beach

BOAT REGISTRATIONS

Status: Good
Trend: Increasing

KRISTEN ROST

Boats docked in Ephraim, Door County

Boating on the Lower Fox River and Green Bay is a popular form of recreation. Recreational boating is also a significant part of the state's tourism industry. As soon as the weather warms, long lines of fishing boats and pleasure craft can be seen almost any weekend at area launch sites.

Boating trends for Green Bay were determined from the number of boat registrations by county for the state (data provided by WDNR). Boat registrations are valid for two years, and boat owners are permitted to use the boat anywhere in the state. Before 2000, boats were reported by the county of residence of the owner; after 2000, boats were reported by the county where the boat was kept. The number of boat registrations does not indicate how many boats were actually used in Green Bay, but it does give a general idea of boat usage trends over time.

Overall, in the counties surrounding Green Bay (Brown, Door, Marinette, and Oconto), the number of boat registrations has been increasing (Figure 47). According to the WDNR, in 2012, 46,360 boats were registered in these four counties compared with 31,970 boats registered in 1990, a 45% increase. For the four counties individually, in 2012, 19,619 boats were registered in Brown County compared with 18,290 boats registered in 1990, a 7% increase. In both Door and Oconto counties, boat registrations increased by 113% and 105% from 1990 to 2012, respectively. During this same period, Marinette saw a 74% increase in boat registrations.

Considering the past 13 years (2000-2012), the number of boat registrations increased by 12% in the four Wisconsin counties surrounding Green Bay (Figure 48). However, in Brown County, the number of boat registrations has been variable with a decrease (6%) from 2000 to 2008 (Figure 48). Door, Oconto, and Marinette counties all increased (20-39%).

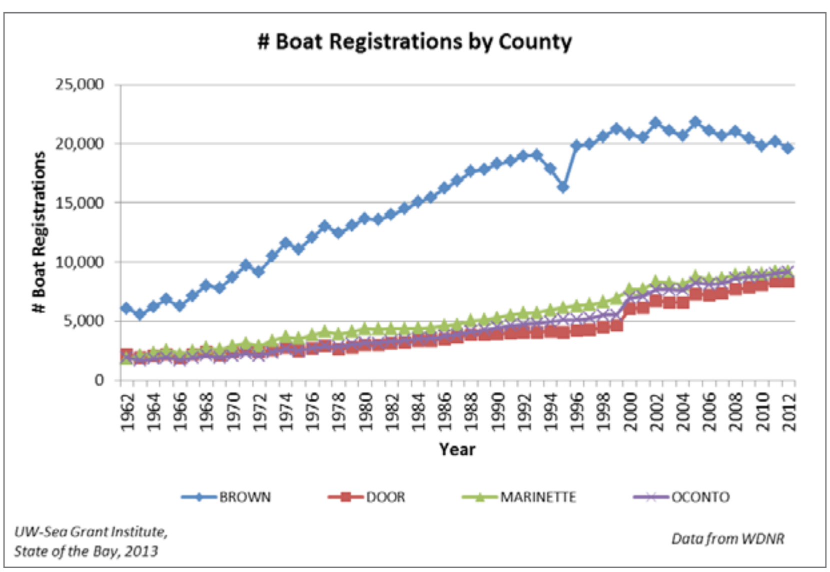


Figure 47: Number of boat registrations by county for years 1962-2012.

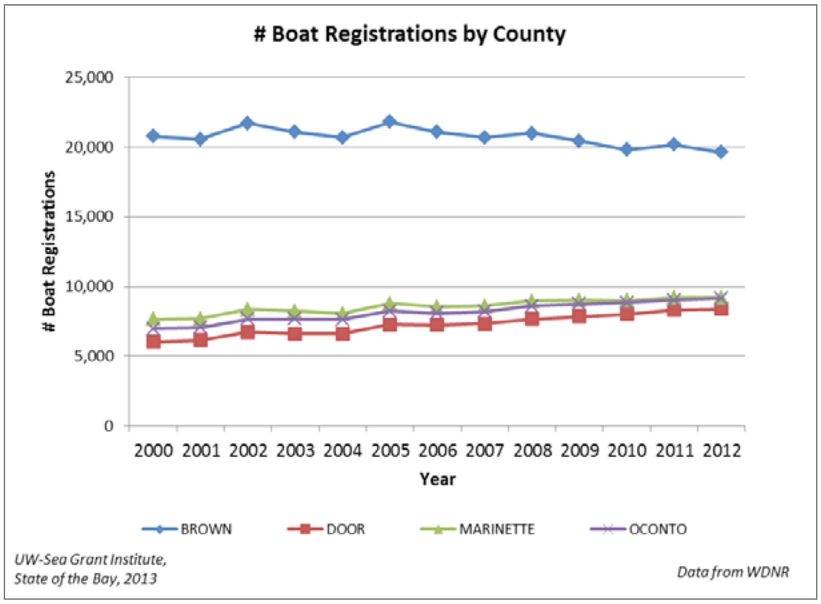


Figure 48: Number of boat registrations by county for years 2000-2012.

SPORT FISHING LICENSE SALES

Status: Fair

Trends: Undetermined

Fishing has been a popular sport on Green Bay, and sport fishing is a significant part of Wisconsin's tourism industry. According to the WDNR, Wisconsin's sport fishing industry is worth $2.75 billion and sport fishing generates $200 million in state tax revenue.

State sport fishing trends can be determined from state fishing license information collected annually by county (data provided by Diane Crawford, WDNR). However, determining the actual number of people who fish in Green Bay is difficult. The number of fishing licenses issued tells how many licenses were purchased in a particular county, not where the fishing license was actually used. Also, fishing license information does not represent the total fishing population because certain individuals, such as those under age 16, are not required to purchase a fishing license.

The total number of fishing licenses issued in the four counties surrounding Green Bay (Brown, Door, Oconto and Marinette) includes resident and nonresident licenses, conservation patron licenses, sports licenses, and two-day Great Lakes fishing licenses. The conservation patron license includes licenses and stamps for several activities, including fishing and hunting. The sports license includes licenses for fishing, small game, and deer gun hunting. The individuals who purchase these licenses may or may not use their license for fishing purposes.

In 2012, 96,115 fishing licenses were issued in Brown, Door, Marinette, and Oconto counties combined. Of the four counties, almost 50% of the licenses were issued in Brown County in 2012. Since 2000, the number of fishing licenses issued in these four counties combined has increased by 14%. Looking at the counties individually, from 2000 to 2012, Brown and Oconto counties had the largest increase in fishing license sales of 30 and 6% respectively, while Door and Marinette counties saw minimal change in the number of fishing licenses issued (Figure 49; Table 13). Additionally, comparing 2011 to 2012, Brown, Door, Marinette and Oconto counties all saw increases in the number of fishing licenses issued.

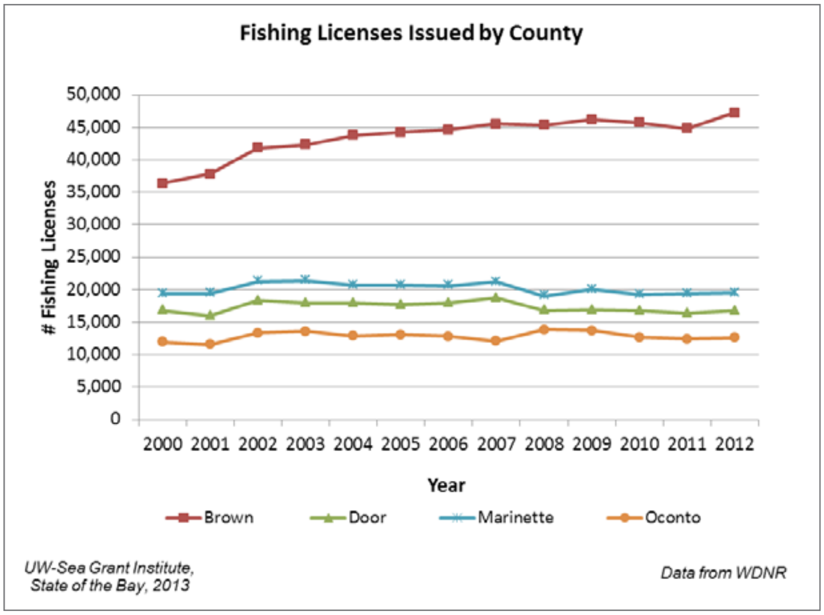


Figure 49: Number of fishing licenses issued in counties surrounding Green Bay for years 2000-2012. Data provided by Diane Crawford, WDNR.

Table 13: Number of fishing licenses issued in counties surrounding Green Bay for years 2000-2012.

Year	Brown	Door	Marinette	Oconto	Total
2000	36,404	16,838	19,379	11,976	84,597
2001	37,843	15,937	19,421	11,592	84,793
2002	41,824	18,333	21,243	13,321	94,721
2003	42,304	17,945	21,390	13,622	95,261
2004	43,773	17,927	20,687	12,879	95,266
2005	44,203	17,680	20,692	13,091	95,666
2006	44,641	17,909	20,583	12,802	95,935
2007	45,545	18,725	21,178	12,067	97,515
2008	45,358	16,818	19,027	13,881	95,084
2009	46,172	16,896	20,001	13,738	96,807
2010	45,702	16,727	19,211	12,663	94,303
2011	44,842	16,358	19,333	12,398	92,931
2012	47,213	16,734	19,521	12,647	96,115

Data provided by the WDNR.

MARINAS

Green Bay and Lake Michigan are popular destinations for those who enjoy boating and fishing. Throughout the region, there are numerous public and private recreational marinas for boaters. Over 90 marinas are located on Green Bay/Lake Michigan (Table 14).

In 2009, the Wisconsin Clean Marina Program formed to help reduce nonpoint source pollution into Wisconsin's waterways. This voluntary program encourages marina operators to protect water quality by engaging in best management practices and obtaining certification as a Wisconsin Clean Marina. As of June 2012, 19 marinas have been certified and 11 additional marinas have pledged to pursue certification. Several of these marinas are located in Green Bay (Figure 50). Visit www.wisconsincleanmarina.org for more information on the program.


KRISTEN ROST

Great Lakes Memorial Marina Park, Marinette

Table 14: Wisconsin marinas located in the counties surrounding Green Bay.

County	Marina	Community
Brown	Debaker Electric & Hardware	Green Bay
	Eagles Nest Supper Club Marina	Green Bay
	Riverplace Marina & Yacht Club	Green Bay
	Green Bay Yacht Club	Green Bay
	Holiday Inn City Center Marina	Green Bay
	South Bay Marina	Green Bay
	Allouez Yacht Harbor Inc.	Green Bay
	Bayshore County Park Boat Launch	Green Bay
	Shipyard Marine	Suamico
	Whale's Tail Marina	Suamico
	Windjammers Sailing Club	Little Suamico
Door	Bailey's Harbor Town Marina	Baileys Harbor
	Bailey's Harbor Yacht Club	Baileys Harbor
	Silver Gull Marina	Baileys Harbor
	Egg Harbor Municipal Dock	Egg Harbor
	Rowleys Bay Resort	Ellison Bay
	Dockside at Gills Rock	Ellison Bay
	Firehouse Marina	Ephraim
	Ephraim Yacht Club , Inc.	Ephraim
	Ephraim Yacht Harbor Inc.	Ephraim

County	Community	
Door (continued)	Alibi Dock Marina	Fish Creek
	Fish Creek Municipal Dock	Fish Creek
	Seaquist Bay Shore Marina	Sister Bay
	Yacht Works Inc	Sister Bay
	Ellison Bay Town Dock	Sister Bay
	Yacht Club Sister Bay	Sister Bay
	Sister Bay Municipal Marina	Sister Bay
	Al Johnson's Marina	Sister Bay
	Center Pointe Marina	Sturgeon Bay
	Sturgeon Bay Marine Center	Sturgeon Bay
	Stone Harbor Resort	Sturgeon Bay
	Quarter Deck Marina - Skipper Buds	Sturgeon Bay
	Snug Harbor Inn Cottages and Marina	Sturgeon Bay
	Leathem Smith Lodge and Marina	Sturgeon Bay
	Harbor Club Marina	Sturgeon Bay
	Wave Pointe Marina and Resort	Sturgeon Bay
	Kap's Marina	Washington Island
	Shipyard Island Marina	Washington Island
	Island Outpost, Ltd.	Washington Island
	Lindgren's Sunrise Cottages & Marina	Washington Island
	Town Dock at Jackson Harbor	Washington Island
Kewaunee	Algoma Marina	Algoma
	Algoma Boat Club	Algoma
	Captain K's Landing	Algoma
	Paul's Landing, LLC	Algoma
	Sunrise Cove Marina	Algoma
	Salmon Harbor	Kewaunee
	Kewaunee Municipal Marina	Kewaunee
	Harbor Express	Kewaunee
Marinette	Nestegg Marine	Marinette
	Harbor Town Marine Inc.	Marinette
Oconto	Hi Seas Marina Inc	Oconto
	Oconto Yacht Club	Oconto
	Breakwater Park & Harbor	Oconto

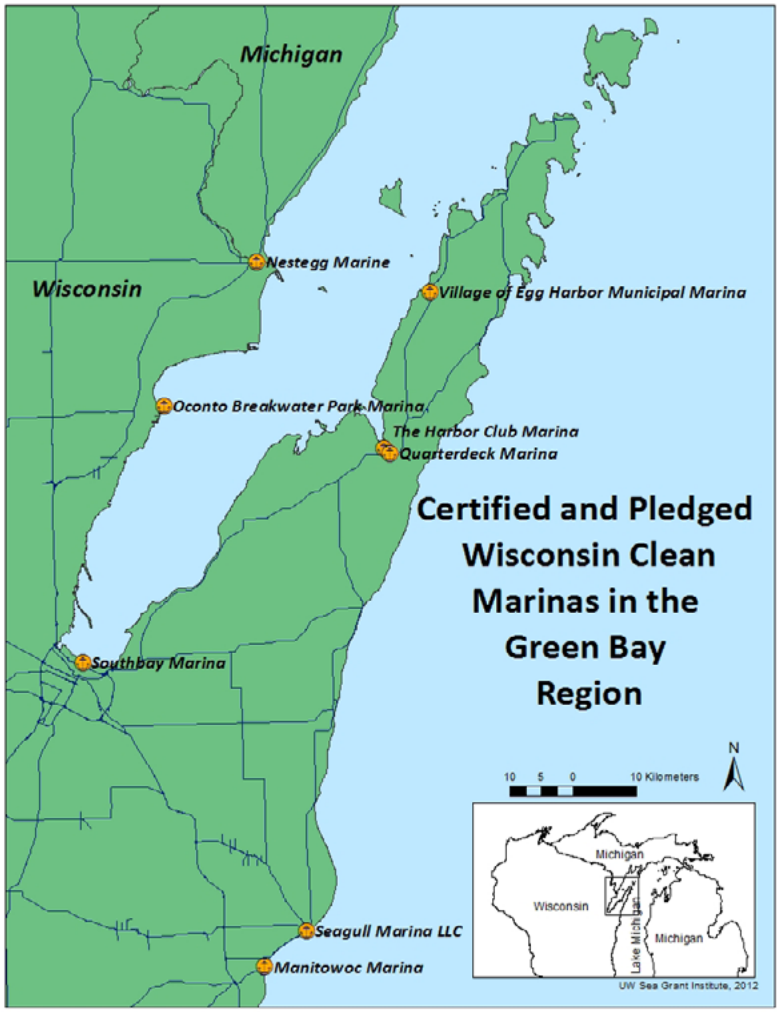


Figure 50: Map of certified and pledged Wisconsin Clean Marinas in Green Bay.

DREDGING

Dredging — removal of sediments from waterways— is frequently required in federal navigation channels, commercial ports, and marinas throughout the Green Bay-Lake Michigan region. Dredging is necessary for commercial navigation, recreational boating, and to maintain harbors and marinas. For the Green Bay harbor, annual maintenance dredging (85,000 -250,000 cubic yards) is necessary for navigation (Table 15). Dredging activities are performed at high economic, social, and environmental costs to communities throughout the Green Bay and Lake Michigan region.

A primary cause of the need for dredging is the soil erosion and sedimentation that fill waterways. Soil erosion and sedimentation are natural processes, but the rate has increased due to urban and rural land use practices. One of the best ways to reduce the cost of dredging is to reduce the amount of sediment that enters waterways. In addition, a study by the Bay-Lake Regional Planning Commission found it is more cost effective to reduce and prevent soil erosion and runoff by changing land use practices than to dredge the same materials (2004 Draft). In addition, low water levels increase the need for dredging at channels and at recreational marinas.

Table 15: Green Bay harbor dredging (2000-2010).

Year	Cubic Yards	Cost	CPY
2000	133,075	$1,269,586	$9.54
2001	160,863	$2,451,379	$15.24
2002	113,934	$1,758,999	$15.44
2003	115,098	$1,804,455	$15.68
2005	84,550	$1,306,955	$15.46
2005	89,981	$1,550,363	$17.23
2006	87,188	$1,803,854	$20.69
2007	124,000	$2,226,900	$18.28
2008	228,000	$3,599,150	$15.79
2009	255,609	$4,164,978	$16.29
2010	175,711	$2,800,000	$15.94

Data Source: U.S. Army Corps of Engineers

LAND COVER AND LAND USE CHANGES

Status: Mixed
Trend: Deteriorating

In the Green Bay Basin, the dominant land cover types are forested (40%), agricultural (26.1%), and wetlands (22%) (Figures 51 and 52). The forested land cover types are located predominately in the northern part of the basin, and agricultural land cover types are mainly found in the southern part of the basin (Figure 52).

The Green Bay Basin includes several major urban areas, including the Fox River Valley, which is one of Wisconsin's most urbanized and industrialized areas. Most of the urban areas are close to rivers and the bay and urban nonpoint source pollution contributes to water quality problems.

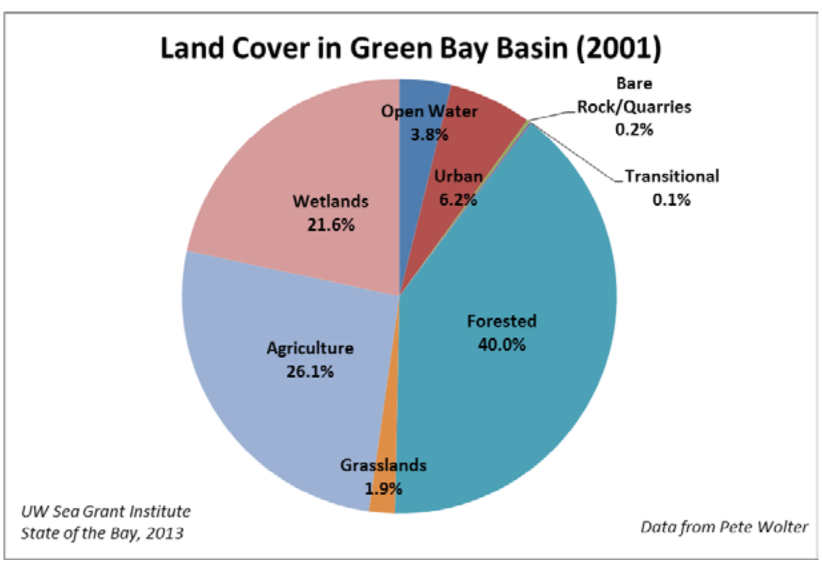


Figure 51: Land cover type by percentage of total land for the Green Bay Basin for 2001. Data from Pete Wolter.

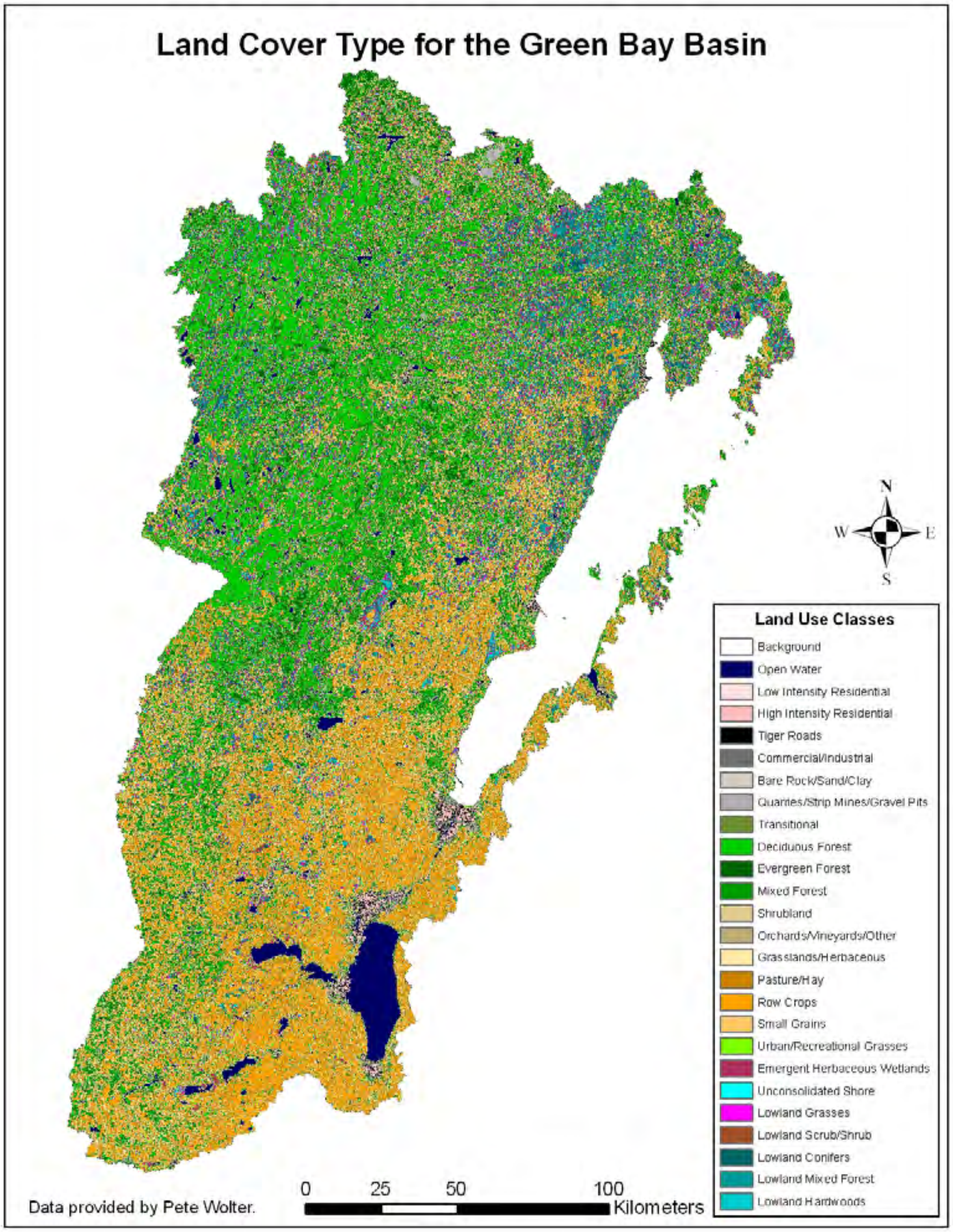


Figure 52: 2001 land cover in the Green Bay Basin.

Previous sections of this report clearly tie degraded conditions in Green Bay to an excess of nutrients being delivered to the bay, predominantly from non-point sources (refer to trophic state section). Non-point source pollution is closely tied to land cover and land use in the watersheds draining to Green Bay. Land cover and land use changes are not readily available by watershed in the Green Bay drainage basin but useful statistics tracking land use changes by county are available through the NOAA Coastal Services Center. Here we choose to present summary statistics related to development, forest fragmentation and wetlands for six counties during the period of 1996 to 2006. Three of the counties, Brown, Outagamie, and Winnebago cover much of the land in the Lower Fox River drainage basin. Two of the counties, Oconto and Marinette, are adjacent to the west shore of Green Bay north to the Wisconsin/Michigan border. The sixth county, Door County, borders the east shore of Green Bay. Land use and land cover changes are summarized in Table 16.

Table 16: Land use and land cover changes in six counties of the Green Bay Basin.

	Brown	Outagamie	Winnebago	Oconto	Marinette	Door
% Developed (2006)	18.1	12.6	12.7	3.4	3.3	3.2
% Impervious (2006)	7.0	4.7	4.9	1.1	1.1	1.0
Mi2 Developed						
(1996-2006)	10.7	7.8	6.0	0.8	1.7	1.3
Mi2 Impervious						
(1996-2006)	4.5	3.2	2.5	0.4	0.6	0.6
Mi2 Ag Land Lost (1996-2006)	8.8	8.5	6.0	0.45	0.85	0.6
% Forest Land (2006)	10.6	13.3	4.7	44	53.6	6.9
Mi2 Forest Change (1996-2006)	-0.65	-0.2	-0.1	2.0	-1.5	-0.8
% Wetland (2006)	6.7	12.9	10.2	26.3	32.8	11.6
Mi2 Wetland Change (1996-2006)	1.1	-5.8	0.2	-0.8	0.5	0.8

Data from the NOAA Coastal Services Center.

Not surprisingly, the percent of developed land is greatest (four to six times) in Brown, Outagamie, and Winnebago counties and least in Oconto, Marinette and Door counties. The developed counties are part of the so-called Fox River corridor. The percent impervious surface logically follows a similar pattern. Brown County, the most developed county, has an area of 600 mi2, of which 98 mi2 is developed and 330 mi2 is used for agriculture (55%). Over the ten year period (1996-2006), 13 mi2 were developed; 70% came from agricultural land (approximately 9 mi2). A similar pattern is evident in the other two developed counties, where 88% of the newly developed land comes from agriculture. Clearly, urban development continues to whittle away at agricultural lands. More development means more impervious surface, which translates into a greater risk for increased flooding and decreased water quality.

Areas with impervious surface rates approaching or exceeding 12 to 15% will likely experience negative impacts on water quality (NOAA Coastal Services Center). While none of the developed counties have percentages this high, Brown County is half-way there. Just as importantly, the development of cropland is a compounding factor because it reduces the available land upon which animal manure can be spread and increases the potential of agricultural runoff. One analysis suggests that the number of animal units in Brown County already exceeds the "spreadable" cropland available (Hagedorn and Hafs, 2010). This combination of urban development, row crop expansion (soybean production has increased two orders of magnitude since 1985), a decrease in hayground and a decrease in available spreadable land for livestock waste has created a nonpoint source "crisis" for water quality. This is true for all the more developed counties.

Both urban and agricultural developmental alternatives must be given serious consideration if water quality in the basin is to meet phosphorus standards. Elsewhere in the Green Bay Basin these issues are not as critical, but merit preventative actions to avoid future problems.

REFERENCES

Hagedorn, M. and B. Hafs. 2010. 7th Annual Clean River, Clean Lakes Conference, September 15, 2010.

BIOLOGICAL INDICATORS

AQUATIC INVASIVE SPECIES

Status: Poor
Trend: Deteriorating

Introduction

Exotic or invasive species are organisms that have moved into areas beyond their native range. Invasive species have and continue to have ecological and economic impacts on the Great Lakes, and Green Bay. These species prey upon native species and may compete with them for food and habitat. They can also have substantial economic impacts on industries, utilities, municipalities, fisheries (sport and commercial), recreation, and tourism. Since the early 1800s, 185 aquatic invasive species were introduced into the Great Lakes ecosystem (Mills et al. 1993; Ricciardi 2001; USGS). In Green Bay, invasions of aquatic species dates back to the 1890s, and the rate of invasions have been increasing exponentially (Figures 53 and 54).

The majority of aquatic invasive species in the Great Lakes region were introduced through human activities, such as releasing aquarium organisms, digging canals that offer new pathways, accidental escape of fish from aquaculture facilities, transferring species from one body of water to another via ballast water, carrying them on the surfaces of recreational boats or outright intentional introductions. Ballast is used in ships for stabilization when the ship is not carrying cargo, and organisms can live in the water and sediments used as ballast. Damages resulting from ship-borne aquatic invasive species are estimated to be $138 million per year in U.S. waters of the Great Lakes. However, there is a chance that damages to sportfishing alone exceed $800 million annually (Rothlisberger 2012).

Not all introduced species become established or have serious impacts. The success of an invasive species depends on several characteristics including adaptability, ability to disperse rapidly, high reproductive rates, and diet.

Included in this section are descriptions and impacts of several established and/or destructive aquatic invasive species in the Green Bay region. For more information on invasive species, please refer to the links provided at the end of this section.

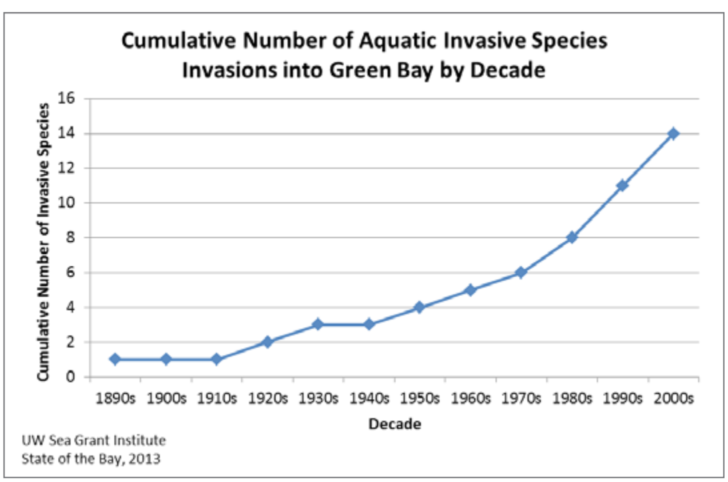


Figure 53: Cumulative number of aquatic invasive species in Green Bay from the 1890s – 2000s.

A Timeline of Aquatic Invasive Species in Green Bay*

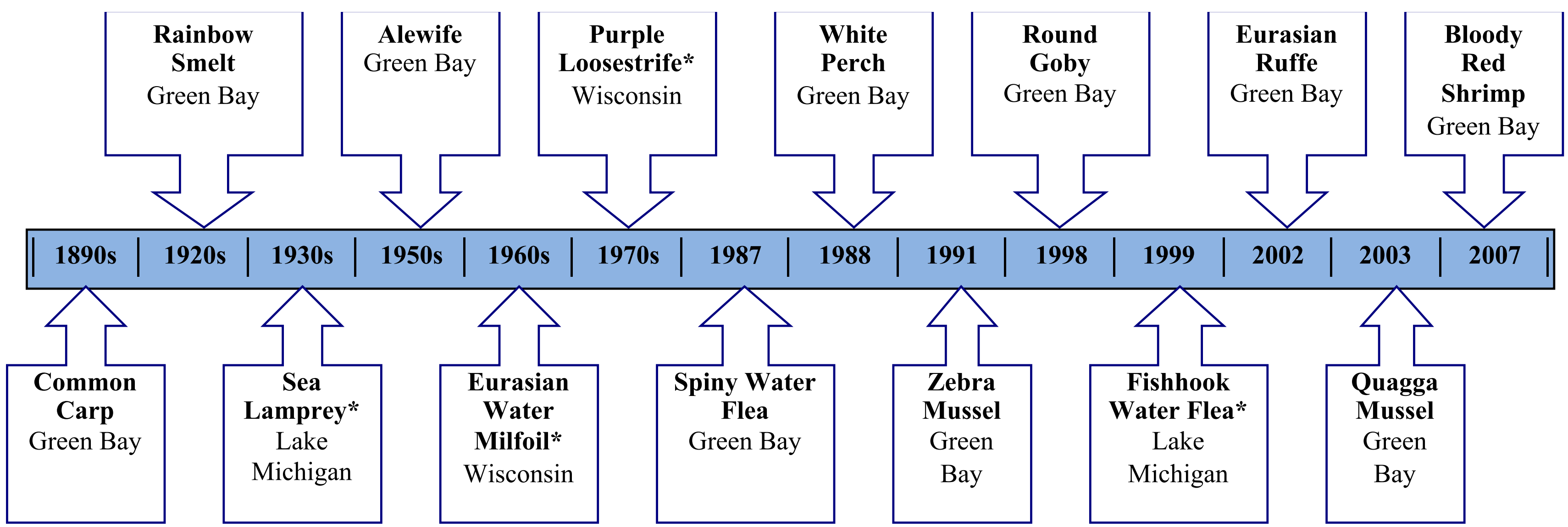


Figure 54: Timeline of aquatic invasive species in Green Bay. * For species where the year of Green Bay invasion is unknown, year of invasion in Lake Michigan or Wisconsin is provided.

Common or Giant Reed Grass *(Phragmites australis)*

Both a native and an introduced European sub-species of *Phragmites* occur in North America, but it is the introduced sub-species that is of concern and therefore will be discussed. The *Phragmites* sub-species was most likely introduced to North America accidentally in ballast in the late 1700s or early 1800s. *Phragmites* is an aggressive invasive species that is widely distributed throughout Wisconsin. It is a tall grass that can grow up to three to four meters. *Phragmites* quickly colonizes disturbed areas and more gradually colonizes native wetlands. *Phragmites* spreads mainly through seeds dispersed by wind and water and through the movement of rhizomes (underground stems). Populations of *Phragmites* are increasing and can form clones that can eliminate other plants including native plants. One of the best ways to control *Phragmites* is to destroy new plants before they can spread. Large stands of *Phragmites* are located along the West Shore of Green Bay. In September, 2011, aerial spraying using a helicopter treated approximately 3,300 acres of Phragmites along the western shore of Green Bay.

Eurasian Watermilfoil *(Myriophyllum spicatum)*

Eurasian watermilfoil is a submersed aquatic plant native to Europe, Asia, and Northern Africa that was probably introduced through an aquarium release. It was found in Wisconsin in the 1960s. Eurasian watermilfoil can form thick underwater stands of tangled stems and vast mats at the surface. These vast mats can interfere with water recreation. In addition, Eurasian watermilfoil can outcompete native plant species, particularly in disturbed areas. Eurasian watermilfoil does not rely on seeds to reproduce; it can reproduce through stem fragmentation and runners. Several methods are used to control Eurasian watermilfoil, including mechanical cutting and harvesting, limited use of herbicide, and the use of weevils as biological control agents. One drawback of mechanical cutting is the machines create shoot fragments, which can contribute to dispersal of Eurasian watermilfoil. Eurasian watermilfoil can be spread by boats, motors, trailers, bilges, live wells, or bait buckets, so it is essential for boats and equipment to be cleaned after use.

DENNIS W. WOODLAND, ANDREWS UNIVERSITY, WISCONSIN STATE HERBARIUM

DAVE BRENNER, MICHIGAN SEA GRANT

Eurasian Watermilfoil

Purple Loosestrife *(Lythrum salicaria)*

Purple loosestrife is a wetland plant native to Europe and Asia that was introduced into the United States as a garden plant and its seeds were also present in ship ballast. Purple loosestrife was first found in Wisconsin in the 1930s, and did not become common in the state until the 1970s. Purple loosestrife invades marshes and lakeshores, displacing native plants such as cattails and other wetland plants. In addition, purple loosestrife degrades habitat for wildlife and can negatively impact rare plants and animals. Eradicating purple loosestrife is difficult because of the large number of seeds in the soil; one adult plant can disperse 2 million seeds each year. In addition, in North America there is a lack of native predators to control purple loosestrife, which contributes to its ability to expand. Purple loosestrife is being controlled through the use of biological agents, such as *Gallerucella* beetles, the physical removal of the plants, and the use of herbicides.

Curly-leaf Pondweed *(Potamogeton crispus)*

Curly-leaf pondweed is an aquatic plant native to Eurasia, Africa, and Australia that was introduced into the United States through an accidental aquarium release in the mid-1800s. Curly-leaf pondweed forms mats that interfere with aquatic recreation. Curly-leaf pondweed was the most severe aquatic nuisance plant in the Midwest until Eurasian watermilfoil was introduced.

DAVE BRENNER, MICHIGAN SEA GRANT

Purple Loosestrife

ROBERT F. FRECKMANN, UW STEVENS POINT, WISCONSIN STATE HERBARIUM

Curly-leaf Pondweed

Common Carp *(Cyprinus carpio)*

The common carp, native to Asia, was brought to the United States in the late 1800s by the U.S. Fish Commission as a food source. From 1890 to about 1895, as many as 35,000 carp were released into Wisconsin waters by the Wisconsin Fisheries Commission and are now found in 63 Wisconsin counties. Carp are considered a pest fish and populations in Lower Green Bay impact the ecosystem by uprooting submergent vegetation, which resuspends sediments and increases turbidity. They can be particularly damaging while spawning in shallow water.

NOAA, GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

Common Carp

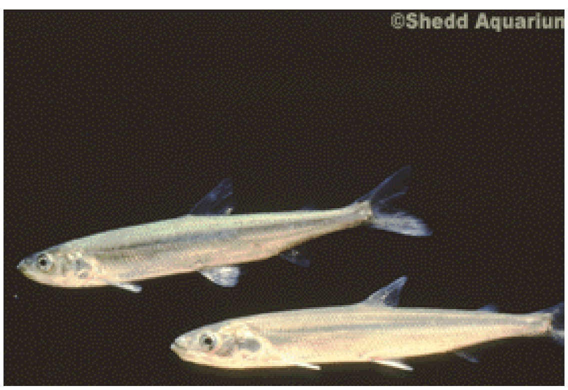
Rainbow Smelt *(Osmerus mordax)*

Smelt are a marine fish, native to the north Atlantic Coast of North America, although there are a few freshwater smelt native to lakes in Maine. Smelt were intentionally introduced into inland lakes in Michigan and escaped into Lake Michigan, and were first found in Lake Michigan and Green Bay in the 1920s. Smelt can compete with native fish species, such as yellow perch, for food. However, smelt have become an important sport and commercial fishery in Wisconsin. The number of smelt returning to area streams to spawn has fallen in recent years - a cause of concern to sport fishermen. According to the WDNR, in 2004, commercial trawlers harvested 155,000 pounds of rainbow smelt from Lake Michigan and Green Bay.

Sea Lamprey *(Petromyzon marinus)*

The sea lamprey, a primitive jawless fish native to Atlantic coastal regions, entered the Great Lakes via the Welland Canal. The sea lamprey was first found in Lake Michigan in the 1930s, and the date of their arrival into Green Bay is unknown. Sea lampreys are parasitic and attach to fish, including sport fish, feeding on body fluids, often killing the fish. Sea lampreys can have tremendous impacts on fish populations, since each sea lamprey can kill up to 40 pounds of fish in its lifetime. In the Great Lakes, sea lamprey populations are kept under control using several control methods including lampricides, trapping, barrier installations, sterile male release and pheromones. However, sea lamprey data for spawning at Oconto, Peshtigo, and other Green Bay tributaries increased in 2000-2007, and estimates of spawning-phase sea lamprey abundance are currently greater than target control values set in 2004 (Spade 2007).

FISHES OF THE GREAT LAKES, WISCONSIN SG



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CLOCKWISE:

Rainbow Smelt

Sea Lamprey on a Lake Trout

Sea Lamprey mouth

FISHES OF THE GREAT LAKES, WISCONSIN SG

Alewife

Alewife *(Alosa pseudoharengus)*

The alewife, native to the Atlantic Coast, entered the Great Lakes through the Welland Canal. The alewife was first found in Lake Michigan and Green Bay in the 1950s. Beginning in 1966, several salmon species were introduced into Lake Michigan to control alewife populations. The alewife preys on larval yellow perch and can compete with native fish species for food. Fewer salmon are being stocked as a consequence of reduced alewife abundance reflected in periodic forage fish trawls (USGS).

NOAA, GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY

White Perch

White Perch *(Monroe americana)*

White perch are native to Atlantic coastal regions and entered the Great Lakes through the Erie and Welland canals. White perch first appeared in Green Bay in 1988. The fish are of concern in the Green Bay area because of their potential to compete with yellow perch, as a predator of fish eggs, and their ability to interbreed with white bass. In western Lake Erie, white perch were found to have hybridized with native white bass. Anglers and commercial fishers are interested in harvesting white perch in Green Bay, however there are fish consumption advisories in place due to elevated PCB concentrations. Learn more about white perch in the Fish section.

TIM RASMAN

Round Goby in Green Bay

Round Goby *(Neogobius melanostomus)*

Round gobies, native to the Black and Caspian Sea Region of Europe, were probably introduced via ballast water. Round gobies are aggressive fish that eat fish eggs, such as smallmouth bass eggs, and benthic invertebrates, including zebra and quagga mussels. The round goby was first found in mid-Green Bay in 1998 (Lederer et al. 2006) and in southern Green Bay in 2001 (USGS). In Green Bay as in other parts of the Great Lakes where both round gobies and smallmouth bass are abundant, round gobies are capable of eating all the eggs from a nest. In addition, the round goby is a bottom-dwelling fish that competes with native fish species for food and habitat. In Green Bay, round gobies compete with smallmouth bass fry for food, but once big enough smallmouth bass eat round gobies. Additionally, a recent study conducted in 2003 along eastern Green Bay in Door County looked at the round goby impacts on zebra and quagga mussels as well as other benthic macroinvertebrates (Lederer et al. 2006). This study found that round gobies feed upon zebra and quagga mussels, as well as other benthic macroinvertebrates, such as isopods and snails. Also, since round gobies prey upon zebra and quagga mussels, there is a loss of microhabitat and food produced by zebra and quagga mussels, which negatively impacts other benthic macroinvertebrates (Lederer et al. 2006). More recently, it has been found that round gobies are moving into tributaries of the Great Lakes and Green Bay, including the Fox, Suamico, Little Suamico, Pensaukee, and Oconto rivers (Kornis and Vander Zanden, 2010; Kornis et al. 2013). This secondary invasive of round gobies into tributaries could impact fish species that depend on tributaries for habiat and refuge (Kornis and Vander Zanden, 2010; Campbell and Tiegs, 2012; Kornis et al. 2013).

Eurasian Ruffe *(Gymnocephalus cernuus)*

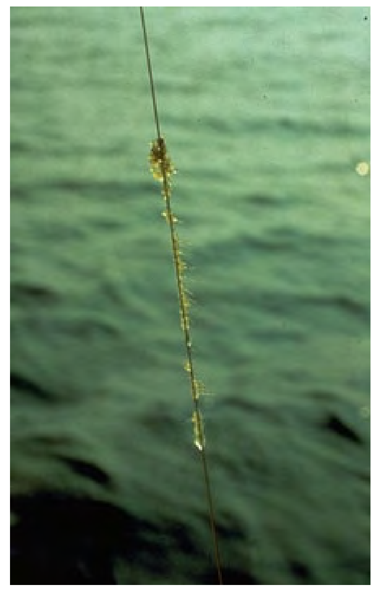
Ruffe are native to Eurasia and were introduced to the Duluth Harbor on Lake Superior through ballast water in 1986. Ruffe are a problem because they compete with native fish species for food and habitat. Ruffe were first found in Green Bay in Little Bay de Noc in 2002 and were found in Big Bay de Noc in 2004 (USFWS 2006). In the summer of 2007, a ruffe was caught by a commercial fisherman off Marinette in Green Bay (WDNR).

GARY CHOWLEK, NATIONAL BIOLOGICAL SERVICE

Eurasian Ruffe

Spiny Waterflea *(Bythotrephes cederstroemi)* and Fishhook Waterflea *(Cercopagis pengoi)*

The spiny and fishhook waterfleas are native to the Black and Caspian Sea region of Europe and most likely entered the Great Lakes in ballast water. The spiny waterflea was first found in southern Green Bay in 1987 (Schneeberger 1991), and the fishhook waterflea was found in Lake Michigan in 1999. It is unknown if and when the fishhook waterflea invaded Green Bay because the WDNR does not distinguish between the spiny and fishhook waterflea (Wisconsin DNR personal communication). Both the spiny and fishhook waterfleas are crustaceans, not insects, and feed on smaller zooplankton and larval fish. Since they feed on small zooplankton, they compete with juvenile fish species for food. Also, the long spiny tails makes it difficult for predators to feed on them. Both the spiny and fishhook waterfleas can reproduce rapidly asexually, without males. The spiny and fishhook waterfleas possess a long tail spine that can foul fishing lines.

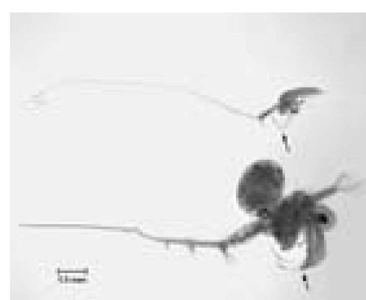


JEFF GUNDERSON/MINNESOTA SEA GRANT

Spiny Waterflea on Fishing Line

Zebra Mussel *(Dreissena polymorpha)*

One of the most notorious invasive species in the Great Lakes is the zebra mussel. Zebra mussels are small mollusks native to the Black and Caspian Sea region of Europe that most likely entered the Great Lakes from ship ballast water. They have now spread throughout the Great Lakes, including Green Bay. Zebra mussels can attach to any hard surface, including rocks, floating debris, and even the shells of native mussel species. In addition to displacing native species, zebra mussels also cost the United States billions of dollars from clogged and damaged water intake structures for municipal, industrial, and hydroelectric plants. Zebra mussels can also affect the entire lake ecosystem; they are filter feeders that tend to increase water clarity.



J. LIEBIG, NOAA, GLERL

Fishhook (top)

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Zebra mussel

FRED SNYDER, OHIO SEA GRANT

Zebra mussels on a native clam

Zebra mussels spread in several ways. Zebra mussel veligers (larva) float and can be carried in bilge water and in livewells. Also, juveniles and adults can attach to surfaces such as boats, boating equipment, and aquatic vegetation.

Zebra mussels were first found in the Great Lakes in 1988 and in Green Bay in June of 1991 (Kraft 1991-1995). However, they did not become a dominant organism in Green Bay until 1993 (Figure 55). In the summer of 2000, sampling of several sites throughout Lower Green Bay found that densities of zebra mussels varied by location, where the East Shore sites had more zebra mussels than the West Shore sites (Figure 56) (Fettes 2001). In August of 2003, less than 10% of sites sampled had zebra mussels present (41 out of 444 sites) (Figure 57) (Reed 2004). Overall, the distribution of zebra mussels in Green Bay and particularly in the AOC is patchy.

One study found that zebra mussels became an abundant food source for diving ducks in Green Bay (Harris 1998). After the establishment of zebra mussels in Green Bay, fall diving duck use days increased by more than 200%, and this increase was attributed to an increase in mollusk-feeding ducks, such as goldeneye (Harris 1998).

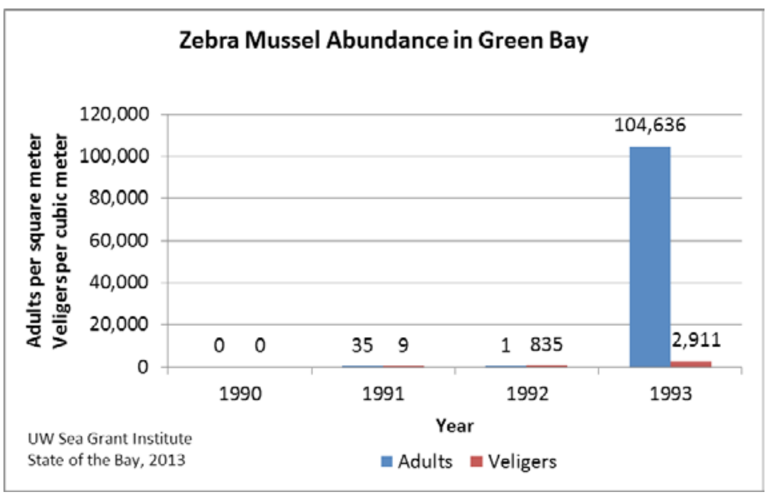


Figure 55: Mean density of zebra mussel adults and veligers (larvae) in Green Bay from 1990-1993 (Kraft 1991-1995).

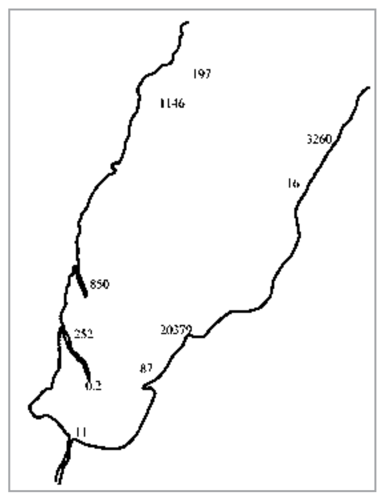


Figure 56: Mean zebra mussel densities (m-2) at sites in Lower Green Bay sampled in the summer of 2000. Adapted from Fettes 2001.

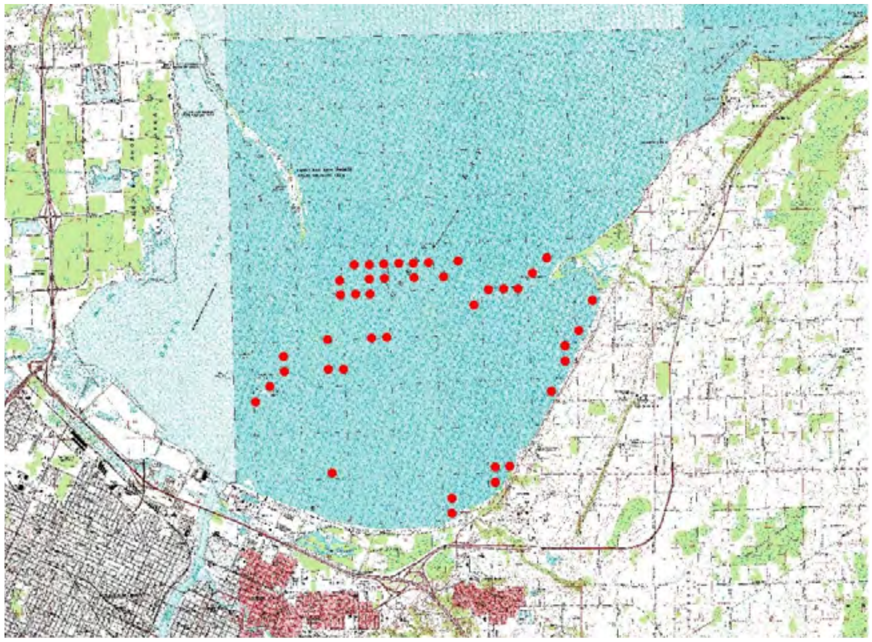


Figure 57: Location of zebra mussels, indicated by the red dots, found in the AOC in August 2003 (Reed, 2004).

Quagga Mussel *(Dreissena bugensis)*

Quagga mussels are non-native mussels that are similar to the zebra mussel, although they differ in genetic composition and shell morphology. Quagga mussels were first found in the Great Lakes in 1989, one year after the arrival of zebra mussels. Even though it took quagga mussels longer to spread to the other Great Lakes than zebra mussels, once quagga mussels became established their populations rapidly increased. Quagga mussels have the same ecological impacts as zebra mussels, but they have the potential to cause even more damage because they can live in deeper and colder water than zebra mussels, and since quagga mussels have a flatter shell, they can colonize soft substrates. In addition, because quagga mussels are more efficient than zebra mussels, they can out-compete them for nutrients.

J. ELLEN MARSDEN, LAKE MICHIGAN BIOLOGICAL STATION

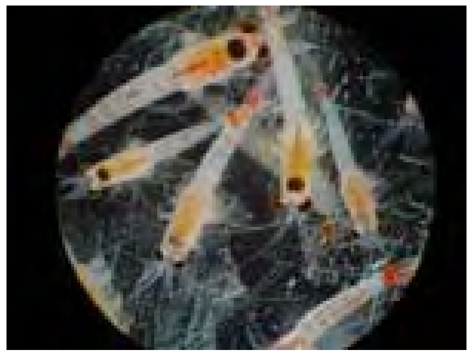
Zebra mussels and quagga mussels

The quagga mussel was found in the Straits of Mackinac in 1997 (Nalepa et al. 2001), and they were first reported in Green Bay in 2003 (Lederer et al. 2006). A survey of 160 sites across Lake Michigan found that quagga mussels are replacing the zebra mussel (Nalepa 2007). In 2000, zebra mussels made up over 98% of the invasive mussel population; in 2005, quagga mussels made up 98% of the population (Nalepa 2007). In Green Bay, it has been reported that quagga mussels are taking over in the upper bay, particularly in the deeper parts (Tara Reed, personal communication). In Lower Green Bay, distribution of both zebra and quagga mussels is patchy (Tara Reed, personal communication).

Bloody Red Shrimp *(Hemimysis anomala)*

The bloody red shrimp is a new invader that was first reported in the Great Lakes by the National Oceanic and Atmospheric Administration (NOAA) in November of 2006 in Lake Michigan. It is a small (less than ½ inch) shrimp-like crustacean native to the Black and Caspian seas and was most likely introduced through ballast water. As of October of 2007, the bloody red shrimp has been found in Lake Michigan, Lake Erie, Lake Ontario and the northern waters of Green Bay. The bloody red shrimp is found on hard bottom substrates and avoids soft bottoms. The impacts from this invader on the ecosystem are unknown, but it may compete with young fish for food and it may be a good food source for larger fish. The bloody red shrimp has been preyed upon by round gobies, white perch, yellow perch, and alewife.

MICROPHOTOGRAPH BY S. POTHOVEN, GLERL



Bloody red shrimp

Aquatic Invasive Species Outreach Around Green Bay

Aquatic invasive species prevention education and outreach efforts in and around Green Bay have helped mitigate the negative impacts that these invaders have. These efforts have helped limit the spread of these invaders out of Green Bay. They have also helped educate Green Bay user groups and the general public on the impacts of aquatic invasive species, actions they can take to prevent the spread of aquatic invasive species, and in some cases, ways they can volunteer to help prevention efforts grow.

The Clean Boats Clean Waters program is a great example of one of these efforts. This program educates boaters at access points on the impacts of invasive species and actions they can take to prevent the spread of aquatic invasive species. In the Green Bay area, the bulk of these efforts come from a watercraft inspector program run by the University of Wisconsin Sea Grant Institute in cooperation with the WDNR. Last year, UW Sea Grant hired nine part-time inspectors and a coordinator for the watercraft inspection efforts. These interns inspected over 6,000 watercraft and contacted over 13,000 people in 2012. A majority of this time was spent around the Green Bay area. Volunteer Clean Boats Clean Waters efforts are providing additional outreach efforts to the boaters of Green Bay.

In addition to Clean Boats Clean Waters, there are full-time outreach staff whose efforts are focused on Green Bay. Aquatic invasive species coordinators are county-level staff. Currently, the coordinators cover Marinette, Oconto, Door, and Kewaunee counties. There are also regional staff that cover Green Bay. The Wisconsin DNR has a Great Lakes aquatic invasive species monitoring and outreach specialist stationed in Green Bay, while UW Sea Grant has a Great Lakes outreach specialist that covers the Great Lakes Basin. Search “Aquatic Invasive Species Contacts” on the Wisconsin DNR website to find the aquatic invasive species contacts for Green Bay.

References

Campbell, T.B. and S.D. Tiegs. 2012. Factors Governing the Distribution and Fish-Community Associations of the Round Goby in Michigan Tributaries of the Laurentian Great Lakes. *Journal of Great Lakes Research*. 38 (3): 569-574.

Fettes, A.L. 2001. *The Bottom of the Bay Then and Now: Investigations into both the Zebra Mussels Colonizing Green Bay and the Pre-Invasion Macroinvertebrate Community.* M.S. Thesis. University of Wisconsin, Green Bay.

Harris, V. A. 1998. *Waterfowl use of Lower Green Bay Before (1977-1978) and after (1994-1997) Zebra Mussel Invasion*. M.S. Thesis. University of Wisconsin, Green Bay.

Kornis, M.S., S. Sharma and M.J. Vander Zanden. 2010. Invasion Success and Impact of an Invasive Fish, Round Goby, in Great Lakes Tributaries. *Diversity and Distributions*. 19: 184-198.

Kornis, M.S. and M.J. Vander Zanden. 2012. Forecasting the Distribution of the Invasive Round Goby *(Neogobius melanostomus)* in Wisconsin Tributaries to Lake Michigan. *Canadian Journal of Fisheries and Aquatic Sciences*. 67: 553-562.

Kraft, C. 1991-1995. *Zebra Mussel Update* newsletter. University of Wisconsin-Sea Grant Advisory Services. Green Bay, Wisconsin #8-24.

Lederer, A., J. Massart, and J. Janssen. 2006. Impact of Round Gobies (*Neogobius melanostomus)* on Dreissenids *(Dreissena polymorpha and Dreissena bugensis)* and the Associated Macroinvertebrate Community Across an Invasion Front. *Journal of Great Lakes Research*. 32(1): 1-10.

Mills, E.L., J.H. Leach, J.T.Carlton, and C.L. Secor.1993. Exotic Species in the Great Lakes: A History of Biotic Crisis and Anthropogenic Introduction. *Journal of Great Lakes Research*. 19(4): 1-54.

Nalepa, T.F., D.W. Schloesser, S.A. Pothoven, D.W. Hondorp, D.F. Fanslow, M.L. Tuchman, and G.W. Fleischer. 2001. First Finding of the Amphipod *Echinogammarus* and the Mussel *Dreissena bugensis* in Lake Michigan. *Journal of Great Lakes Research*. 27(3): 384-391.

Nalepa, T.F. 2007. *The Continued Expansion of the Quagga Mussel Population in Lake Michigan*. Lake Michigan: State of the Lake Conference 2007, Michigan. Oral presentation.

Reed, T. 2004. *Survey of Submergent Vegetation in Inner Green Bay Prior to Cat Island Chain Restoration*. Final report to the Wisconsin Coastal Management Program.

Ricciardi, A. 2001. Facilitative Interactions among Aquatic Invaders: Is an "Invasional Meltdown" Occurring in the Great Lakes? *Canadian Journal of Fisheries and Aquatic Sciences*. 58: 2513-2525.

Rothlisberger, J.D., D.C. Finoff, R.M. Cooke, and D.M. Lodge. 2012. Ship-borne Nonindigenous Species Diminish Great Lakes Ecosystem Services. *Ecosystems*. 15: 462-475.

Schneeberger, P.J. 1991. Seasonal Incidence of *Bythotrephes cederstroemi* in the Diet of Yellow Perch (ages 0-4) in Little Bay de Noc, Lake Michigan, 1988. *Journal of Great Lakes Research*. 19(2): 281-285.

Spade, J. 2007. *Status of Sea Lampreys in Lake Michigan in 2006*. Lake Michigan: State of the Lake Conference 2007, Michigan. Oral presentation.

Links

Wisconsin Invasive Species-WDNR:
http://dnr.wi.gov/topic/Invasives

National Sea Grant Network Exotic Species Graphics Library:
http://www.iisgcp.org/NabInvader/sgnisimages/CATALOG1.HTM

Information on non-indigenous species-Wisconsin Sea Grant:
http://www.seagrant.wisc.edu/home/Topics/InvasiveSpecies.aspx

Information on Great Lakes Exotic Species:
http://www.great-lakes.org/exotics.html

Information on Great Lakes Invasive Species:
http://www.great-lakes.net/envt/flora-fauna/invasive/invasive.html

Great Lakes Aquatic Nonindigenous Species Informational System (GLANSIS)
(includes information on Hemimysis anomala):
http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html

Information on how to stop the spread of aquatic invasive species:
http://www.protectyourwaters.com

Information and distribution maps of invasive species-USGS:
http://nas.er.usgs.gov/

Invasive Northeastern Wisconsin Plants:
http://www.uwgb.edu/biodiversity/herbarium/invasive_species/invasive_plants01.htm

BENTHIC MACROINVERTEBRATES

Status: Poor
Trend: Unchanging

Background

Benthic macroinvertebrates, invertebrates that live on the bottom of aquatic habitats, include insects, worms, leeches, snails, and mussels. These organisms are an important food source for fish and waterfowl and are important as processors of organic particles. Benthic macroinvertebrates are indicators of environmental health and water quality because they live in aquatic habitats for all or most of their lives, are easy to collect and identify, differ in their pollution tolerance, are relatively long-lived and immobile, and are integrators of environmental conditions.

Degraded benthos was listed in the Lower Green Bay RAP as one of the use impairments in the AOC (WDNR, 2012). This was primarily because of low diversity and abundance of benthic macroinvertebrates in the AOC. In order for the degradation of benthos use impairment to be delisted, the WDNR developed criteria that need to be met. These criteria include:

- Completion of remediation for known contaminated sediment sources and monitoring according to an approved plan and meet the remedial action goal.
- The benthic community index of biological integrity (IBI) within the site being evaluated is statistically similar to a reference site with similar habitat and minimum sediment contamination
- *Hexagenia* (mayfly) populations return to the AOC in stable annual abundances between 100-400 nymphs/m2.
- Sediment toxicity is not present at levels that are acute or chronically toxic to the benthic community.
- Native benthic communities adequately support the trophic level species that depend upon them.

Major Groups

Based on differences in pollution tolerance, benthic macroinvertebrates can be classified as sensitive, moderately tolerant, or pollution tolerant (Table 17). Generally, a greater variety of organisms or "richness" is consistent with a healthier environment. Examples of sensitive benthic macroinvertebrates include plecoptera (stoneflies), ephemeroptera (mayflies), and mussels and clams. Mayflies have a wide range of pollution tolerance, but some species are pollution intolerant, and mussels are sensitive to low dissolved oxygen. Amphipods (scuds and sideswimmers), isopods (sow bugs), and trichoptera (caddisflies) are examples of moderately tolerant bentho organisms. Pollution tolerant macroinvertebrates, indicating very poor water quality, include oligochaetes (aquatic worms), chironomids (midgeflies), and hirudinea (leeches).

Table 17: Examples of sensitive, moderately tolerant, and pollution tolerant benthic macroinvertebrates.

Sensitive Benthos	Moderately Tolerant Benthos	Pollution Tolerant Benthos
Stonefly 	Amphipods 	Oligochaetes 
Mayfly 	Isopods 	Midgefly Larvae 
Mussels 	Caddisfly 	Leeches 

ALL PHOTOS FROM THE EPA

Green Bay Historical Trends

Benthic macroinvertebrates have been monitored in Green Bay since the mid-1900s. Data collected from stations during the 1930s found mainly pollution tolerant organisms (chironomids and oligochaetes), but at several stations more pollution sensitive benthic macroinvertebrates, such as *Hexagenia* (a genus of mayflies), fingernail clams and snails were present (WDNR 1985). Additionally, small numbers of other benthic macroinvertebrates were found including leeches, isopods, amphipods, baetid mayfly nymphs, damselfly nymphs, and caddisfly larvae.

In 1952, 1969, and 1978 stations were sampled in Green Bay to find out if changes were occurring in the benthic community. In 1952, oligochaetes and chironomids were the dominant organisms, and Hexagenia was found at only one station (Surber and Cooley 1952). From 1952 to 1969, oligochaete abundance increased in the inner bay, distribution of more pollution sensitive species (such as fingernail clams, snails, and amphipods) decreased, and no *Hexagenia* were found (Howmiller and Beeton 1971). In 1978, oligochaetes and chironomids were again the dominant organisms found, however oligochaetes's relative abundance decreased to 57%, whereas the relative abundance of fingernail clams increased (Table 18) (Harris 1998). As in 1969, no *Hexagenia* were found in 1978 (Harris 1998).

In the late 1970s through the early 1990s (1978, 1983, 1987, and 1994), Integrated Paper Services, Inc., of Appleton monitored benthic macroinvertebrates in Green Bay. As in previous studies, the data was analyzed to determine benthic community changes (Fettes 2001). Overall, species richness (total number of species at each location) was greater in 1994 than in 1978 (Fettes 2001) (Figure 58). Looking at oligochaetes, in all four years, the inner bay (zone 1) was classified as highly polluted and the rest of the bay has become more polluted over the years (Figure 59). In 1994, only one site was considered to have low pollution compared to five sites in 1978. Chironomids were found in high densities in the inner bay, but there were no apparent trends in chironomids over time (Figure 60). In all four years, fingernail clams were absent in the inner bay, and densities of fingernail clams decreased though the years (Figure 61). Densities of *Diporeia* increased between 1978 and 1994 in Upper Green Bay (Figure 62), and isopods were found at the fewest number of sites in 1994 (Figure 63).

Table 18: The relative abundance (percent) of benthic macroinvertebrates from 27 stations in Lower Green Bay.

Taxon	1952	1969	1978
Oligochaetae	83.0%	83.0%	57.0%
Chironomidae	11.0%	15.3%	24.0%
Sphaeriidae	4.5%	1.6%	15.0%
Gastropoda	0.5%	0.03%	1.0%
Amphipoda	0.5%	0.09%	0.7%
Isopoda	0.1%	0.06%	2.0%
Hirudinea	0.7%	0.02%	0.5%

Source: Harris 1998

Current Status: Fox River

Benthic macroinvertebrate populations remain impaired within the Fox River below the De Pere dam. A 1999 study of depositional substrates within the AOC stated that the benthic community "throughout the past 19 years has remained relatively poor and suggests compromised physiochemical conditions" (Integrated Paper Services, 2000). More recently, the WDNR deployed an artificial substrate sampler in the Lower Fox River in 2005 and 2011. The 2005 and 2011 Lower Fox River Index of Biotic Integrity (IBI) scores were 10 and 9 respectively or "very poor" on a qualitative rating scale between 0 (worst) and 100 (best) (Weigel and Dimick, 2011). Benthic macroinvertebrate monitoring is a new addition to the WDNR's Tier I Monitoring Program and will be repeated in the Lower Fox River on a five-year cycle. In addition, in the spring and summer of 2012, benthos samples were collected using ponar grabs and artificial substrate samples at two sites in the Fox River, but results are not yet available (WDNR, 2012).

Current Status: Lower Green Bay

In June 2011, the Great Lakes WATER Institute collected benthic macroinvertebrate samples from 21 stations throughout Southern Green Bay to determine current population trends for comparison with historic data collected by Harris 1978, Howmiller 1969, and Surber 1952 (Rupp and Kaster, 2011). Rupp and Kaster (2011) list changes from historic samples that include "notable decline in populations of worms (Oligochaeta), midge larvae (Chironomidae), isopods, and fingernail clams within the past thirty years" and no *Hexagenia* were recorded in any of the samples. Adult *Hexagenia* mayflies have been occasionally observed in the area and a single nymph was found during an educational sampling activity by the *RV Jackson* near the GBMSD outfall (Victoria Harris, UW Sea Grant Institute, personal communication). Preliminary results of an experiment on *Hexagenia* egg viability in Green Bay sediments suggest that sediment quality did not limit *Hexagenia* egg or nymph survival (Jerry Kaster, UW-Milwaukee, personal communication). *Hexagenia* may be present in the AOC but in quantities insufficient to be documented in recent studies.

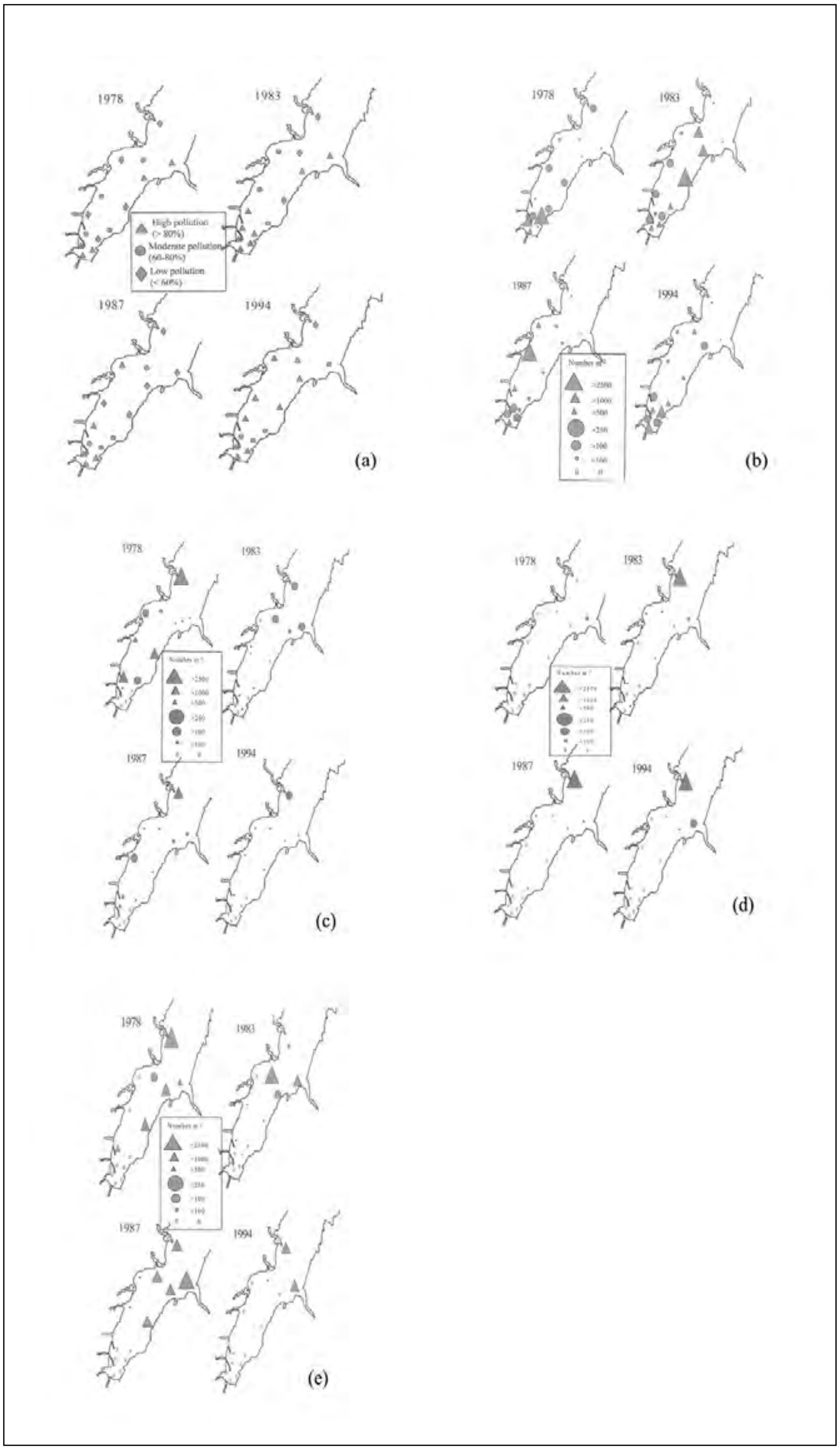


Figure 58: Comparison of the distribution (a) oligochaetes and (b) chironomids and (c) fingernail clams (*Sphaeriidae*) and (d) the amphipod, *Diporeia* and (e) isopods. From Fettes, 2001.

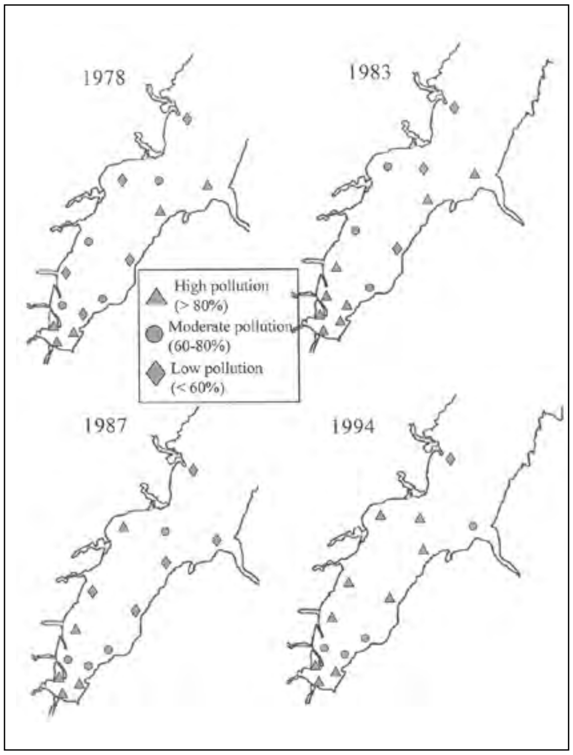


Figure 59: Comparison of the distribution of oligochaetes. From Fettes, 2001.

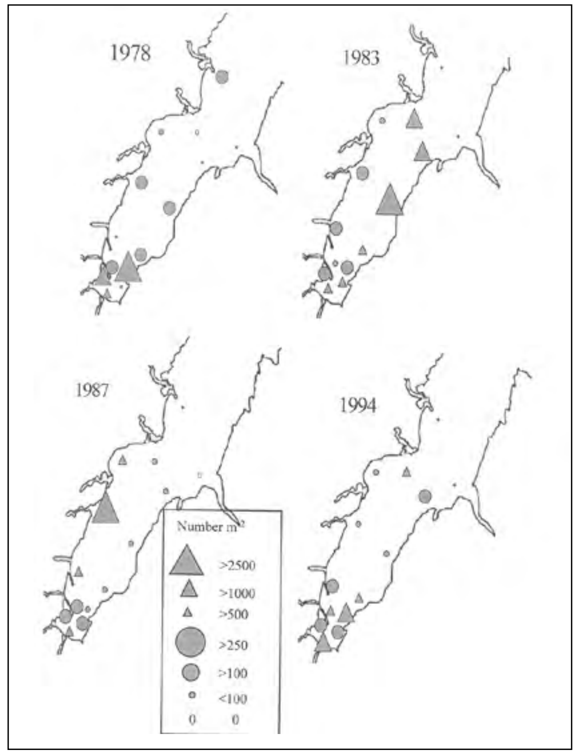


Figure 60: Comparison of the distribution of chironomids. From Fettes, 2001.

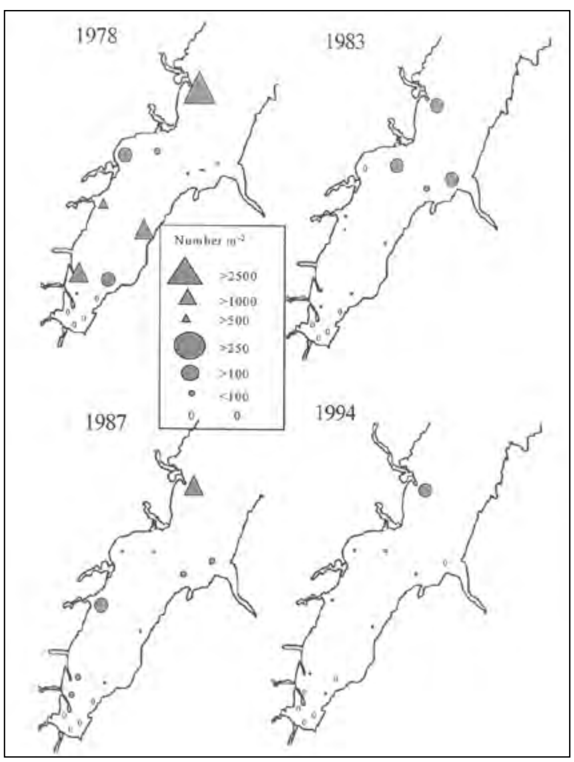


Figure 61: Comparison of the distribution of fingernail clams (*Sphaeriidae*). From Fettes, 2001.

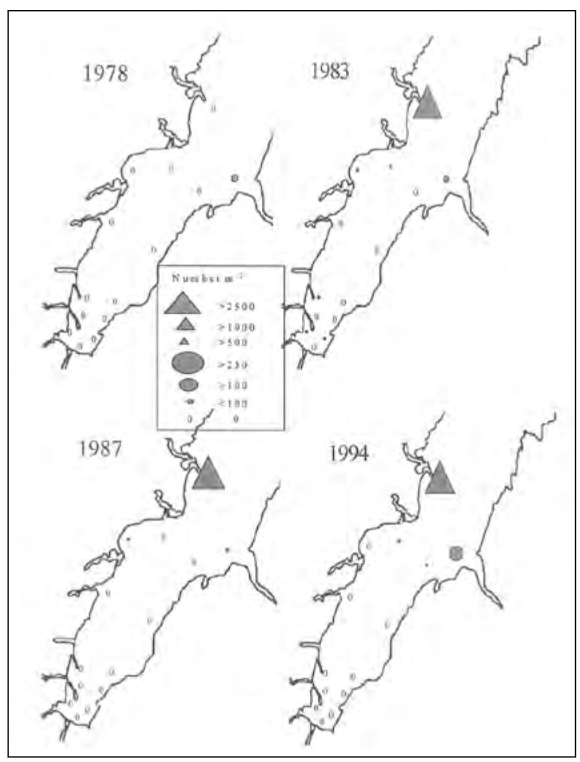


Figure 62: Comparison of the distribution of the amphipod, *Diporeia*. From Fettes, 2001.

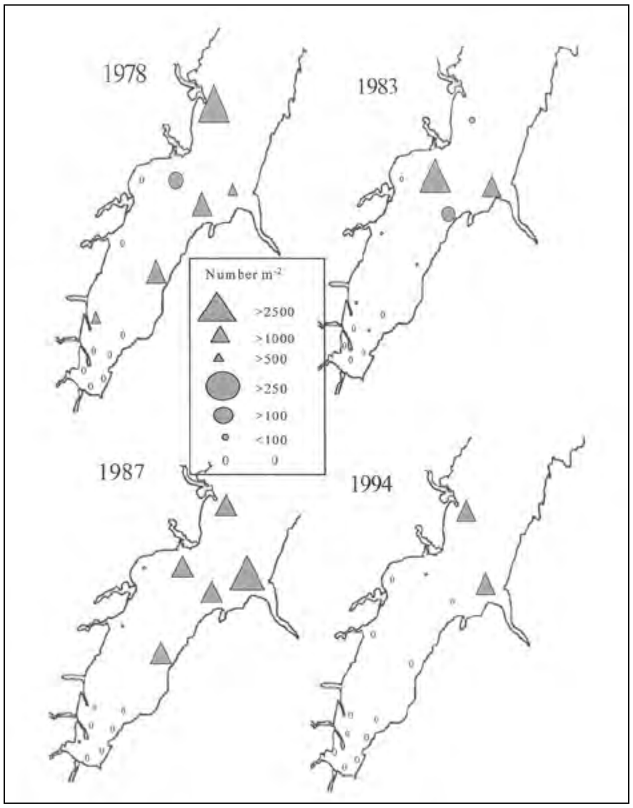


Figure 63: Comparison of the distribution of isopods. From Fettes, 2001.

References

Fettes, A. L. 2001. *The Bottom of the Bay Then and Now: Investigations into both the Zebra Mussels Colonizing Green Bay and the Pre- Invasion Macroinvertebrate Community*. M.S. Thesis. University of Wisconsin, Green Bay.

Harris, V. A. 1998. *Waterfowl use of Lower Green Bay Before (1977-1978) and After (1994-1997) Zebra Mussel Invasion*. M.S. Thesis. University of Wisconsin, Green Bay.

Howmiller, R.P. and A.M. Beeton. 1971. Biological Evaluation of Environmental Quality, Green Bay, Lake Michigan. *Journal Water Pollution Control Federation*, Washington, D.C., 43(1)123-133.

Integrated Paper Services, Inc. 2000. *A Macroinvertebrate Study of the Depositional "Soft" Substrates of the Lower Fox River, Wisconsin – 1999*. Project 5015. Monitoring Study Series Report No. Four.

Rupp, D.L. and J.L. Kaster. 2011. *Benthic Habitat Survey and Historical Exosystem Evaluation of the Lower Green Bay, The Recruitment of* Hexagenia *Mayfly Nymphs on Green Bay Sediment*. UW-Milwaukee WATER Institute unpublished report.

Surber, E.W. and H.L. Cooley. 1952. Bottom Fauna Studies of Green Bay, WI, in Relation to Pollution. *U.S. Public Health Service and WI State Comm. Water Poll.* 7 pp.

Weigel, B. and J.J. Dimick. 2011. Development, Validation, and Application of a Macroinvertebrate Based Index of Biotic Integrity for Nonwadeable Rivers of Wisconsin. *Journal of the North American Benthological Society*. 30(3): 665-679.

Wisconsin Department of Natural Resource: Bureau of Water Resources Management and Bureau of Fish Management. 1985. *Lower Fox River-De Pere to Green Bay Water Quality Standards Review*.

Wisconsin Department of Natural Resources. 2012. *Stage 2 Remedial Action Plan Update for the Lower Green Bay and Fox River Area of Concern*. Draft. December 2012.

COASTAL WETLANDS

Status: Fair
Trend: Deteriorating

Geology of Green Bay/West Shore

Natural features of our landscapes (forests, lakes, wetlands, etc.) are largely created by the geology of the region. This is certainly true for the coastal wetlands of Green Bay, which are mostly found on the gently sloping west shore of the bay. The east side of Green Bay has only a few wetlands in shallow bays and at river mouths, due to a steep dolomitic outcropping called the Niagara Escarpment.

The edge of the bowl for Lake Michigan pierces the earth's surface near Green Bay and consists of three layers (Figure 64). The hard Silurian dolomite is the upper layer. It slopes gently to the east, and has remained relatively resistant to erosion. The middle layer, the softer Maquoketa Formation, has been scraped away by glaciers to reveal the harder, more erosion-resistant Sinnipee Formation. As the glaciers receded, the Sinnipee Formation became flooded and now forms the bedrock under the gently sloping bed of Green Bay and the west shore coastal zone, which was conducive to the development of coastal wetlands.

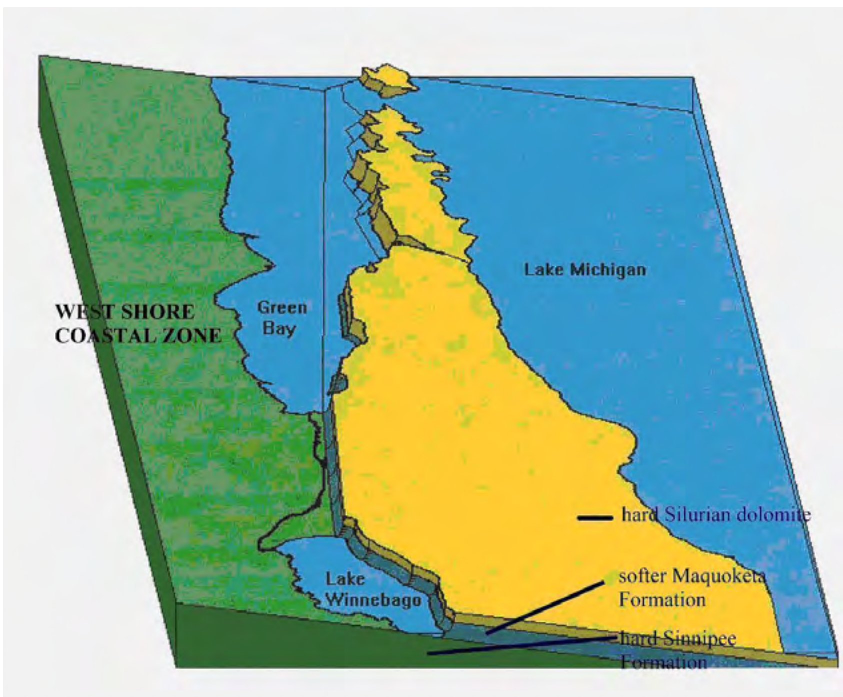


Figure 64: Green Bay post-glacial geology (by Steven Dutch, UWGB). Figure from Rost 2003.

What are Coastal Wetlands?

In 1978, the Wisconsin State Legislature defined wetlands as:

"An area where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic (water-loving) vegetation and which has soils indicative of wet conditions."

From the Wisconsin Department of Natural Resources (WDNR): http://dnr.wi.gov/topic/wetlands/function.html

Coastal wetlands are typically characterized by transitional zones from aquatic to upland, and each of the zones can be recognized by the wetland vegetation present (Figure 65).

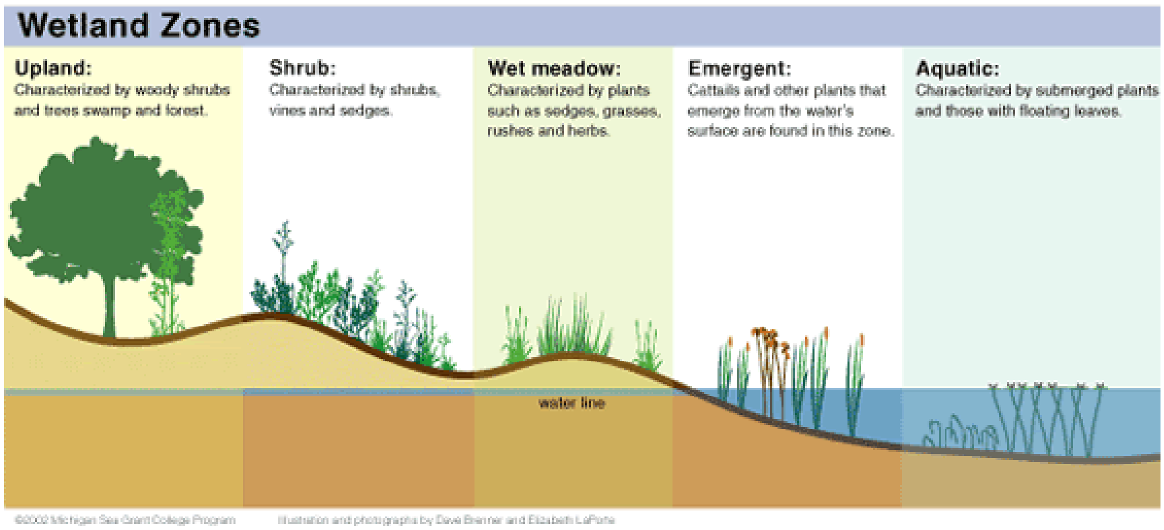


Figure 65: Diagram of a typical coastal wetland transition from lake to upland. Figure from Michigan Sea Grant.

Wetlands vary significantly in form and function. Six main types of Great Lakes coastal wetlands are readily recognized—lagoon and barrier, ridge and swale, shoreline, embayed, riverine, and delta.
Where are the Coastal Wetlands?

The west shore of Green Bay is a major wetland complex for Lake Michigan. Approximately half of the coastal wetlands in Wisconsin are located along the west shore of Green Bay (Table 19).

Table 19: Wetland acreage per county within the coastal zone.

County	Total Surface Area (Acres)	Acres of Wetland	% of County Mapped as Wetland	Wetlands as % of Statewide Total
Brown	335,360	25,288	7.5	0.5
Door	314,880	52,559	16.7	1
Kewaunee	219,520	31,933	14.5	0.6
Marinette	892,800	227,708	25.5	4.3
Oconto	641,280	160,263	25	3

Data source: WDNR, Coastal Wetland, Phase 1 Report: http://dnr.wi.gov/topic/wetlands/cw/reports_maps.asp

The WDNR conducted an assessment of existing coastal wetlands to determine coastal wetland sites that are ecologically significant and to identify data gaps. (http://dnr.wi.gov/topic/wetlands/cw). The project identified 64 primary sites within the coastal areas of Lake Michigan and Lake Superior. Twenty-four of the sites are located in the northern Lake Michigan coastal region, with 16 of the sites around Green Bay (Figure 66 and Table 20). The WDNR website provides a detailed description and photographs of each wetland site, http://dnr.wi.gov/topic/wetlands/cw/NLMich.

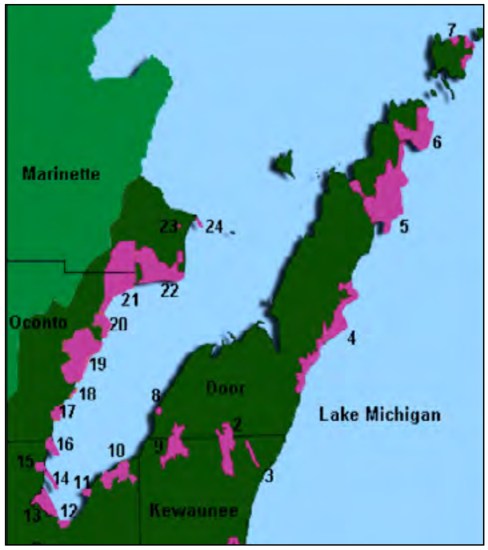


Figure 66: Wetland sites around Lake Michigan and Green Bay. Map adapted from the WDNR, http://dnr.wi.gov/topic/wetlands/cw/NLMich.

Table 20: Wetland sites and acreage by site around Lake Michigan and Green Bay.

Number	Wetland	Total Acreage	Wetland Acreage
1	Kewaunee River Wetland Complex	1,930	810
2	Black Ash Swamp Area	5,660	4,600
3	Ahnapee River Wetlands	890	480
4	Shivering Sands Area	12,020	6,590
5	Northeast Coast Door County Area	20,600	8,670
6	Upper Door County Area	9,160	1,640
7	Washington Island Wetlands	2,020	350
8	Renard Swamp Area	300	130
9	Duvall Swamp	5,290	2,800
10	Red Banks Glades	5,300	1,610
11	Point au Sable	310	200
12	Whitney Slough	550	300
13	Lower Green Bay	4,090	490
14	Longtail Point	1,120	300
15	Sensiba Wildlife Area	530	450
16	Little Tail Point	1,600	550
17	Mud Creek Wetland	1,370	800
18	Charles Pond	440	210
19	Pensaukee River Wetland Complex	16,290	6,390
20	Oconto Marsh	3,700	2,340
21	County Line Swamp	15,730	10,630
22	Lower Peshtigo River	11,480	6,890
23	Ansul Patterned Dunes	120	10
24	Seagull Bar	270	50

Data Source: http://dnr.wi.gov/topic/wetlands/cw/NLMich

Why are Coastal Wetlands Valuable?

Coastal wetlands are transition zones between land and water. As such, they are areas of diverse physical conditions and habitat and support a large number of different plants and animals. In addition, they are productive ecosystems that produce a quantity of plant biomass close to that produced by a temperate deciduous forest and approximately 18 times that of cultivated lands (Smith 1993). This large amount of biomass is produced over the growing season and then dies back, creating an environment rich in nutrients and organic matter. This "organic soup" hosts countless invertebrates and bacteria, which provide a food base for young-of-the-year fish. Clearly, these areas are of great importance to the Green Bay fishery. Popular fish species like yellow perch and northern pike use the submergent vegetation zone for spawning and nursery areas (please refer to fish section for more information). Other predator species, such as walleye, sunfish, and largemouth bass use this zone for feeding. Also, waterfowl use this zone extensively for feeding on both invertebrates and plant material. In addition to this important ecological value, wetlands provide recreational opportunities and aesthetic value.

SUBMERGED AQUATIC VEGETATION

Aquatic plants (macrophytes) can be divided into three groups—emergent, submergent, and floating plants. Emergents are rooted plants that reach above the water's surface. Submergents are mostly rooted and grow submerged under water. Floating plants may be rooted underwater, but their leaves float on the surface.

In Green Bay, submerged aquatic vegetation (outermost zone Figure 65) is essential to the overall health of the Green Bay ecosystem. Submergents form the basis of an important near shore (littoral community) and not only provide habitat and food but also anchor substrate, which helps to curtail resuspension. Unfortunately, there is limited information available on the distribution of submerged aquatic vegetation in Green Bay. Information is available on the distribution and species composition of submergent plants on the west shore of Green Bay from Duck Creek to Pensaukee for years 1989 and 1990 (Tables 21 and 22) (McAllister 1991). In August of 2003, 444 sites in the AOC were sampled, and submergent plants were present at only 27 sites (Reed 2004). Of the plants found, the majority were located along the west shore near Duck Creek (Figure 67). *Potamogeton pectinatus* (sago pondweed) was found at 25 of the 444 sites in 2003(Reed 2004). *Myriophyllum spicatum* (Eurasian watermilfoil) was located at two of the sites, and at one site both *Elodea canadensis* (Canadian waterweed) and *Potamogeton pectinatus* were found in 2003 (Reed 2004). These limited data sets are significant only to the extent that they record the presence of these species at a particular point in time.

Table 21: Submerged aquatic vegetation species list.

Site	1989	1990
Duck Creek	*Potamogeton pectinatus*	*Potamogeton pectinatus*
Sensiba	*Vallisneria americana*	*Vallisneria americana*
	Myriophyllum spicatum	*Myriophyllum spicatum*
	Potamogeton pectinatus	*Potamogeton pectinatus*
	Potamogeton Richardson	*Potamogeton Richardson*
	Heteranthera dubia	*Heteranthera dubia*
	Najas flexilis	*Potamogeton spp. 1*
Little Tail	*Vallisneria americana*	*Vallisneria americana*
	Myriophyllum spicatum	*Myriophyllum spicatum*
	Heteranthera dubia	*Heteranthera dubia*
	Potamogeton pectinatus	*Potamogeton pectinatus*
	Potamogeton richardsonii	*Potamogeton richardsonii*
	Elodea canadensis	*Potamogeton spp. 1*
Little Suamico	*Vallisneria americana*	*Vallisneria americana*
	Myriophyllum spicatum	*Myriophyllum spicatum*
	Potamogeton pectinatus	*Potamogeton pectinatus*
		Ceratophyllum demersum
Pensaukee	*Vallisneria americana*	*Potamogeton pectinatus*
	Potamogeton pectinatus	*Myriophyllum spicatum*
	Myriophyllum spicatum	*Potamogeton richardsonii*
	Potamogeton richardsonii	*Potamogeton gramineus*
	Elodea canadensis	*Potamogeton spp. 1*
	Potamogeton spp. 2	

Data Source: McAllister 1991
Note: Two unidentified species of Potamogeton *are referred to as species 1 and 2.*

Table 22: Species and common names of submerged aquatic vegetation found in Green Bay.

Species Name	Common Name
Vallisneria americana	Wild Celery
Myriophyllum spicatum	Eurasian water milfoil
Potamogeton pectinatus	Sago pondweed
Potamogeton richardsonii	Richardson's pondweed
Potamogeton gramineus	Grass-leaved pondweed
Najas flexilis	Northern water-nymph
Elodea canadensis	Canadian waterweed
Ceratophyllum demersum	Coontail
Heteranthera dubia	Water star-grass

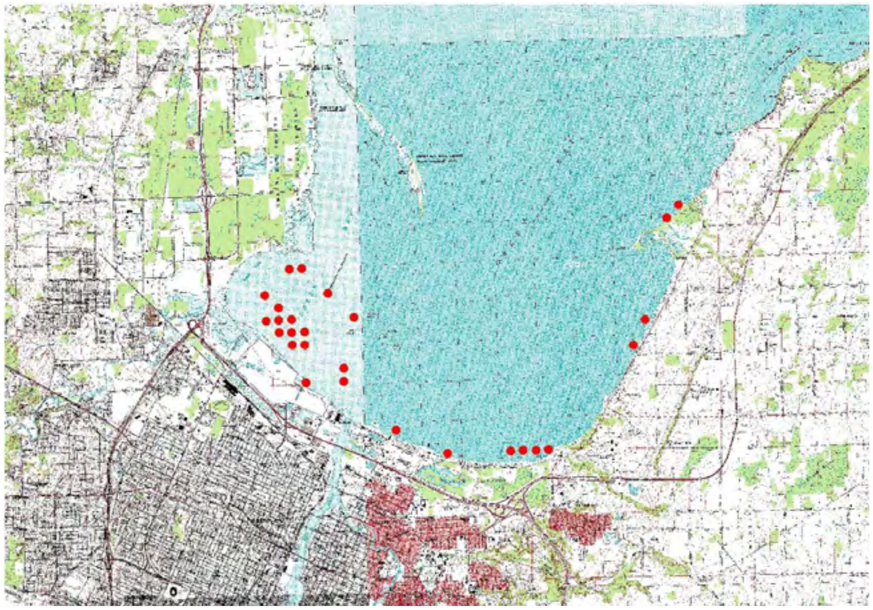


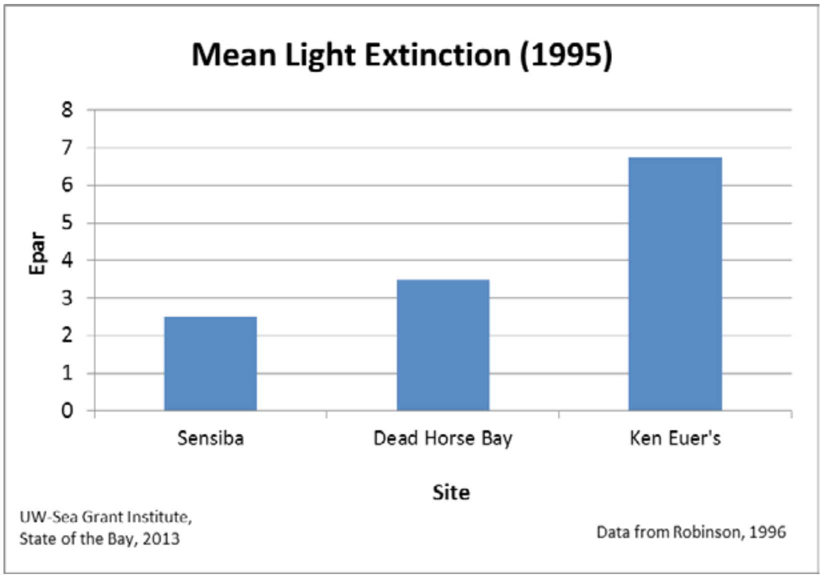
Figure 67: Location of macrophytes, indicated by the red dots, found in the AOC in August 2003 (Reed 2004).

In the AOC, submerged aquatic vegetation populations have been all but eliminated. This loss is attributed to high water turbidity in Lower Green Bay. One of the Green Bay RAP objectives is the re-establishment of aquatic habitat—in particular, submerged aquatic vegetation. In order to restore submerged aquatic vegetation, improved light conditions are necessary. Specifically, an average Secchi depth goal of 0.7-1.3 meters was established. *Vallisneria americana* (wild celery) is a submergent plant that was once abundant in Green Bay, and it was the dominant submergent plant along the west shore of Green Bay, south of Longtail Point. A study conducted in Green Bay found that light is the primary limiting factor and that an average Secchi depth goal of 0.7 meters would just meet the limit for *Vallisneria* in the AOC (McAllister 1991).

A study of factors that affect light attenuation in the near shore environment in Green Bay found that algae (chlorophyll *a*), inorganic (ashed) solids, and organic detritus all play a part (Robinson 1996). In the study, three sites representing the north-south turbidity gradient along the west shore of Green Bay were sampled, from south to north the sites are outside Ken Euler's Waterfowl Preserve, Dead Horse Bay, and outside Sensiba Waterfowl Preserve. The first two sites are located in the AOC, and the third is slightly north. The results clearly illustrate differences in light extinction, ashed solids, chlorophyll *a*, and detritus between the sites (Figures 68-71). These differences are related to the proximity of the sites to tributaries, exposure of the sites to waves and wind, and to chlorophyll *a* production (Robinson 1996).

GARY FEWLESS, UWGB

Vallisneria in shallow water at Sensiba.



**Epar is a measure of light intensity (photosynthetically active radiation) as it changes with depth.*

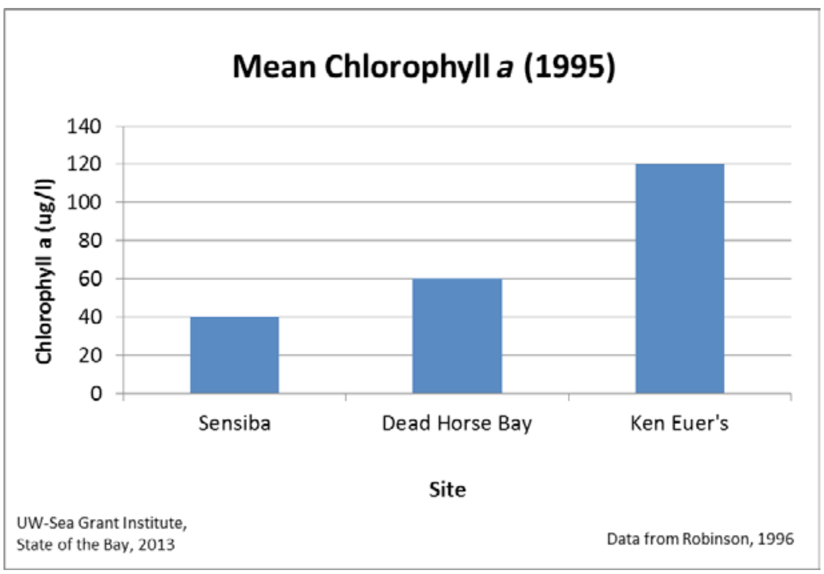
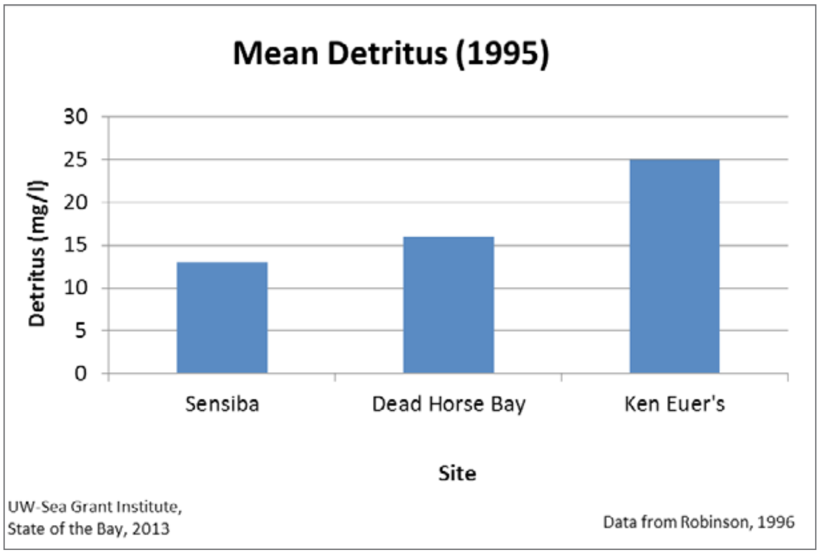


Figure 68 and 69: Mean light extinction, chlorophyll *a*, ashed solids, and detritus by site. Sites were sampled in the summer of 1995 (June-August). Figures adapted from Robinson 1996.

An improved littoral zone and increased submerged aquatic vegetation are vital for the fish community. A study conducted in Green Bay concluded that fish diversity is high in the littoral zone (Brazner 1997). The study also found that undeveloped wetland sites had a higher fish diversity and abundance than developed wetland sites and developed and undeveloped beach sites. In addition, the undeveloped wetland sites contained the majority of sport fish species caught in the study.

Distribution and abundance of fish have been related to the distribution and abundance of macrophytes (Brazner 1997). One study found that turbidity was the primary factor affecting fish assemblages and macrophytes were the next most important factor (Brazner and Beals 1997). Specifically, it was found that where macrophyte richness and distribution were high, fish species richness and abundance were also high (Brazner and Beals 1997).



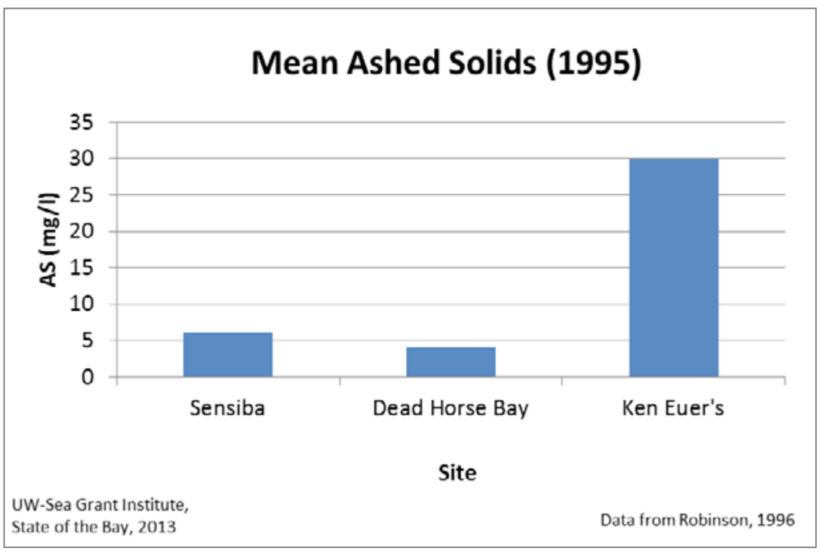


Figure 70 and 71: Mean light extinction, chlorophyll *a*, ashed solids, and detritus by site. Sites were sampled in the summer of 1995 (June-August). Figures adapted from Robinson 1996.

Landward from the submergent zone, the emergent, wet meadow, shrub, and upland zones (Figure 65) are used for nesting and foraging by a wide variety of birds, a few mammals, reptiles, and amphibians (Figure 72). It is interesting to observe how different bird species have adapted to nesting in different habitats provided by the vegetative zones. For example, yellow-headed blackbirds, marsh wrens, and least bitterns build their nests suspended with the support of robust emergent vegetation (e.g. cattails). Black terns, Forster's terns, and American coots build floating platforms from sedges and other decaying vegetation. Rails and American bitterns frequently use wet meadow habitat, while yellow-throats and willow flycatchers frequent shrubs.

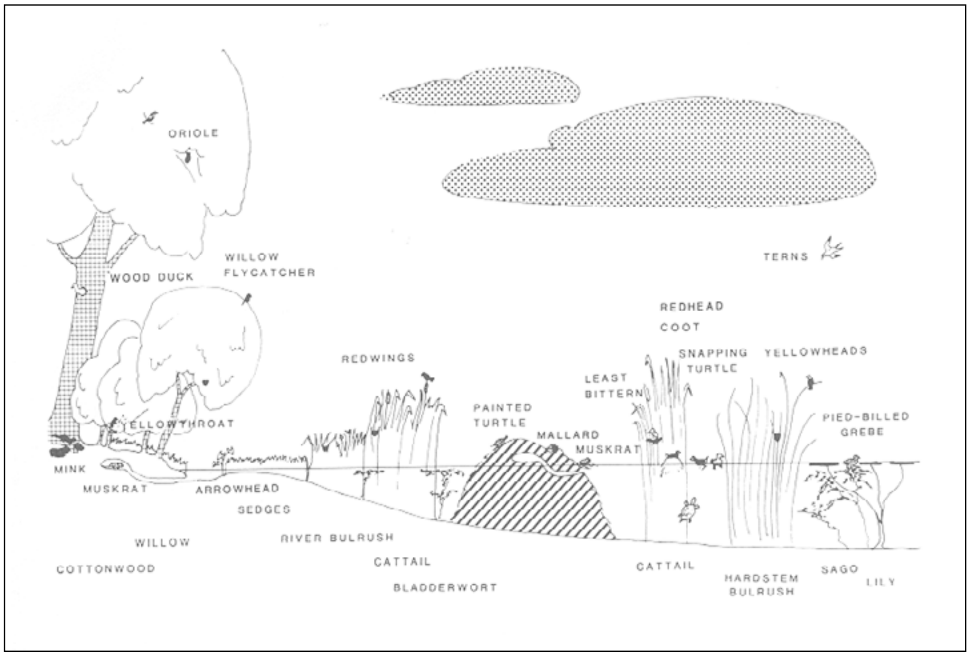


Figure 72: Diagram of bird, mammal, reptile, and amphibian species associated with a typical coastal marsh from lake to upland. Figure from Weller 1987.

The emergent and sedge meadow zones of two Green Bay marshes (Numbers 13 and 15, Table 20) were surveyed extensively for nesting bird species in the 1980s (Harris et al. 1983). Fourteen species were recorded as nesting in these two zones (Table 23).

Table 23: Percent of total nests (1004) found in sample transects for two Green Bay marshes over six survey years, 1978, 1979, 1980, 1981, 1983, and 1986.

Species	Percent
Marsh Wren	50
Yellow-Headed Blackbird	20
American Coot	9
Red-Winged Blackbird	8
Black Tern	6
Sora Rail	2
Least Bittern	2
Virginia Rail	<1
Blue-Winged Teal	<1
Forster's Tern	<1
Pied-Billed Grebe	<1
American Bittern	<1
Common Gallinule	<1
Swamp Sparrow	<1

Data source: Unpublished data, H.J. Harris

One value often ascribed to wetlands is that they function as nutrient and pollution "sinks," sequestering these materials before they reach streams and lakes. The truth is that some coastal wetlands are effective in this regard while others are much less so. It depends on the morphology of the coastal wetlands and the time of year. For example, MacKenzie (2001) studied three types of coastal wetlands associated with a river—embayed, riverine, and delta. The embayed wetland trapped approximately 60% of sediment flowing through, the riverine 20%, and the Peshtigo delta only 4%. The Peshtigo delta was also a minor sink for phosphorus. In essence, all of the coastal wetlands act more as transformers of nutrients than sinks, but they do store carbon for long periods of time (Sager and Harris, 1985). This nutrient processing provides energy in the form of carbon, which supports the complex foodweb in a coastal marsh.

How Have the Coastal Wetlands in Green Bay Changed Over Time?

Hydrologic conditions are of singular importance for the maintenance of a wetland's structural and functional characteristics. The water level of Green Bay has a history of dramatic change (see section on water levels). Changes in lake levels clearly impact the macrophyte communities of coastal wetlands (Fewless, 1986). Although these wetland changes appear damaging to the vegetation (http://www.uwgb.edu/biodiversity/herbarium/GreatLakesCoastalWetlands/petersMarsh/peters.htm), they are a part of a cyclic change of species composition and the extent of vegetative cover. For some wetland communities to remain viable they must be subjected to periodic disturbances in water levels. Such communities are sometimes called "pulse stable" (Harris et al. 1977). These cyclic changes of plant associations in the coastal marshes of Green Bay have apparently been disrupted by the fall of water levels in 2000 and the invasion of giant reedgrass (*Phragmites*) to major portions of the coastal wetlands. It remains to be seen how the vegetation responds when and if water levels reach above-average conditions.

Whatever the future conditions may be, it is apparent from ground and aerial observations of the west shore wetlands that *Phragmites* has dramatically altered the structural characteristics of the emergent marsh. It is a highly invasive species which has replaced much of the emergent zone and wet meadow habitat. While there has been no quantitative nesting surveys since 1980s (Table 23), these changes have undoubtedly had impacts on nesting waterfowl and other marsh birds.

Permanent changes in coastal wetlands have been caused by human activity. It is estimated that during the 1840s, 15 mi2 of coastal marshes and 72 mi2 of coastal swamps existed along Green Bay's west shore (Bosley 1976). Within the past century, however, 60% of the coastal marshes have been converted to agricultural land, filled with dredge material, or invaded by cottage settlements. Swamp forests of tamarack, alder, white cedar, and black ash have been harvested for timber—almost 60 mi^2 of these forests have disappeared altogether (Bosley 1976). Today, approximately only 6 mi^2 of marsh and 12 mi^2 of swamp remain at high water levels.

The loss of these wetlands is permanent. An accurate assessment of the effect these wetland losses have had upon the Green Bay ecosystem can probably never be made. However, wetland losses have significantly influenced the decline of Green Bay and Lake Michigan fisheries as well as waterfowl populations and water quality.

Over the past several decades, state and federal regulations have remained in flux regarding protection of wetlands. There is no comprehensive federal or state law that explicitly protects coastal wetlands. Water and wetland laws are complex; an overview can be found at the Wisconsin Wetlands Association website: http://www.wisconsinwetlands.org/protectingregulations.htm.

With some regulations in place, the loss of Green Bay west shore coastal wetlands has been slowed, but certainly not stopped. Before 1991, accurate data on wetland loss due to a particular land use were not kept. New accounting procedures after 1991, instituted by the WDNR and the USACE, allowed for more accurate tracking of the losses of wetlands. A study was conducted in 1998 of the loss of coastal wetlands in Brown, Oconto, and Marinette counties from 1991 to 1996 (Michalek 1998). Examination of permit records of the Army Corps of Engineers Regulatory Analysis and Management System II revealed that 257 permits to alter wetlands had been recorded during the five-year period. Eight percent of these permits resulted in wetland losses totaling 6.7 acres. Most losses occurred in Brown and Oconto counties for residential development (Table 24).

Table 24: Coastal wetland losses by land use and county from 1990-1996.

County	Land Use	Total Number of Applications	Acres Lost
Brown	Agricultural	0	
	Commercial	6	
	Industrial	1	
	Institutional	1	
	Recreational	13	0.17
	Residential	46	2.018
	Transportation	9	1.14
	Utility	5	
	Totals	81	3.328
Oconto	Agricultural	0	
	Commercial	2	
	Industrial	3	
	Institutional	7	
	Recreational	11	0.93
	Residential	62	2.025
	Transportation	5	
	Utility	11	
	Totals	101	2.955
Marinette	Agricultural	0	
	Commercial	7	
	Industrial	11	0.03
	Institutional	2	
	Recreational	6	
	Residential	41	0.42
	Transportation	3	
	Utility	5	
	Totals	75	0.45

Table from Michalek 1998

These losses seem minimal compared with losses during the previous half-century. They are not inconsequential, however, particularly when they do not consider developmental impacts on adjacent wetlands. The term "adjacent to" is defined by the USACE as any permit application in which the adjacent properties to the application property contains a delineated wetland. This includes 48% of permits applied for during the five-year period.

At first glance, it may not be obvious how development adjacent to a wetland can constitute a significant disturbance. However, the controlling "driver" of a wetland is its hydrology, and any change in surface or groundwater hydrology can have significant and long-term effects on coastal wetlands. Unfortunately, these impacts are somewhat insidious because they are "hidden" at first and do not manifest themselves until changes are advanced. Consequently, assessment of development impacts should include hydrologic changes. Because of these adjacent disturbances, the true loss of wetlands is likely greater than permit records indicate.

The good news is that a west shore wetland protection and acquisition project was started by the WDNR in 1962. The state currently owns 7,896 acres in Marinette, Oconto, and Brown counties (Charbonaue, personal communication). Since 1990, the WDNR has purchased approximately 2,053 acres. The total acreage goal of the project is 13,933 acres. The total acreage is not all wetland but, nonetheless, the acquired upland acres provide an important buffer, protecting the wetlands from adjacent development.

References

Bosley, T.R. 1976. *Green Bay's West Shore Coastal Wetlands: A History of Change*. M.S. Thesis. University of Wisconsin-Green Bay.

Brazner, J.C. 1997. Regional, Habitat, and Human Development Influences on Coastal Wetland and Beach Fish Assemblages in Green Bay, Lake Michigan. *Journal of Great Lakes Research*. 21(1): 36-51.

Brazner, J.C. and E.W. Beals. 1997. Patterns in Fish Assemblages from Coastal Wetland and Beach Habitats in Green Bay, Lake Michigan: A Multivariate Analysis of Abiotic and Biotic Forcing Factors. *Canadian Journal of Fish and Aquatic Sciences*. 4: 1743-1761.

Fewless, G.A. 1986. *Ecology of Softstem Bulrush (*Scirpus validus vahl.*) in a Freshwater Coastal Marsh Ecosystem.* M.S. Thesis. University of Wisconsin-Green Bay.

Harris, H.J., T.R. Bosley and F.D. Roznik. 1977. Green Bay's Coastal Wetlands – A Picture of Dynamic Change. pp: 337-358. *Proceeding of the Waubesa Conference on Wetlands held in Madison, Wisconsin, June 2-5, 1997*. Instutitue for Environmental Studies, University of Wisconsin-Madison.

Harris, H. J., M.S. Milligan, and G. Fewless. 1983. Diversity: Quantification and Ecological Evaluation in Freshwater Marshes. *Biological Conservation*. 27: 99-110.

MacKenzie, R.A. 2001. *Great Lakes Coastal Wetland Estuarine Systems: Invertebrate Communities, Particle Dynamics, and Biogeochemical Cycles*. Ph.D. Thesis. University of Wisconsin-Milwaukee.

McAllister, L.S. 1991. *Factors Influencing the Distribution of Submerged Macrophytes in Green Bay, Lake Michigan: A Focus on Light Attenuation and Vallisneria americana*. M.S. Thesis. University of Wisconsin-Green Bay.

Michalek, B.P. 1998. Trends in Wetland Loss 1990 to 1991: *A Case Study of the West Shore of Green Bay, Wisconsin*. M.S. Thesis. University of Wisconsin-Green Bay.

Reed, Tara. 2004. *Survey of Submergent Vegetation in Inner Green Bay Prior to Cat Island Chain Restoration*. Final report to Wisconsin Coastal Management Program.

Robinson, P. 1996. *Factors Affecting the Nearshore Light Environment and Submersed Aquatic Vegetation in Lower Green Bay*. M.S. Thesis. University of Wisconsin-Green Bay.

Rost, R. 2003. *Northern Pike within the Western Shore of Green Bay Coastal Zone*. Wisconsin Department of Natural Resources (WDNR). Publication concept by Kendra Axeness, UW-Extension.

Sager, P.E., S. Richman, H.J. Harris, and G. Fewless. 1985. Preliminary Observations on the Seiche-Induced Flux of Carbon, Nitrogen and Phosphorus in Great Lakes Coastal Marsh in *Coastal Wetlands*. H.H. Prince and F.M. D'Itri, ed. Lewis Publishers, Inc.

Smith, R.L. 1996. *Ecology and Field Biology*. Harper Collins.

Weller, M.W. 1987. Freshwater Marshes: *Ecology and Wildlife Management*. University of Minnesota Press, Minneapolis, MN.

Links

Wisconsin Wetlands Association
http://www.wisconsinwetlands.org

Coastal Wetlands of Wisconsin's Great Lakes
http://dnr.wi.gov/topic/wetlands/cw

Wisconsin Wetlands-WDNR
http://dnr.wi.gov/topic/wetlands

Wetlands in the Great Lakes Region (Great Lakes Information Network)
http://www.great-lakes.net/envt/air-land/wetlands.html

EPA-Wetlands
http://www.epa.gov/owow/wetlands

State of Wisconsin Department of Administration-Coastal Management
http://www.doa.state.wi.us/section.asp?linkid=65&locid=9

University of Wisconsin Sea Grant Institute-Coastal Processes
http://www.seagrant.wisc.edu/home/Topics/CoastalEngineering.aspx

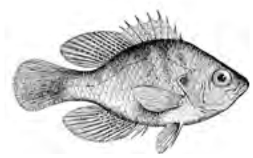
United States Fish and Wildlife Service Great Lakes Coastal Program
http://www.fws.gov/coastal

Michigan Sea Grant- Great Lakes Coastal Wetlands:
http://www.miseagrant.umich.edu/explore/great-lakes-coastal-habitats/coastal-wetlands

FISH

Background and History of Green Bay Fishery

Commercial fishermen were among the first white settlers around Green Bay. The early fishery was geared primarily for taking whitefish, lake trout, and lake herring (Kraft 1982). But as more people moved into the area, these species were overfished and began to decline. The area's booming lumber and paper industries also changed the bay environment – water pollution increased, dams blocked fish migrations, and spawning grounds were covered in silt and lumber mill debris (Kraft 1982). In 1885, fish surveys were conducted throughout the Great Lakes and Green Bay was noted as an important fishery location on Lake Michigan (Smith and Snell 1891). Though the early fishery was not managed or regularly monitored by any government agency, an increase in the bay's perch population was observed near the Oconto shoreline in one of the first Green Bay fish surveys (Kraft 1982). This increase in perch coincided with a decline in whitefish abundance, which was attributed to overfishing (Smith and Snell 1891). By 1891, whitefish became a trivial portion of the catch in this region. It is also interesting to note that the catch in 1885 in Brown County was diverse and consisted of perch, pike pickerel, herring, suckers, bay-fish, and catfish and in smaller amounts muskellunge, black bass, bull-heads, white bass, crappies, sunfish, and shad (Smith and Snell 1891).



Diversity of 1885 Brown County catch:

- Perch
- Pike Pickerel
- Herring
- Suckers
- Bay-fish
- Catfish
- Muskellunge
- Black Bass
- Bull-heads
- White Bass
- Crappies
- Sunfish
- Shad

Smith and Snell, 1891

One of the impaired uses listed in the Lower Green Bay RAP is degraded fish and wildlife populations (WDNR 1993). Generally, species diversity has been reduced through overfishing, invasive species, and poor water quality. In addition, in the Fox River and Green Bay, the fish community is unbalanced: there are fewer species and numbers of top predator fish and an overabundance of rough fish (Tables 25 and 26). Also, the forage fish population is dominated by just a few species.

Wisconsin Department of Natural Resource fishery managers have initiated several measures to achieve a more balanced fishery in the AOC. In 1989, a re-introduction of the spotted musky, a Great Lakes strain of muskellunge, began in order to establish a self-sustaining population and to add diversity to top predators in Green Bay. In addition, this re-introduction of the spotted musky also provided sport-fishing opportunities in the bay. Walleye management programs were continued and expanded to increase walleye and other fish habitat. In addition, yellow perch management programs were continued to stabilize yellow perch populations (WDNR 1993).

Table 25: Green Bay fish species list.

Common Name	Scientific Name
ALEWIFE	*Alosa pseudoharengus*
BLUEGILL	*Lepomis macrochirus*
BOWFIN	*Amia calva*
BULLHEAD	*Ameiurus spp.*
BURBOT	*Lota lota*
COMMON CARP	*Cyprinus carpio*
CARP SUCKER	*Carpiodes carpio*
CHANNEL CATFISH	*Ictalurus punctatus*
BLOATER CHUB	*Coregonus hoyi*
COMMON SHINER	*Luxilus cornutus*
EMERALD SHINER	*Notropis atherinoides*
FATHEAD MINNOW	*Pimephales promelas*
GIZZARD SHAD	*Dorosoma cepedianum*
HERRING	*Alosa chrysochloris*
JOHNNY DARTER	*Etheostoma nigrum*
LAKE STURGEON	*Acipenser fulvescens*
WHITEFISH	*Coregonus clupeaformis*
LOG PERCH	*Percina caprodes*
LONGNOSE SUCKER	*Catostomus catostomus*
MADTOM	*Noturus gyrinus*
MIMIC SHINER	*Notropis volucellus*
MUDMINNOW	*Umbra limi*
NINESPINE STICKLEBACK	*Pungitius pungitius*
NORTHERN PIKE	*Esox lucius*
PUMPKINSEED	*Lepomis gibbosus*
RAINBOW SMELT	*Osmerus mordax*
ROUND GOBY	*Neogobius melanostomus*
RUFFE	*Gymnocephalus cernuus*
SAUGER	*Sander canadense*
SCULPIN	*Cottus spp.*
SEA LAMPREY	*Petromyzon marinus*
SHEEPSHEAD	*Aplodinotus grunniens*
SMALLMOUTH BASS	*Micropterus dolomieu*
SPOTTAIL SHINER	*Notropis hudsonius*
SPOTTED MUSKY	*Esox masquinongy*
THREESPINE STICKLEBACK	*Gasterosteus aculeatus*
TROUT PERCH	*Percopsis omiscomaycus*
WALLEYE	*Sander vitreus*
WHITE BASS	*Morone chrysops*
WHITE PERCH	*Morone americana*
WHITE SUCKER	*Catostomus commersoni*
YELLOW PERCH	*Perca flavescens*

Table 26: Lower Fox River fish species list since 1980.

SPECIES	SCIENTIFIC NAME	EXOTIC	TRANSIENT
ALEWIFE	*Alosa pseudoharengus*	YES	YES
AMERICAN EEL	*Anguilla rostrata*		YES
BIGMOUTH BUFFALO	*Ictiobus bubalus*		
BLACK BULLHEAD	*Ictiobus cyprinellus*		
BLACK CRAPPIE	*Pomoxis nigromaculatus*		
BLUEGILL	*Lepomis macrochirus*		
BLUNTNOSE MINNOW	*Pimephales notatus*		
BOWFIN	*Amia calva*		
BROOK TROUT	*Salvelinus fontinalis*		YES
BROWN BULLHEAD	*Ameiurus nebulosus*		
BROWN TROUT	*Salmo trutta*	YES	YES
BURBOT	*Lota lota*		
CHANNEL CATFISH	*Ictalurus punctatus*		
CHINOOK SALMON	*Oncorhynchus tshawytscha*	YES	YES
COMMON CARP	*Cyprinus carpio*	YES	
COMMON SHINER	*Luxilus cornutus*		
CREEK CHUB	*Semotilus atromaculatus*		
EMERALD SHINER	*Notropis atherinoides*		
FLATHEAD CATFISH	*Pylodictis olivaris*		
FRESHWATER DRUM	*Aplodinotus grunniens*		
GIZZARD SHAD	*Dorosoma cepedianum*		
GOLDEN SHINER	*Notemigonus crysoleucas*		
GREEN SUNFISH	*Lepomis cyanellus*		
JOHNNY DARTER	*Etheostoma nigrum*		
LAKE STURGEON	*Acipenser fulvescens*		YES (Spawning run)
LAKE TROUT	*Salvelinus namaycush*		YES
LAKE WHITEFISH	*Coregonus clupeaformis*		YES
LARGEMOUTH BASS	*Micropterus salmoides*		
LOGPERCH	*Percina caprodes*		

SPECIES	SCIENTIFIC NAME	EXOTIC	TRANSIENT
LONGNOSE GAR	*Lepisosteus osseus*		
LONGNOSE SUCKER	*Catostomus catostomus*		
MOONEYE	*Hiodon tergisus*		
MUSKELLUNGE	*Esox masquinongy*		
NORTHERN PIKE	*Esox lucius*		
PUMPKINSEED	*Lepomis gibbosus*		
QUILLBACK	*Carpiodes cyprinus*		
RAINBOW SMELT	*Osmerus mordax*	YES	YES
RAINBOW TROUT	*Oncorhynchus mykiss*	YES	YES
RIVER REDHORSE	*Moxostoma carinatus*		
ROCK BASS	*Ambloplites rupestris*		
ROUND GOBY	*Neogobius melanostomus*	YES	
SAUGER	*Sander canadense*		YES, From Lake Winnebago
SEA LAMPREY	*Petromyzon marinus*	YES	YES
SHORTHEAD REDHORSE	*Moxostoma macrolepidotum*		
SHORTNOSE GAR	*Lepisosteus platostomus*		
SILVER LAMPREY	*Ichthyomyzon unicuspis*		
SILVER REDHORSE	*Moxostoma anisurum*		
SMALLMOUTH BASS	*Micropterus dolomieu*		
SPOTFIN SHINER	*Cyprinella spiloptera*		
SPOTTAIL SHINER	*Notropis hudsonius*		
TROUTPERCH	*Percopsis omiscomaycus*		
WALLEYE	*Sander vitreus*		
WHITE BASS	*Morone chrysops*		
WHITE PERCH	*Morone americana*	YES	
WHITE SUCKER	*Catostomus commersoni*		
YELLOW BASS	*Morone mississippiensis*		YES
YELLOW BULLHEAD	*Ameiurus natalis*		
YELLOW PERCH	*Perca flavescens*		

Data provided by the WDNR.

Populations Changes in Other Species

The Wisconsin DNR conducts annual late summer trawl surveys throughout Green Bay to collect young-of-the-year (YOY) and adult yellow perch. In addition to information on yellow perch, the number of other species present is collected. Both adult and YOY are included for each fish species (Figure 73). Yellow perch and white perch data are not included. For those species, refer to individual sections in this report. Fish species in the rough fish category include: common carp, bullhead species, bloater chub, quillback, white sucker, longnose sucker, sheepshead, and lamprey. Fish species in the other forage fish category include: nine spine stickleback, threespine stickleback, sculpin, common shiner, emerald shiner, Johnny darter, and log perch. Fish species in the predator category include: walleye, sauger, white bass, bluegill, northern pike, spotted musky, pumpkinseed, smallmouth bass, channel catfish, and burbot.

Based on trawl data, the composition of fish species in Green Bay has changed since 1988 (Figure 73). Some of these changes include the introduction of invasive species to the Green Bay system. The round goby first appeared in trawl catches in 2003. Other apparent changes are the decrease in abundance of spottail shiners beginning in 1998 and alewives beginning in 2001. Also, since the mid-2000s, Lake Whitefish increased in Green Bay.

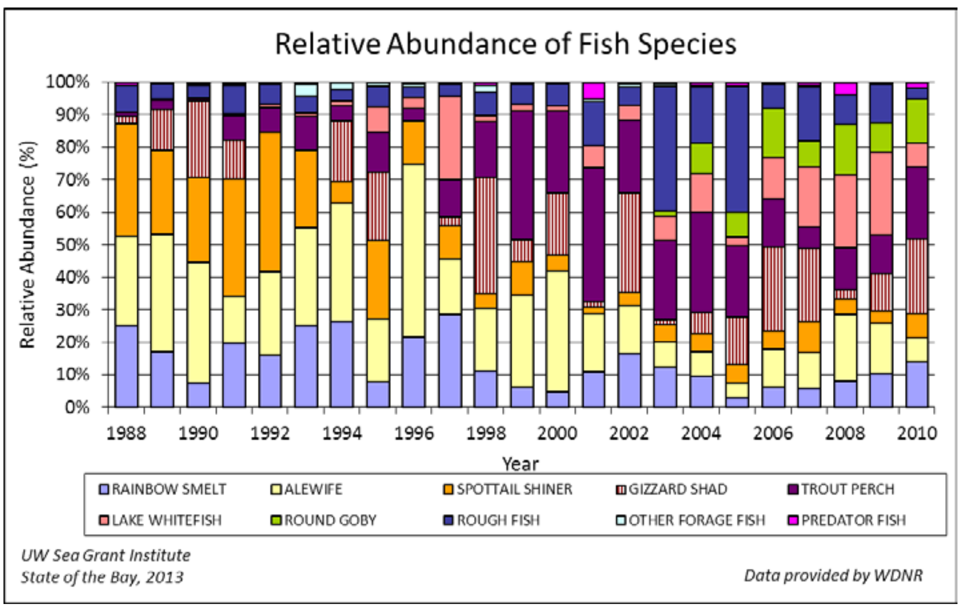


Figure 73: Relative abundance of fish species as measured by number per trawl hour from late summer bottom trawl data. Data provided by the WDNR.

Walleye *(Sander vitreus)*

Status: Good
Trend: Unchanging

The status and trend assessments are provided by WDNR fishery biologists. According to these biologists, Green Bay supports a walleye trophy fishery, especially in spring. Additionally, Green Bay walleye are abundant and have an above-average body condition (heavy for their length).

The re-establishment of the walleye fishery to Green Bay and the Fox River is one of the successful efforts to restore the Fox River system. In the early-to mid-1900s, walleye stocks in southern Green Bay were decimated due to habitat destruction, pollution, invasive species interactions, and over-exploitation. In the 1970s, carp and bullhead were the dominant fish species in the Fox River. The establishment of the Clean Water Act (1972) led to reduction of organic waste loading in the river and improvements in water quality in Lower Green Bay during the 1970s. These improvements in water quality led to the successful restoration of walleye and other species to the Fox River system. From the 1970s through 1984, walleye were stocked in the Lower Fox River and southern Green Bay. Stocking was so successful in southern Green Bay and the Lower Fox River that it was discontinued in 1984 to allow for surveys of natural reproduction and recruitment (George Boronow, personal communication).

Surveys have indicated that walleye spawning abundance and YOY production have been variable since monitoring began, but additional stocking has not been necessary since walleye stocking ended in 1984.

Current Status

Spring fyke net surveys targeting spawning walleye were conducted in the Lower Fox River below the De Pere dam during 1981-1984 and 1987-2004. However, this survey was discontinued after 2004 because the walleye stock was considered self-sustaining and resources were needed for other surveys.

Fall Electrofishing Surveys

RECRUITMENT OF YOY WALLEYE

Beginning in 1990, the WDNR conducted fall index electrofishing surveys and used the data to determine relative abundance of YOY walleye. Data from the 1990-2010 surveys are presented in Figure 74. The 2010 year class was strong and the catch rate for the Fox River was well above the 15 year average, whereas the catch rate for the bay was below the 15-year average. The difference between the bay and river catch rates may be attributed to warmer temperatures at the time of sampling. Abundant gizzard shad provided plenty of food and likely resulted in better than normal growth for the YOY walleye, with the mean length of captured YOY walleye greater in 2010 than 2009 (240 mm verse 224 mm). Stable water temperatures, an extended warming period during spawning and hatching and abundant food likely produced favorable environmental conditions that resulted in a strong year class in 2010. Year-class failures have not been observed in more than two consecutive years during 2001-2010 (Figure 74). The WDNR plans to continue these fall index electrofishing surveys in the future.

WALLEYE STOCK SIZE AND AGE STRUCTURE

Length-frequency distributions were determined for captured walleye during the 2010 electrofishing index surveys. In 2010, for the Fox River, 946 walleye were captured and averaged 401 mm in total length (ranged from 188 to 706 mm). The length-frequency distribution of captured walleye indicates that the stock's size structure has not been negatively affected by poor year classes, low recruitment, slow growth or excessive mortality (Figure 75). Age structure was also determined from captured walleye. Fish from the 2010 year class and the strong 2008 and 2009 year classes dominated the catch. Few of the walleye captured were older than 7 years (Figure 76).

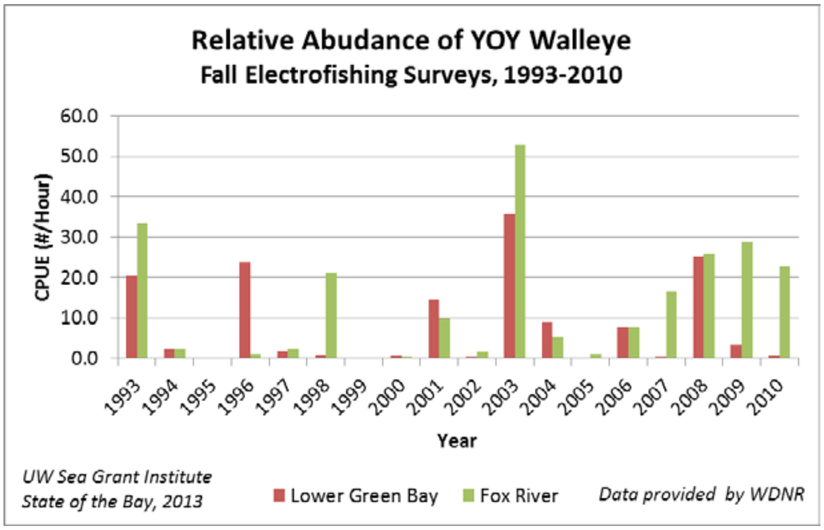


Figure 74: Relative abundance of YOY walleye in the Lower Fox River (De Pere dam to mouth) and Lower Green Bay (south of a line drawn from Longtail Point to Point Sable) as measured by catch per unit effort (CPUE) from data collected in fall electrofishing surveys for the years 1993-2010. Data and graph from the WDNR, 2011.

For Green Bay, 132 walleye were captured and averaged 428 mm in total length (ranged from 193 to 655 mm). Few small (YOY) walleye were captured and other sizes were much more abundant (Figure 77)

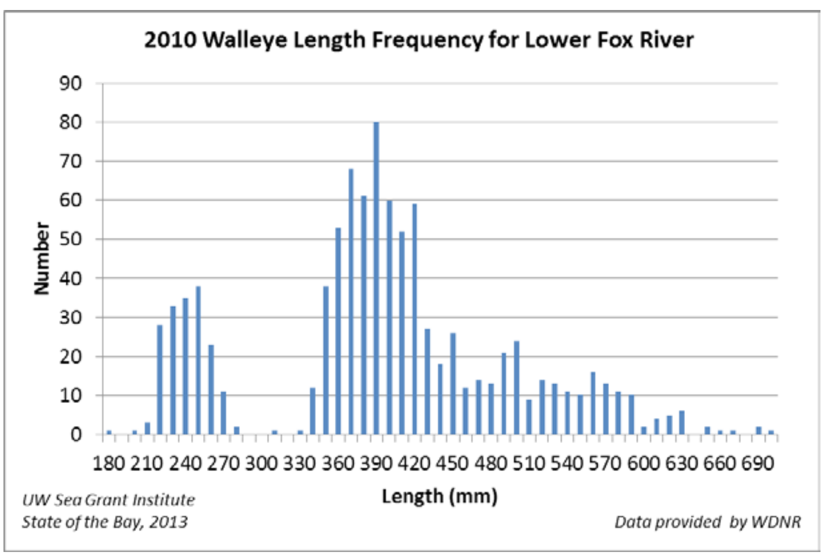


Figure 75: Length-frequency distribution of walleye sampled while electrofishing in the Lower Fox River during 2010. Data and graph from the WDNR, 2011.

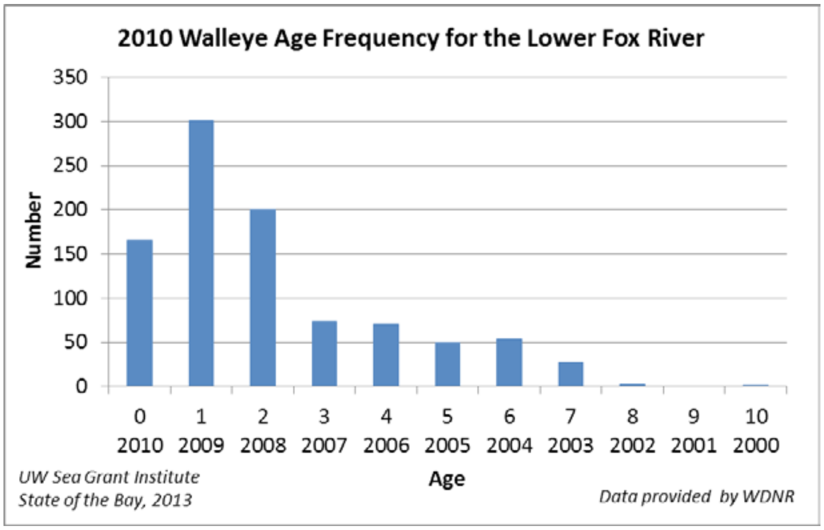


Figure 76: Estimated age-frequency distribution of walleye sampled while electrofishing in the Lower Fox River during 2010. Data and graph from the WDNR, 2011.

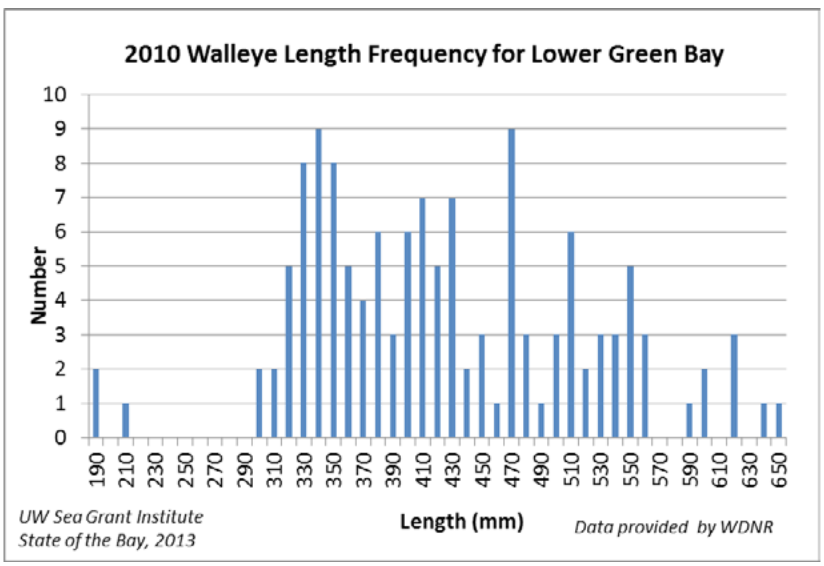


Figure 77: Length-frequency distribution of walleye sampled while electrofishing in Lower Green Bay during 2010. Data and graph from the WDNR, 2011.

Catch and Harvest

Catch is the number of walleye estimated to have been caught by anglers, regardless of whether the walleye were kept or released. Harvest is the number of walleyes caught and kept. The total walleye catch for Wisconsin waters of Green Bay was estimated at 112,725 walleye in 2010. This was a 52% decrease from the estimated 234,872 walleye in 2009, but still greater than the average walleye catch since 1986 of 96,900 (Figure 78). For 2010, the largest decreases in catch were in Brown and Marinette counties, while Oconto and Door and Kewaunee Counties had small increases.

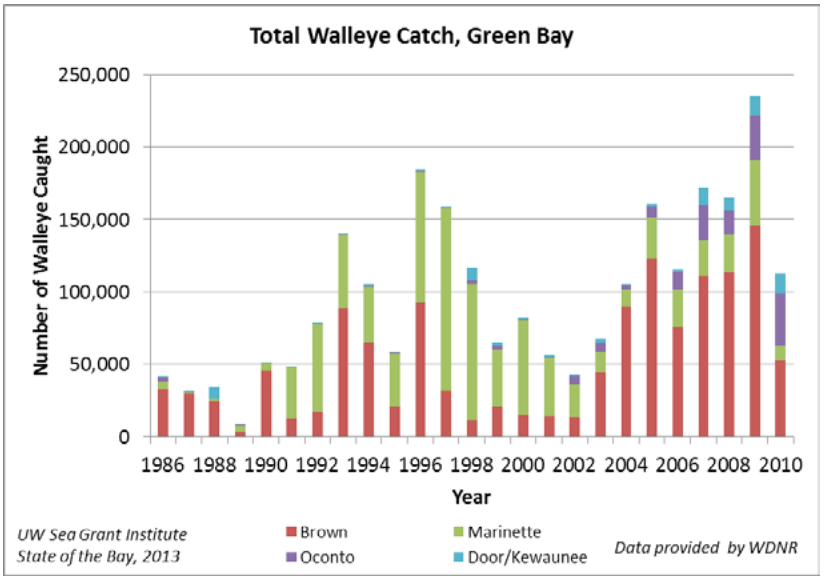


Figure 78: Total walleye catch for Green Bay by county for the years 1986-2010. Data and graph from the WDNR, 2011.

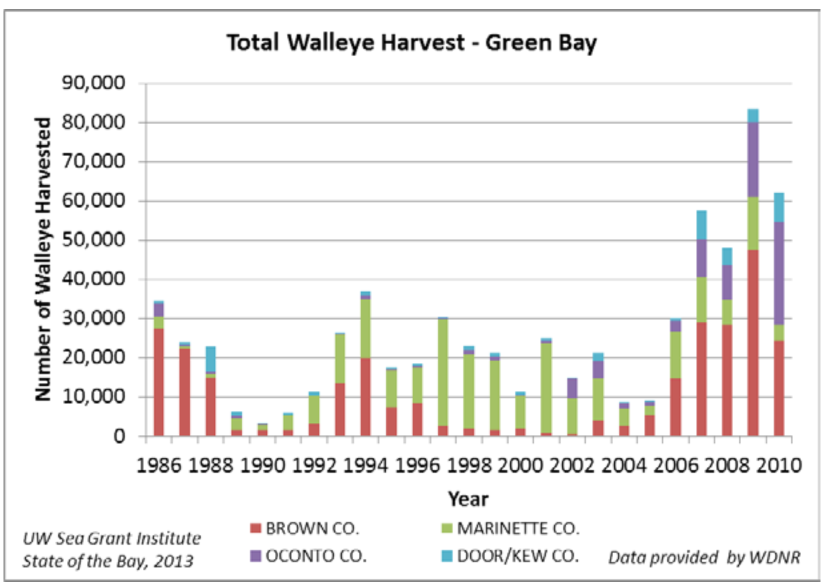


Figure 79: Total walleye harvest for Green Bay by county for the years 1986-2010. Data and graph from the WDNR, 2011.

The total walleye harvest for Green Bay decreased from 83,425 walleye in 2009 to 62,222 walleye in 2010 (Figure 79). Even though harvest was down in 2010, it was still the second highest measured since the creel survey began in 1986. Walleye harvest increased in Oconto and Door and Kewaunee counties in 2010 and decreased in Brown and Marinette counties. Most of the decrease can be attributed to the large decrease noted in Brown County, where harvest was down almost 50% compared to 2009.

The walleye catch has been relatively high for the last five seasons, with the greatest contribution from the Lower Fox River and Brown County waters of Green Bay. This is most likely attributed to the very strong and abundant year class in 2003 (Figure 78). The decrease in harvest in 2010 is probably due to a decrease in the abundance of the 2003 year class and the lack of fish from much smaller 2004 and 2005 year classes. According the WDNR (2006), "The relationship between catch and harvest of walleye from Green Bay is complicated by anglers targeting trophy walleye, catching most of their walleye during the restricted spring season, practicing catch and release, or some combination of these three scenarios".

The Future of the Sport Fishery

According to the WDNR, the near future of the Lower Green Bay/Lower Fox River walleye population and sport fishery appears to be promising. Substantial walleye year classes have been measured during the past three fall electrofishing surveys. Furthermore, year-class failures have not been observed in more than two consecutive years during 1994-2010. The 2008 and 2009 year classes will recruit to the fishery in the next couple of years and increase the abundance of fish. However, there will be a noticeable shift downward in the population size structure as the 2003 year class continues to be reduced through harvest and as the younger and smaller 2008 and 2009 year classes take their place. The harvest will be monitored in relation to PCB contamination levels, and as contaminant levels continue to decrease, harvest will likely continue to increase (WDNR 2011).

Yellow Perch *(Perca flavescens)*

Status: Mixed
Trend: Improving

WDNR

Green Bay yellow perch year class photos

TAMMI PAOLI, WDNR

Green Bay yellow perch ready to spawn

The status and trend assessments are provided by Tammie Paoli, WDNR. Yellow perch abundance in Green Bay increased steadily throughout the 1980s. The estimated total biomass of yearling and older yellow perch rose from under one million pounds in 1978 to nearly nine million pounds in 1987. The population growth was fueled by the production of strong year classes in 1982, 1985, 1986, and 1988. Following the late 1980s, yellow perch populations and the biomass estimate dropped to between 500 and 600 thousand pounds by 2002. The decline in the population during the 1990's and early 2000s can be attributed to poor recruitment. From 1988 to 2002, only two reasonably strong year classes (1991 and 1998) appeared during summer trawling surveys (Figure 80). More recent summer trawling surveys, however, show a trend toward improved recruitment and surveys from 2002 to 2010 indicate reasonably strong year classes (Figure 80).

Annual late summer trawl surveys have been conducted since 1978 at 46 shallow sites and an additional 32 deep-water sites beginning in 1988. The average number of yellow perch collected per trawl hour was adjusted based on the amount of habitat that standard and deep sites represent, creating a weighted area average value. The trawling surveys indicate that 2010 produced a strong year class with the relative abundance of YOY yellow perch (2,583/hr) ranking as the second highest since the deep water sites were added in 1988, and the third highest since the surveys began (Figure 80).

Harvest

The annual commercial harvest is reported by commercial fisherman. Since 1983, the commercial harvest for yellow perch in Green Bay has been managed under a quota system ranging from 20,000 pounds to 475,000 pounds. The quota has remained at 100,000 pounds since 2008 (Figure 81). In 2010, commercial fishers harvested a total of 75,641 pounds using gill and drop nets, compared to 61,509 pounds in 2009.

Sport fishing harvest of yellow perch is estimated from an annual creel survey. The yellow perch sport fishery has fluctuated with changes in yellow perch populations. Open water harvest of yellow perch in 2010 was 225,995 (49,182 pounds) compared to 204,209 yellow perch (52,630 pounds) in 2009 (Figure 82).

Figure 80: Relative abundance of YOY yellow perch as measured by number per trawl hour from data collected in annual late summer trawl surveys for years 1980-2010. Data provided by the WDNR.

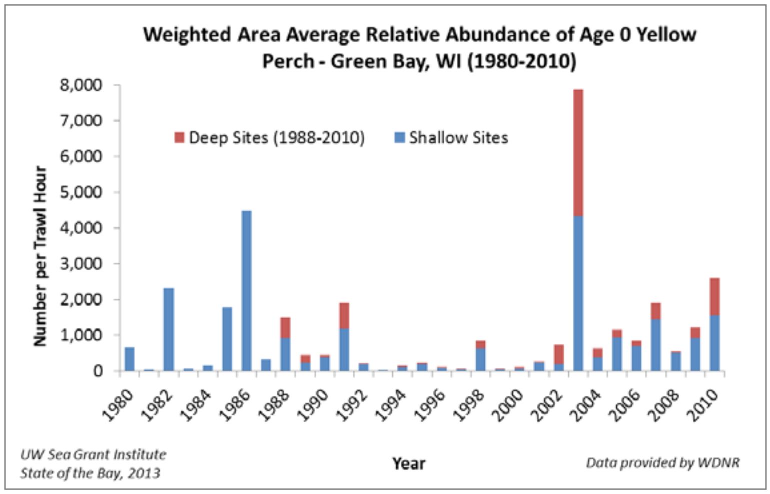


Figure 81: Commercial harvest of yellow perch in Green Bay from 1936 to 2010. Total allowable commercial harvest changes (thousands of pounds) are indicated by arrows. Data provided by the WDNR.

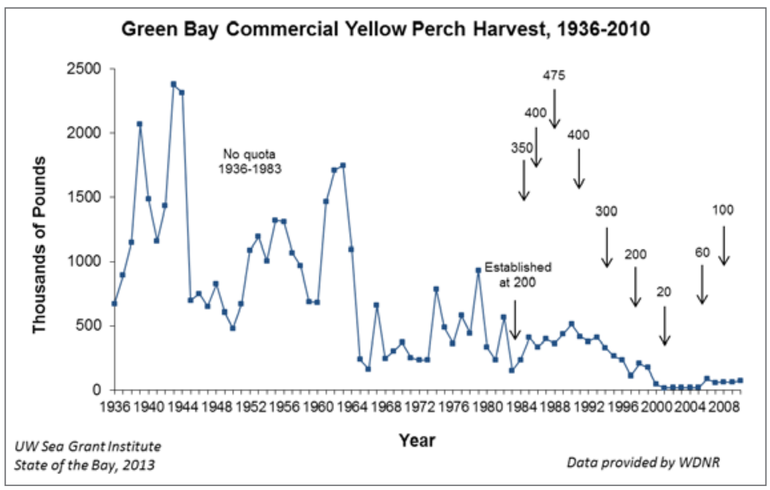
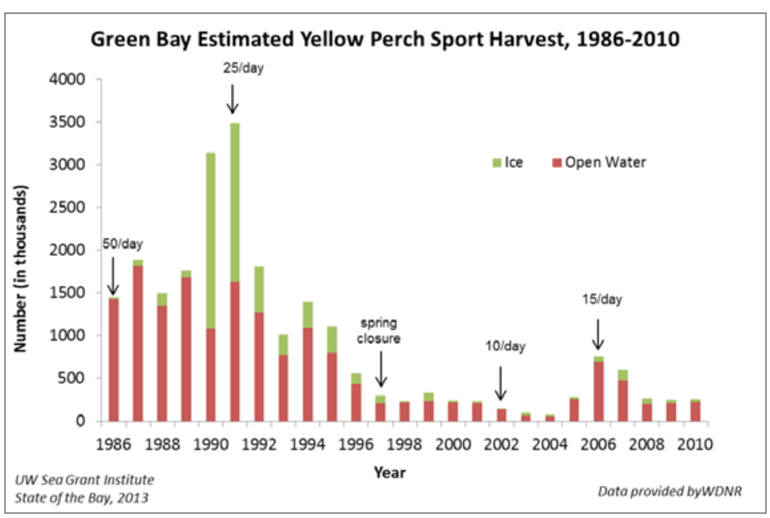


Figure 82: Estimated sport harvest of yellow perch in Green Bay from 1986 to 2010. Regulation changes are indicated by arrows. Data provided by the WDNR.



Winter harvest is influenced largely by ice conditions, daily bag limits, angler effort and abundance of adult perch. Since the creel survey began in 1986, angler harvest of yellow perch during winter months has ranged from 2 million fish in 1990 to 6,930 in 2002 (Figure 82). Winter harvest of yellow perch in 2010 (33,070) fell compared to 2009 (42,782). In addition, 2010 was lower than the previous four years and well below the 13-year harvest average (45,093).

In summary, yellow perch recruitment has been steady for the last nine years, with peak year classes occurring in 2003, 2005, and 2010. Of concern is the lack of a corresponding increase in the total adult population as indicated by reduced sport harvest rates. No single cause can be attributed to the poor recruitment of YOY yellow perch in Green Bay. However, several factors could prevent recruitment including: water temperature, prey abundance, competition for food at varying life stages, loss of habitat and spawning area reduction, and predation across all life stages. Double-crested cormorants are opportunistic feeders that prey on fish, including yellow perch. Since cormorants are a predator of yellow perch, they may play a part in yellow perch abundance. Many anglers view these birds as a threat to commercial and sport fish species. Effort to reduce cormorant numbers by egg-oiling and shooting by USDA Wildlife Services have been underway since 2006 in Wisconsin waters of Green Bay. Please refer to the colonial nesting bird section for more information on cormorants.

White Perch *(Morone americana)*

Status: Established
Trend: Increasing

The white perch is an exotic species native to Atlantic coastal regions and was first found in Green Bay in 1988. White perch are of concern in the Green Bay area because of their potential to compete with yellow perch, prey on fish eggs, and interbreed with white bass.

Due to the increase in white perch populations in Green Bay, anglers and commercial fishers are interested in harvesting white perch. The WDNR conducted a study to determine if PCB concentrations in white perch are above the consumption advisory threshold. In the early 1990s, white perch were analyzed for PCBs, and it was shown that PCB concentrations were more than 2 ppm (the upper limit for PCBs in fish for sale in commercial markets) (WDNR fact sheet). Refer to the contaminant section for information on PCBs in the Fox River/Green Bay. The WDNR and the Wisconsin Department of Health and Family Services issues fish consumption advice for sport fishers based on PCB concentrations. The fish consumption advisory recommends that individuals eat no more than six meals of white perch each year from Green Bay or the Lower Fox River (below De Pere dam). Currently, sport fishing for white perch is open all year and commercial fishers are allowed limited incidental harvest from Green Bay.

Annual late summer trawling surveys have shown a slow establishment of white perch until 1998, followed by annual variation in year class strength with a strong year class every 2-3 years (Figure 83).

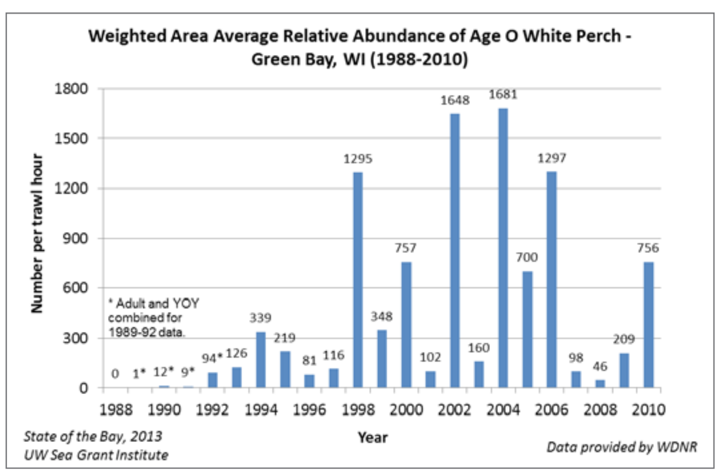


Figure 83: Relative abundance of YOY white perch as measured by number per trawl hour from data collected in annual late summer trawl surveys for years 1988-2010. Data provided by the WDNR.

Spotted Musky *(Esox masquinongy)*

Status: Fair
Trend: Improving

The status and trend assessments are provided by Steve Hogler, WDNR. The trend assessment of increasing abundance of spotted musky is due to current higher stocking rates than in the past. According to Steve, spotted musky in Green Bay are extremely fast growing with above average body condition. However, there have been only limited numbers of documented natural reproduced musky found in Green Bay.

The spotted musky or Great Lakes strain musky is native to the Great Lakes and has been missing from Green Bay since the mid-1900s as a result of habitat destruction, pollution, and over-exploitation. The WDNR in cooperation with several local musky clubs and the Musky Clubs Alliance of Wisconsin initiated a reintroduction program in 1989 in the Green Bay waters of Lake Michigan. The need to re-establish a native inshore predator fish species was identified in the Lake Michigan Integrated Fisheries Management Plan and the Lower Green Remedial Action Plan. The WDNR drafted a three-phase plan to reintroduce musky in Green Bay: (1) identify an appropriate egg source, obtain eggs, and successfully hatch, rear and stock fish, (2) establish an inland lake broodstock population, and (3) develop a self-sustaining population in Green Bay.

Stocking

Beginning in 1989, the spotted musky was stocked at three locations in Green Bay (Fox River, Communiversity Park, and the Menominee River) (Figure 84). From 2002 to 2006, the number of fingerlings stocked increased to average 20,324 musky, due to improved rearing techniques at the hatcheries, another hatchery began to rear spotted muskies, and there was added emphasis on restoration of the spotted musky in Green Bay (WDNR, personal communication) (Table 27). In 2007, Viral Hemorrhagic Septicemia (VHS) was discovered in Lake Michigan and therefore no stocking occurred in 2008 and 2009. Stocking resumed in 2010. Since 2005, stocking has occurred at more locations around Green Bay (Figure 84).

WDNR

Fox River Musky

Figure 84: Stocking locations of Great Lakes spotted musky in Green Bay and tributaries before and after 2005. Map provided by the WDNR.

Table 27: Number of spotted musky fall fingerlings and yearlings stocked in the waters and tributaries of Green Bay, Lake Michigan from 1989-2010.

Stocking	Fingerlings	Yearlings	Stocking	Fingerlings	Yearlings
1989	5261	0	2000	2451	295
1990	1274	9	2001	1854	176
1991	2624	0	2002	9281	140
1992	2107	152	2003	33107	103
1993	1394	215	2004	20772	161
1994	0	237	2005	18609	325
1995	1803	0	2006	18785	421
1996	3135	247	2007	0	640
1997	1842	130	2008	0	0
1998	4311	278	2009	0	0
1999	3305	294	2010	2791	0

Data provided by the WDNR.

Annual Assessments

Annual assessments on the status of the Green Bay musky populations have been conducted by the WDNR using fyke nets in spring and electrofishing in fall. Spring netting began in 2004 and mean size measured during the sampling period as increased. This indicates that the spotted musky continues to mature as it becomes re-established. Nighttime fall electrofishing surveys have been conducted in the Fox River (De Pere dam to mouth) to index musky and walleye populations. The CPUE in the fall index surveys has steadily increased over the past eight years, which suggests a growing population (Figure 85). The increases are most likely a result of stocking increases in the early 2000s (Table 25).

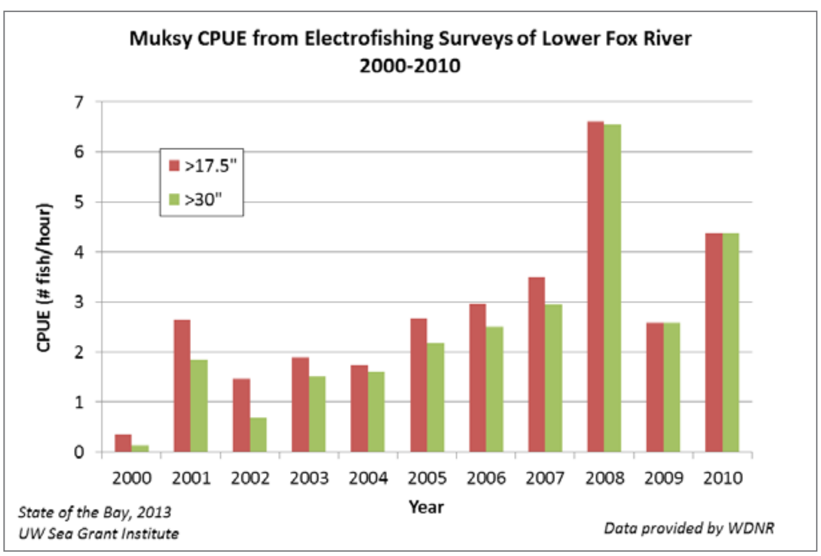


Figure 85: Catch per unit effort (CPUE) of musky greater than 17.5 inches and greater than 30 inches in the Lower Fox River from data collected in fall nighttime electrofishing surveys for the years 2000-2010. Data from the WDNR, 2011.

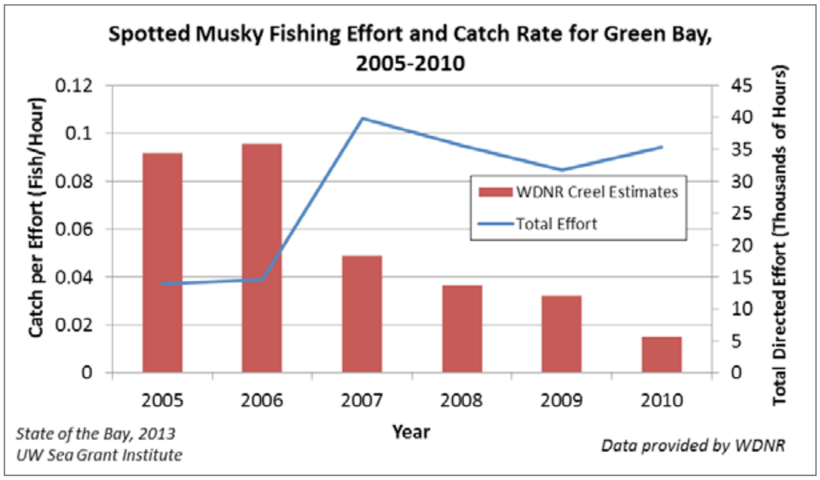


Figure 86: Total directed fishing effort (blue line) and catch rate in number of musky caught per hour of directed fishing (red bars) for spotted musky on Green Bay from 2005-2010. Data provided by the WDNR, 2011.

Fishery

For 2010 (March 15 – October 31), the Lake Michigan creel survey estimated a total of 35,342 hours of directed effort for spotted musky on Green Bay and the Lower Fox River (Figure 86). Although the 2010 total effort estimate increased from the 2009 total, it is likely that this value still underestimates total effort since a substantial amount of angling occurs in November after the creel survey ends. The creel estimated catch rate has decreased since 2006, reaching its lowest level of 0.015 fish/hour in 2010 (Figure 86). For comparison, statewide directed muskellunge catch rates average 0.039 fish/hour (25.6 hours/fish) for naturally reproduced populations, and 0.020 fish/hour (50 hours/fish) for populations maintained by stocking. In 2010, the creel survey estimated that anglers caught 541 musky but the harvest was estimated at zero.

Future

The adult population of spotted musky in Green Bay waters is increasing. This is documented by the fall index CPUE, which has been steadily increasing since 2000. This is likely in response to the increases in stocking and hatchery production. Based on tagged recaptured fish, the Green Bay population appears to be separate from the populations in the Menominee River and Peshtigo River area, and the Sturgeon Bay area.

Fishing effort has sharply increased since 2005, prompting concern among musky anglers regarding overharvest despite low harvest estimates from the creel survey. This concern has led to development of a new management plan and a review of the current minimum size limit for Great Lake Muskellunge in the Wisconsin waters of Green Bay.

Lake Sturgeon *(Acipenser fulvescens)*

Status: Recovering Population
Trend: Improving

BUD HARRIS

Two lake sturgeon

Background

Historically, lake sturgeon were abundant in Lake Michigan and especially in Green Bay and its tributaries. Early settlers did not highly regard lake sturgeon, and commercial fishers did not like sturgeon because they interfered with the ability to catch more desirable species. So, lake sturgeon were clubbed to death, buried as fertilizer, and burned. Populations of lake sturgeon decreased drastically in the late 1800s due to habitat destruction, degraded water quality, and overexploitation associated with settlement and development in the region. By the 1860s, lake sturgeon became one of the most commercially valuable fish in Lake Michigan due to the production of caviar and smoked sturgeon flesh. Due to overexploitation, lake sturgeon populations crashed. In 1879, 3.8 million pounds of sturgeon were harvested from Lake Michigan and in 1928, 2,000 pounds of sturgeon were harvested from Lake Michigan. In addition, water pollution from saw mills contributed to the decline of sturgeon populations. Also, construction of dams on tributaries used for spawning contributed to decreases in sturgeon populations. Dams prevent sturgeon from reaching suitable spawning habitat upstream (Gunderman and Elliott 2004).

Current Status

In Lake Michigan, the largest remaining populations of lake sturgeon are located in southern Green Bay tributaries. Lake Sturgeon are known to spawn in only eight of Lake Michigan's tributaries and four of these tributaries are located in Green Bay. The Lower Menominee River is believed to support the largest population of lake sturgeon with free access to Green Bay. Populations of lake sturgeon are also found in the Lower Fox River, the Peshtigo, and Oconto rivers.

The Fox River is the largest tributary to Green Bay. The De Pere Dam is a current barrier to lake sturgeon migrating upstream from Green Bay. Upstream in Lake Winnebago, there is a large lake sturgeon population and Lake Winnebago sturgeon have been observed migrating downstream into the Lower Fox River. Of the four tributaries surveyed during the U.S. Fish and Wildlife Service assessment, the Oconto River is the smallest. Due to pulp mills discharging into the Lower Oconto River, fish habitat was severely degraded from the 1890s to the 1970s, but restoration efforts during the 1980s have improved water quality. The Stiles Dam on the Oconto River is the current barrier to lake sturgeon migrating upstream and there are no known existing lake sturgeon populations upstream of Stiles Dam. The Lower Peshtigo River has the least development of the four rivers examined and ends in a large natural marsh. The Peshtigo Dam is a current barrier to lake sturgeon migrating upstream from Green Bay. Only 3.9 km of the Menominee River is available to lake sturgeon migrating from Green Bay. The Menominee Dam is a current barrier to lake sturgeon migrating upstream from Green Bay. There are reproducing populations of lake sturgeon upstream of the Menominee Dam.

The U.S. Fish and Wildlife Service (USFWS) conducted an assessment of lake sturgeon populations in the Green Bay Basin. In this study, over 450 lake sturgeon were captured using a variety of gear types from 1997 to 2003. Spawning run size estimates ranged from about 25 individuals in the Oconto River to over 200 individuals in the Peshtigo and Menominee Rivers. The lake sturgeon population in Lower Green Bay is dominated by younger individuals (≤ 15 years) and is estimated to be approximately 2,000 individuals (≥ 112 cm total length).

In the study conducted by the USFWS, the availability of suitable spawning habitat for lake sturgeon was also examined. The number of potential spawning sites and the amount of suitable spawning habitat varied between the four Green Bay tributaries (Table 28). In the Fox, Oconto, and Peshtigo rivers, there appears to be sufficient spawning habitat available at current population levels.

The study also assessed the abundance of larval lake sturgeon and found that lake sturgeon larvae were produced in all four tributaries. The largest numbers of larval lake sturgeon were collected in the Peshtigo River and the lowest numbers of larval lake sturgeon were captured in the Oconto River.

Table 28: Summary of potential and marginal lake sturgeon spawning habitat in four Green Bay tributaries.

River	# Potential Spawning Sites	Total Area of Potential Spawning Habitat (ha)	# Marginal Spawning Sites	Total Area of Marginal Spawning Habitat (ha)
Fox	1	6.03	1	0.52
Oconto	6	18.46	3	0.84
Peshtigo	8	7.59	1	1.51
Menominee	1	18.18	0	0.00

Data from Gunderman and Elliott, U.S. Fish and Wildlife Service, 2004.

The USFWS study provided lake sturgeon spawning run estimates for the Fox, Oconto, and Peshtigo Rivers; however the estimates for the Oconto and Peshtigo rivers are preliminary. The WDNR performed lake sturgeon surveys in the Lower Menominee River in 2005-2006. They handled 554 fish with an average size of 48.8 inches. A population estimate was calculated at 1,679 adult sturgeon (> 42 inches) (Michael Donofrio, personal communication). The USFWS and the WNDR will continue conducting lake sturgeon spawning assessments. It is difficult to accurately assess the status of lake sturgeon in Green Bay at this point and additional fieldwork is needed to more accurately estimate lake sturgeon spawning populations and lake sturgeon abundance in Green Bay.

Northern Pike *(Esox lucius)*

Status: Fair

Trend: Stable

Northern pike are a top predator in the Green Bay ecosystem and play a role in maintaining ecosystem stability. Northern pike impact prey species and exert some control of invasive species, such as carp and alewife. Northern pike use wetlands as spawning habitat. The majority of Green Bay wetlands (see wetlands section) are located along the west shore of Green Bay. This area is critical for northern pike populations.

In the spring, Green Bay northern pike migrate up streams and roadside ditches along the west shore of the bay, seeking shallow wetlands to spawn in. Northern pike have been documented traveling as far as 15 miles inland from Green Bay to spawn (Rost 2003). Beginning in late April, YOY start drifting with the current downstream to Green Bay.

Since the 1990s and early 2000s, the WDNR regularly conducted surveys of YOY to determine where fish are spawning, where the most productive habitat is located, and which areas can be restored or created to benefit northern pike (Rost 2003). The WDNR has restored or created northern pike spawning and rearing habitat within the wet shore coastal zones. The largest (8 acres) and most effective (in terms of YOY produced) restoration project was at the Barkhausen Waterfowl Preserve (Rost 2004).

The production levels of individual streams, roadside ditches, and connected wetlands vary annually (Rost 2004). The success of a northern pike year class depends upon the amount of water from snow melt and spring precipitation. On average, spring conditions produce strong year classes once every four to five years. Therefore, in order to maintain northern pike populations, they must have adequate spawning and rearing habitat available to them when favorable spring conditions exist (Rost 2004). Comparing YOY counts at five index sites from 1998-2004, 2003 had the highest number of YOY captured (Table 29) (Paoli 2004).

RICHARD ROST, WDNR

Female northern pike at Barkhausen marsh

Green Bay tributary

Table 29: Northern pike YOY captured at five index sites for years 1998-2004.

Year	Dittman	Pecor Pt. Spawning Marsh	End of Pecor Pt.	Barkhausen Spawning Marsh	Lineville Ditch at Barkhausen	Total
1998	264	103	No Trap	218	224	809
1999	900	1,340	No Trap	4,829	4,794	11,863
2000	0	0	0	51	1,479	1,530
2001	119	619	248	2,158	2,771	5,915
2002	No Trap	No Trap	69	59	1,125	1,253
2003	95	21,714	429	53,901	4,792	80,931
2004	4	25	10	90	1,745	1,874

Data provided by the WDNR, 2004.

Unlike YOY assessments, which occur in smaller wetland complexes, it is difficult to assess the adult pike population in a waterbody as large as Green Bay. Instead, the WDNR uses creel survey information to help understand general trends in the adult population. Catch and harvest of northern pike fluctuated throughout the years, but overall remains fairly stable over the long-term (Figure 87).

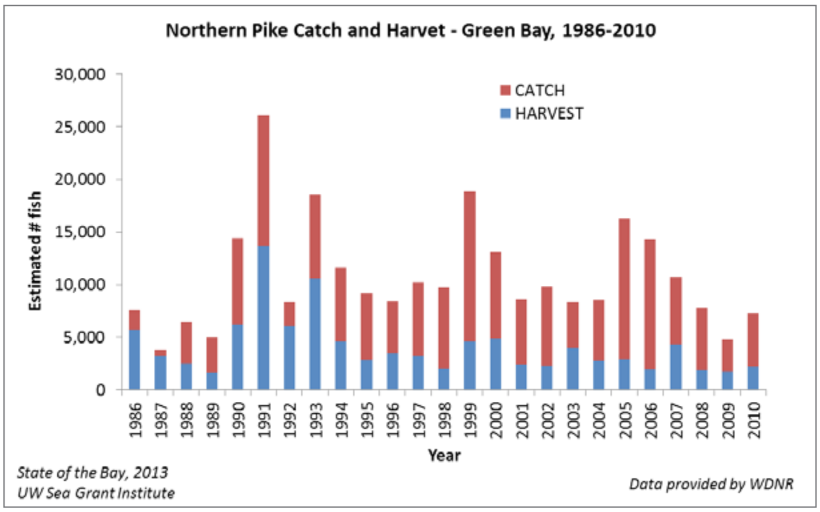


Figure 87: Total northern pike catch for Green Bay from 1986-2010. Ice and open water creel estimated were used. Data from the WDNR.

Recent Threats to the Fishery

VIRAL HEMORRHAGIC SEPTICEMIA (VHS)

VHS is a fish virus discovered in Lake Ontario in 2005 that seriously threatens the sport and commercial fisheries of the Great Lakes. VHS is an invasive pathogen, but scientists are unsure how it arrived. It may have come in with migrating fish from the Atlantic Coast, with bait, or in ship ballast water. Prior to being discovered in the Great Lakes, VHS was only known in marine environments of the Atlantic and Pacific where it primarily affects salmonids. VHS is highly contagious and in the right conditions can kill 80% of the fish it infects. The disease does not pose a threat to humans. This virus has been found in walleye, smallmouth bass, musky, freshwater drum, yellow perch, northern pike and others and has caused large fish die-offs in lakes Ontario, Erie, and St. Clair. Test results for Wisconsin from 2006-2012, show that VHS has been detected in fish from the Lake Winnebago system, Lake Superior, Lake Michigan and Green Bay. As of June 2011, fish species in Wisconsin waters that have tested positive for VHS include freshwater drum, brown trout, smallmouth bass, lake whitefish, round goby, yellow perch, lake herring, and gizzard shad. Newly revised regulations went into effect in 2008 in order to prevent the spread of VHS. Additional information can be found at http://dnr.wi.gov/topic/fishing/vhs/index.html.

References

Gunderman, B. and R. Elliott. 2004. *Assessment of Remnant Lake Sturgeon Populations in the Green Bay Basin 2002-2002*. Report to the Great Lakes Fishery Trust. Project Number 2001.113.

Kraft, C. 1982. *Green Bay's Yellow Perch Fishery*. Wisconsin Sea Grant Publication. WIS. SG.82-725.

Paoli, T.J. 2004. 2004 *Relative Production Assessment of YOY Northern Pike on the West Shore of Green Bay.* Wisconsin Department of Natural Resources (WDNR).

Rost, R. 2003. *Northern Pike within the Western Shore of Green Bay Coastal Zone*. Wisconsin Department of Natural Resources (WDNR). Publication concept by Kendra Axeness, UW-Extension.

Rost, R. 2004. *Western Shore of Green Bay Northern Pike Habitat Protection and Restoration-A Summary*. Wisconsin Department of Natural Resources (WDNR).

Smith, H.M. and M.M Snell. 1891. *Review of the fisheries of the Great Lakes in 1885*. U. S. Commission of Fish and Fisheries.

WDNR. Factsheet: Green Bay's other Perch. Factsheet available: *http://dnr.wi.gov/topic/fishing/documents/species/whiteperch.pdf*

WDNR. 1987. *Lower Green Bay Remedial Action Plan: Biota and Habitat Management Technical Advisory Committee Report*. Wisconsin Department of Natural Resources. Madison, WI. 102 pp.

WDNR. 1993. *Lower Green Bay Remedial Action Plan Update*. Wisconsin Department of Natural Resources., Madison, WI. 152 pp.

WDNR. 2010. Lake Michigan Management Report Series (Annual). 2010 Report available: *http://dnr.wi.gov/topic/fishing/lakemichigan/ManagementReports.html*

Links

Fish of the Great Lakes-Wisconsin Sea Grant:
http://www.seagrant.wisc.edu/greatlakesfish

Wisconsin Fish: Types of Fish-WDNR:
http://dnr.wi.gov/topic/fishing/species

Wisconsin Fishing Regulations-WDNR:
http://dnr.wi.gov/topic/fishing/regulations/index.html

Wisconsin Fish Identification Database:
http://www.wiscfish.org/fishid

Information on VHS:
http://www.seagrant.wisc.edu/home/Topics/FishandFisheries.aspx
http://dnr.wi.gov/topic/fishing/vhs/index.html

COLONIAL NESTING BIRDS

What are colonial nesting waterbirds?

Colonial nesting waterbirds are birds that nest in groups or colonies, usually on islands or in marshes which provide a water barrier from mammalian predators. Their diet consists of fish, amphibians and aquatic invertebrates.

Colonial Nesting Birds in Green Bay

Green Bay and the Lower Fox River provide important nesting sites for several colonial nesting bird species. Twenty species of colonial waterbirds are found in Wisconsin, with most also present in Green Bay (Table 30).

THOMAS ERDMAN

Gulls, pelicans, and cormorants on Cat Island, Lower Green Bay

Table 30: Wisconsin's colonial waterbirds.

Species	Scientific Name	Present in Green Bay	Nesting in Green Bay	Nesting Historically in Green Bay
American White Pelican	*Pelecanus erythrorhynchus*	x	x	
Black-crowned Night Heron	*Nycicorax nycticorax*	x	x	x
Black Tern	*Childonias niger*	x		x
Bonaparte's Gull	*Chroicocephalus philadelphia*	x		x
Caspian Tern	*Sterna caspia*	x	X	x
Cattle Egret	*Bubulcus ibis*	x	x	x
Common Tern	*Sterna hirundo*	x		x
Double-crested Cormorant	*Phalacrocorax auritus*	x	x	x
Eared Grebe	*Podiceps nigricollis*			
Forster's Tern	*Sterna forsteri*	x		x
Great Black-backed Gull	*Larus marinus*	x		
Great Blue Heron	*Ardea herodias*	x	x	x
Great Egret	*Casmerodius albus*	x	x	x
Green Heron	*Butorides virescens*	x	x	x
Herring Gull	*Larus argentatus*	x	x	x
Little Gull	*Larus minutus*			x
Ring-billed Gull	*Larus delawarensis*	x	x	x
Snowy Egret	*Egretta thula*	x	x	x
Western Grebe	*Aechmophorus occidentalis*			
Yellow-crowned Night Heron	*Nyctanassa violacea*			

List of Wisconsin's colonial nesting birds from the WDNR

The U.S. Fish and Wildlife Service recorded the following observations on May 22, 2013:

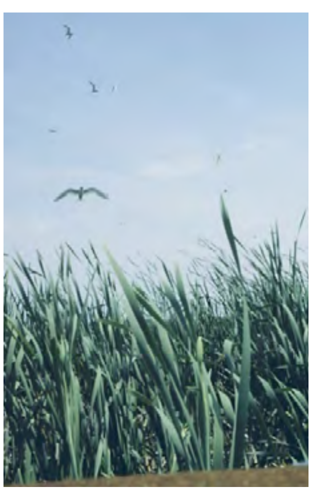
- 400 cormorants on Cat Island,
- 100 on Lone Tree Island
- 600 pelicans on Cat Island, large colony on Lone Tree Island
- 20 Caspian terns on Willow Shoal
- 10 common terns on Willow Shoal
- 12 great egrets on Lone Tree Island, a few active nests on Lone Tree
- 5 black-crowned night herons on Lone Tree Island—views disrupted because the shrubs where black crowns are typically seen now have dense foliage
- Large numbers of gulls, both ring-billed and herring

Terns

Status: Poor
Trend: Deteriorating

Four species of terns (black, Forster's, common, and Caspian) can be found in the Green Bay area. The black and Forster's terns nest in marsh areas, Caspian terns nest on the ground in open sparsely vegetated islands, while common terns prefer nesting on small islands, but have nested in marshes more than once on the west shore. The Caspian, Forster's and common terns are all listed as endangered species in Wisconsin. Currently, black terns are listed as a species of Special Concern in Wisconsin (WDNR), which means there are suspected, but not proven problems of abundance or distribution. However, in 2012, the WDNR proposed listing the black tern as endangered due to population declines.

Tern populations in Lower Green bay have decreased as a result of PCB contamination, water level changes, vegetation loss, and invasive species impacts. For the common, Caspian and Forster's terns, nesting has not occurred in Lower Green Bay since the late 1990s (Wisconsin Wildlife Surveys 2005); however for the past seven to eight years, ample nesting sites have been available for common and Caspian terns. A small number of Forster's Terns were observed nesting and feeding young at the base of Longtail Point in the AOC in 2011 (Robert Howe, personal communication) and a few pairs were observed at the Oconto breakwater and south marsh (Thomas Erdman, personal communication). In 2012, a small group of common terns attempted to re-nest on the north tip of Willow Island, but the attempt failed (Thomas Erdman, personal communication).


H.J. HARRIS

Forster's terns over a marsh

The black tern population along the western shore of Green Bay has essentially disappeared (Matteson et al. 2012). Based on the results of the Wisconsin Black Tern Survey, no terns were found in the period 2009-2011, whereas the period from 1980-82 had some of the highest counts in the state (Table 31; Figure 88) (Matteson et al. 2012). There is no single known cause that can be linked to the decline in black tern populations. Over the period in which black terns declined (see above) changes in habitat, water levels and forage base are all possible factors.

Table 31: Numbers of black terns recorded on roadside transects for Brown and Oconto counties, Wisconsin Black Tern Survey 1980-1982, 1995-1997, and 2009-2012.

	Period 1 (1980-82)			Period 2 (1995-1997)			Period 3 (2009-2011)		
Transect	1980	1981	1982	1995	1996	1997	2009	2010	2011
Brown	76	41	50	11	3	2	0	0	0
Oconto	132	100	166	14	10	27	0	0	0

Data from: Matteson et al. 2012. Population Declines of Black Terns in Wisconsin: A 30-Year Perspective. Waterbirds, 35(2):185-193.

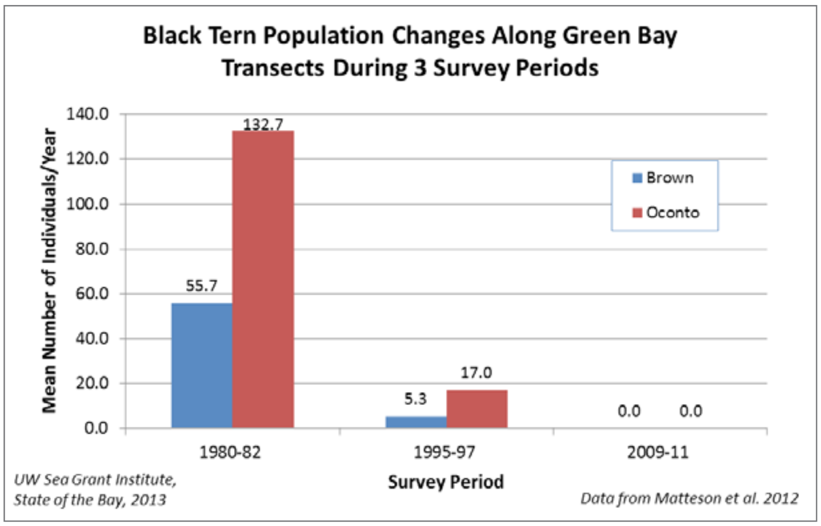


Figure 88: Mean numbers of black terns recorded on roadside transects for Brown and Oconto counties for the periods 1980-1982, 1995-1997 and 2009-2011. Data from Matteson et al., 2012.

Gulls

Ring-billed and Herring gulls are the most common gulls found in the Green Bay region. Smelt and alewife populations have been the biggest factor impacting gull populations. Ring-billed Gulls first came to the Great Lakes from the Great Plains when smelt became established (Thomas Erdman, personal communication). These gulls are adaptable and non-aggressive. In Green Bay, Ring-billed Gulls did not become established until after the alewife invasion (Tom Erdman, personal communication). As alewife populations increased in the 1960s, so did Ring-billed Gull populations. Currently, Ring-billed Gulls remain in very low numbers on Lower Green Bay, but they have the potential for population increases provided the right situation and habitat (Thomas Erdman, personal communication).

Herring Gulls are the dominant gull species in the area and populations have increased dramatically on Lower Green Bay with a population of over 300 pairs, mainly on Cat Island. Unlike Ring-billed Gulls, Herring Gulls are very aggressive birds and are egg and chick predators. Like the smaller Ring-billed Gulls, their population increases have been influenced by smelt, alewife and gizzard shad populations.

THOMAS ERDMAN

Black-crowned night herons on Lone Tree

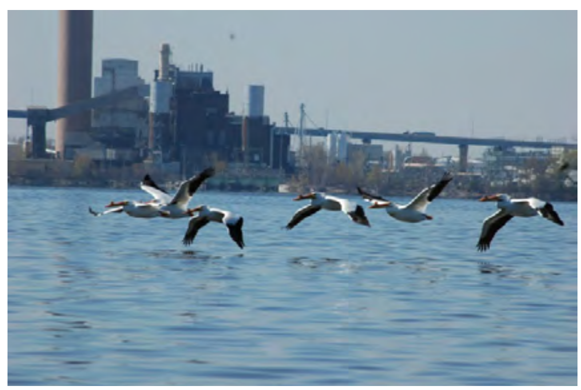
Egrets and Herons

Both egrets and herons are found in the Green Bay area. Black-crowned night herons have moved around considerably and most of the colony is located at Lake Poygan along with cattle and snowy egrets. Egrets and herons moved from Green Bay because of a loss of woody vegetation on islands (Tom Erdman, personal communication). The arrival of great egrets displaced cattle egrets and snowy egrets because great egrets are aggressive (Tom Erdman, personal communication). Since there is a lack of adequate habitat, egrets are nesting on the ground, which is highly unusual. Lone Tree Island is the only egret and heron colony left on Lower Green Bay. Lack of nesting shrubs and gull predation coupled with human disturbance resulted in birds leaving Cat Island. Great egrets have increased in numbers with very good reproduction even though they are nesting on the ground among stone rubble on the north end of Lone Tree. Black-crowned night herons are also nesting in and under the stone rubble in low numbers. In addition, two pair of cattle egrets nested in the shrubs on Lone Tree Island in 2011 and a single snowy egret has been reported on Lone Tree and north along the west shore in recent years (Thomas Erdman, personal communication).

Pelicans

Status: Good
Trend: Improving

Populations of American white pelicans have been increasing in Wisconsin since 1990, and the first pelican nest was discovered in 1994 at Cat Island in Lower Green Bay. Pelicans are listed as a species of Special Concern in Wisconsin (WDNR), which means there are suspected, but not proven problems of abundance or distribution. In Lower Green Bay, Cat Island and Lone Tree Islands are known pelican nesting sites as well as Hat Island in northern Green Bay (Table 32). Pelican populations have continued to increase on both Cat and Lone Tree Islands. In 2013, Cat and Lone Tree Islands each had about 600 pair (Thomas Erdman, personal communication).



THOMAS ERDMAN

American white pelicans in Lower Green Bay

Table 32: American white pelican nests in Green Bay, Lake Michigan.

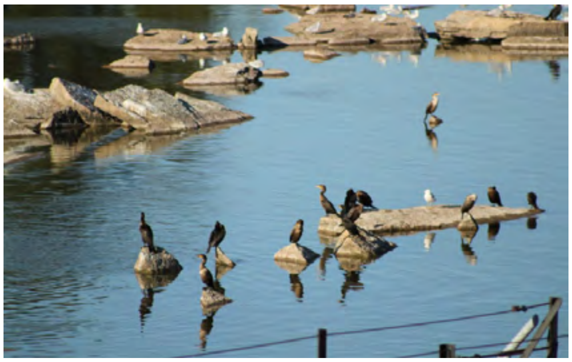
	Cat Island	Lone Tree Island	
Year	# Nests	# Fledged	# Nests
1999	180	230	
2002	185-220	200	
2003	170-185	n/a	>200
2004	334	350	314
2005	345	n/a	249

Data from: Wisconsin Wildlife Survey, April 2003, April 2004, and April 2005; Conservation of Endangered, Threatened and Nongame Birds Performance Report: Sumner W. Matteson

Double-crested Cormorant

Status: Good
Trend: Unchanging

NATHAN QUALLS



Double-crested cormorants at De Pere dam

Double-crested cormorants are colonial water-birds that usually nest in undisturbed areas and on islands. During the 1960s and 1970s, populations of double-crested cormorants in the Great Lakes drastically decreased primarily due to chemical contamination, in particular DDT and PCBs. Since 1986, populations of double-crested cormorants have increased because of an increase in their food supply, federal and state protection, and a decrease in toxic chemicals. In the Great Lakes, populations of cormorants are at all-time highs. In Green Bay and in Wisconsin, the number of cormorant nests has increased over time and the number of nests in Upper Green Bay and Cat Island represents a large proportion of the cormorants in Wisconsin (Figure 89). In 2008, more than 10,000 pairs of cormorants resided on islands in northern Door County (Hat Island west of Egg Harbor, Jack Island west of Peninsula State Park, Spider Island east of Newport State Park and Pilot Island east of the Northport ferry docks). However, because of control efforts, cormorant populations on Green Bay islands decreased 18% to 12,534 nests in 2011 from 15,227 nests in 2009 (WDNR 2011).

Double-crested cormorants are opportunistic feeders, primarily feeding on fish. Double-crested cormorants usually consume roughly 20% of their body weight (about one pound of fish) each day. Since they eat fish, including yellow perch, many anglers view the birds as a nuisance and a threat to commercial and sport fish species. From 2004-2006, a study was conducted on double-crested cormorant feeding habits on Green Bay to determine their impacts on the yellow perch fishery (Meadows 2007). Researchers examined the stomach contents of 1,429 cormorants. Results from the study showed that cormorants are not responsible for the decline in yellow perch populations (Meadows 2007). While yellow perch are an important food source for cormorants in mid-June, they are a small part of their diet by mid-July. Later in the summer, other fish, including gizzard shad and round gobies make up a large part of their diet. Since double-crested cormorants are opportunistic feeders, it is important to note their feeding habits can change throughout a season and year to year depending on the availability of prey fish populations.

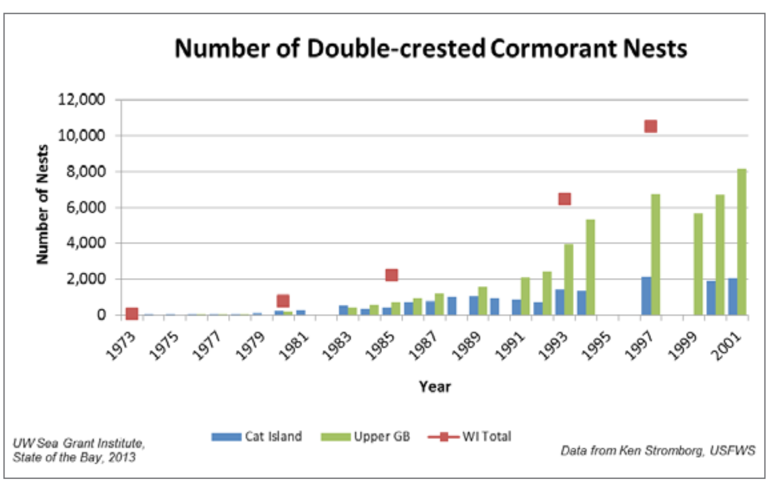


Figure 89: The number of Double-crested cormorant nests. Data from Ken Stromborg, USFWS.

References

Graetz, J.L. and S.W. Matteson. 1996. The Status of Black Terns in Wisconsin, 1995. *Passenger Pigeon* 58(3): 241-248.

Matteson, S.W. and M.J. Mossman. 2000. *Changes in Wisconsin Black Tern Populations, 1980-1997*. Unpublished Report. Wisconsin Department of Natural Resources. Madison. 13 pp.

Matteson, S.W., M.J. Mossman, and D.A. Shealer. 2012. Population Decline of Black Terns in Wisconsin: A 30-year Perspective. Waterbirds 35(2): 185-193.

Meadows, S.A. 2007. *Food Habits of Double-Crested Cormorants in Southern Green Bay with Emphasis on Impacts on the Yellow Perch Fishery -Final Summary Report*. Report prepared for the Wisconsin Department of Natural Resources by the University of Wisconsin, Madison.

Wisconsin Department of Natural Resources (WDNR). 2011. *Cormorant Population Decreasing along Green Bay, Lake Michigan*. Wisconsin DNR weekly news article.

Wisconsin Department of Natural Resources (WDNR). *The Natural Heritage Working List: Wisconsin Rare Birds*. Website accessed May 11, 2012:
http://dnr.wi.gov/topic/endangeredresources/Animals.asp?mode=list&Grp=7

Wisconsin Department of Natural Resources (WDNR): Bureau of Endangered Resources. 2005. *Wisconsin Wildlife Surveys: Conservation of Endangered, Threatened and Nongame Birds, Performance Report, 1 July 2004 to 30 June 2005*. pp. 120-134.

Links

Wisconsin endangered and threatened species:
http://dnr.wi.gov/topic/EndangeredResources/ETList.html

Information on double-crested cormorants:
http://www.fws.gov/migratorybirds/CurrentBirdIssues/Management/cormorant/cormorant.html

Patuxent Bird Identification Center:
http://www.mbr-pwrc.usgs.gov/id/framlst/infocenter.html

Great Wisconsin Birding and Nature Trail: Lake Michigan Region:
http://www.travelwisconsin.com/PDF/Lake_Michigan_Guide.pdf

Checklist of Wisconsin birds - Wisconsin DNR:
http://dnr.wi.gov/files/pdf/pubs/er/er0633.pdf

Wisconsin Breeding Bird Atlas:
http://www.uwgb.edu/birds/wbba

RESTORATION PROJECTS

Several key actions for the restoration of Green Bay emerged from the RAP and ecological risk assessment for Green Bay (Harris et al. 1994). Restoration projects have been undertaken over the past 20 years to address these key actions, which are: eliminate toxicity of wastewater discharges and remediate contaminated sediments, protect and restore wetlands and ecological services, prevent further invasive species introductions, and reduce nutrients and solids loading.

Contaminant Cleanup

For the Lower Fox River and Green Bay, a comprehensive cleanup plan was developed (WDNR 2003). Under the plan, contaminated sediments were removed from areas in Little Lake Butte des Morts and the stretch of the river from Little Rapids to the De Pere dam, and from the De Pere dam to the mouth of the Fox River. Contaminated sediments were processed in a specially built treatment facility. In the treatment process, PCBs were concentrated in sludge. The sludge was disposed of in an off-site landfill. Clean sand resulting from the treatment has been used in various highway projects. The clean water was returned to the river. Under the plan, dredging will not occur in the section of the Fox River from Appleton to Little Rapids and in Green Bay. Instead these areas will be monitored since they are expected to recover naturally.

Cleanup began in Little Lakes Butte des Morts in 2004 and was completed in May 2009. More than 784,000 cubic yards of PCB-contaminated sediment was removed. Monitoring of Little Lake Butte des Morts in 2010 showed that PCB concentrations were reduced by 94% in surface sediments and 73% in walleye fillets.

Cleanup from Little Rapids to De Pere was completed in 2011 with 236,000 cubic yards of sediment removed and 90 acres capped. The only segment left to complete is from the De Pere dam to Green Bay, which is expected in 2017. In 2011 and 2012, 1.87 million cubic yards were dredged from this segment. Since this part of the Fox River contains the largest mass of PCB contamination, it will take the longest to cleanup.

Remedial action reduces the exposure of aquatic organisms to toxic substances in the sediments, including PCBs. Consequently, the level of PCBs in the food chain will be reduced, leading to reduced PCBs in fish tissue. The rate of reduction depends on the progress and extent of remediation. Realistically, because the system is large and complex, it may take two decades before some fish advisories are lifted. A long-term monitoring plan has been developed to measure success of the cleanup (WDNR 2009).

The Cat Islands

A chain of small islands once formed the backbone of extensive wildlife habitat in southern Green Bay. Known as the Cat Islands, they were washed away in the 1970s by high water levels, storm waves, and ice shoves. The original concept to restore the chain of islands was suggested in an international working group (Harris et al. 1982). Years later, the Brown County Port and the U.S. Army Corps of Engineers (USACE) partnering with the U.S. Fish and Wildlife Service, the WDNR, UW-Green Bay, UW Sea Grant Institute and W.F. Baird & Associates designed a plan for rebuilding the Cat Islands and restoring habitat and the many ecological functions they once provided for the bay.

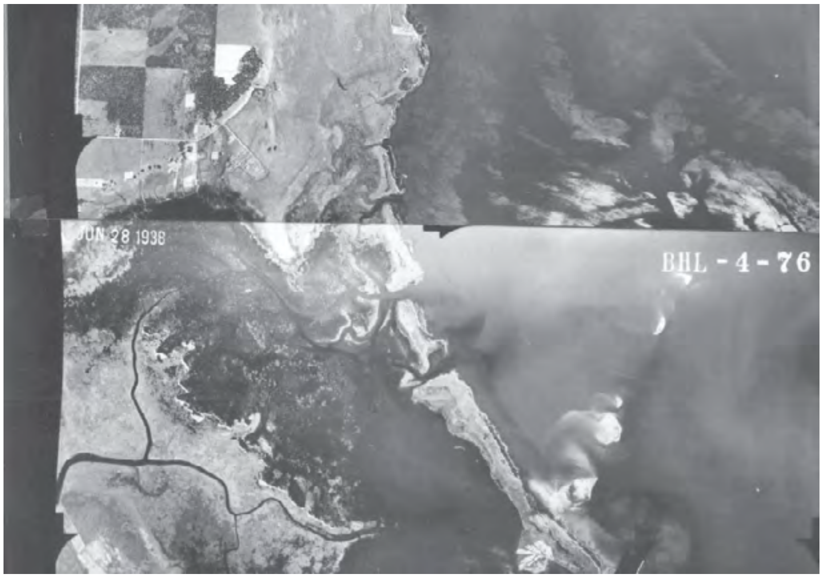


Figure 90: 1938 air photo of the Cat Island Chain and Duck Creek Delta.

Figure 91: Cat Island spine construction, May 2013.

Restoration of the Cat Island Chain began in 2012. The Cat Island Chain historically functioned much like coastal barrier islands, protecting a large expanse of shallow bay waters and wetlands that provided fish and wildlife habitat. When the spine of the islands is established, nearby coastal marsh and underwater plant communities will be protected from destructive wave action. These habitats are critical in sustaining important sport and commercial fisheries, such as the yellow perch. The restored islands were designed to fit the "footprint" of the original island chain (Figure 90) and to provide needed habitat for shorebirds, waterfowl, colonial nesting birds, amphibians and reptiles. The project also provides beneficial use of clean dredge materials from Green Bay navigation channel. Construction of the spine is anticipated to be complete by the end of 2013 and construction of the islands may start as early as 2014 (Figure 91).

West Shore Wetland and Watershed Restoration

Two projects central to coastal wetland restoration have been undertaken by the Brown County Land and Water Conservation Department (LWCD) and The Nature Conservancy. The Brown County LWCD began a project in 2008 to expand habitat for northern pike along the west shore of Green Bay. Project objectives include creating or enhancing spawning areas, removing stream impediments such as improperly placed or undersized culverts, and establishing buffers along shallow headwater streams. Beginning in 2011, Brown County LWCD began monitoring spawning areas to document fish use. Additional work and research focusing on northern pike on the west shore began in 2011 by Oconto County Land Conservation Department as well as The Nature Conservancy and partners.

The Duck-Pensaukee Watershed Approach—a collaborative product of The Nature Conservancy, Environmental Law Institute (ELI), and key agency and NGO partners—ranks the relative value of wetlands to people and wildlife in a Great Lakes coastal watershed. This information is used to focus the collective efforts of watershed partners, from both regulatory and non-regulatory conservation perspectives, on sites that can be protected or restored to ensure long-term watershed health and provision of services. The approach has the two-fold goal of increasing the success and relevance of mitigation work under the Clean Water Act, while also steering private mitigation dollars (recently estimated by ELI to approach $3 billion annually across the nation) toward watershed-based conservation priorities (The Nature Conservancy Conservation Gateway).

References

Harris, H.J., R.B. Wenger, V.A. Harris, and D.S. Devault. 1994. A Method for Assessing Environmental Risk: A Case Study of Green Bay, Lake Michigan, USA. *Environmental Management*. 18(2): 295-306.

Harris H.J., D.R. Talhelm, J.J.Magnuson, and A.M. Forbes. 1982. *Green Bay in the Future – A Rehabilitative Prospectus*. Great Lakes Fishery Commission Technical Report, No. 38.

Wisconsin Department of Natural Resources (WDNR). 2009. *Baseline Monitoring Data Report, 2006-2007, Lower Fox River, Wisconsin.* Prepared by: Anchor QEA, LLC, Tetra Tech EC, Inc., Shaw Environmental and Infrastructure, Inc., and Limno Tech, Inc.

Wisconsin Department of Natural Resources (WDNR). 2003. *Record of Decision Operable Units 3, 4, and 5 Lower Fox River and Green Bay, Wisconsin.* *http://www.epa.gov/region05/cleanup/foxriver/pdf/foxriver_rod_200306.pdf*

APPENDIX

Descriptive Statistics for TP, NO_3, NO_2, NH_3, TSS, chlorophyll *a*, Secchi depth, and Cl.

Table A-1: Mean and standard deviation for TP.

YEARS 1986 TO 1994

Year	Zone	N	TP Mean (mg/L)	Std Dev
1986	River	53	0.1373	0.0521
	1	82	0.1134	0.0239
	2	57	0.0925	0.0256
	3	30	0.08	0.0179
1987	River	27	0.1741	0.0578
	1	45	0.1328	0.0549
	2	35	0.0941	0.0354
	3	22	0.0861	0.0336
1988	River	30	0.1868	0.0451
	1	50	0.1371	0.0541
	2	40	0.0571	0.0101
	3	23	0.0503	0.0013
1989	River	45	0.178	0.0543
	1	75	0.1584	0.0576
	2	60	0.0681	0.0235
	3	39	0.05	0
1990	River	42	0.1492	0.0312
	1	70	0.1501	0.0376
	2	52	0.0795	0.0224
	3	23	0.0513	0.0033
1991	River	33	0.2145	0.0639
	1	55	0.1444	0.0435
	2	40	0.0593	0.0248
	3	25	0.0326	0.0137
1992	River	30	0.1947	0.0516
	1	50	0.1353	0.0378
	2	40	0.0614	0.0314
	3	17	0.0301	0.0092
1993	River	25	0.1853	0.0508
	1	43	0.1845	0.0623
	2	31	0.092	0.0456
	3	15	0.0451	0.0337
1994	River	36	0.1906	0.0634
	1	60	0.133	0.0421
	2	45	0.0504	0.0191
	3	24	0.0292	0.0103

YEARS 1995 TO 2003

Year	Zone	N	TP Mean (mg/L)	Std Dev
1995	River	39	0.1857	0.0555
	1	66	0.1463	0.0639
	2	45	0.0612	0.0429
	3	26	0.035	0.0179
1996	River	36	0.1783	0.0683
	1	49	0.1396	0.0519
	2	36	0.0577	0.0246
	3	23	0.0355	0.0126
1997	River	40	0.1772	0.0691
	1	57	0.126	0.0669
	2	43	0.0632	0.0367
	3	23	0.0418	0.0271
1998	River	33	0.1515	0.0346
	1	44	0.1156	0.0314
	2	24	0.0579	0.0141
	3	4	0.0275	0.0126
1999	River	45	0.1451	0.0593
	1	68	0.1257	0.0533
	2	53	0.0854	0.0362
	3	19	0.0797	0.0433
2000	River	39	0.1731	0.0559
	1	59	0.1592	0.0607
	2	44	0.1131	0.0518
	3	18	0.0953	0.0339
2001	River	42	0.2177	0.0979
	1	54	0.2306	0.0866
	2	36	0.1956	0.0873
	3	14	0.1596	0.0692
2002	River	33	0.2539	0.1006
	1	55	0.2003	0.1017
	2	36	0.1529	0.0547
	3	26	0.1608	0.0519
2003	River	33	0.2942	0.1592
	1	48	0.2363	0.1382
	2	39	0.1901	0.1251
	3	24	0.2096	0.215

YEARS 2004 TO 2012

Year	Zone	N	TP Mean (mg/L)	Std Dev
2004	River	33	0.1989	0.0262
	1	45	0.1673	0.0327
	2	40	0.104	0.0251
	3	12	0.1008	0.0162
2005	River	34	0.2779	0.0421
	1	59	0.1815	0.0536
	2	43	0.0689	0.04
	3	30	0.0362	0.014
2006	River	33	0.1698	0.0579
	1	51	0.1213	0.0395
	2	44	0.057	0.0203
	3	21	0.0404	0.0202
2007	River	37	0.2752	0.1216
	1	41	0.0969	0.0652
	2	49	0.0311	0.0198
	3	26	0.0233	0.0014
2008	River	41	0.12	0.0455
	1	41	0.1013	0.0539
	2	52	0.0385	0.0281
	3	30	0.0193	0.0114
2009	River	36	0.1115	0.0412
	1	39	0.0461	0.029
	2	52	0.0189	0.0115
	3	34	0.0154	0.0079
2010	River	29	0.1502	0.0308
	1	28	0.1005	0.0372
	2	41	0.0463	0.0293
	3	21	0.0184	0.0069
2011	River	28	0.1357	0.0407
	1	32	0.1072	0.037
	2	44	0.0438	0.0216
	3	31	0.0215	0.0042
2012	River	35	0.2686	0.0833
	1	38	0.1451	0.0682
	2	57	0.0481	0.0228
	3	40	0.0282	0.0120

Table A-2: Mean and standard deviation for NO_3.

YEARS 1986 TO 1994

Year	Zone	N	NO_3 Mean (mg/L)	Std Dev
1986	River	56	0.0716	0.0774
	1	89	0.0542	0.0514
	2	68	0.0337	0.029
	3	36	0.0303	0.0332
1987	River	27	0.068	0.05
	1	45	0.0561	0.1322
	2	35	0.0284	0.0138
	3	22	0.0282	0.0215
1988	River	33	0.0448	0.0379
	1	55	0.0132	0.0137
	2	44	0.0117	0.0153
	3	29	0.0226	0.0281
1989	River	45	0.0483	0.0843
	1	75	0.0461	0.0827
	2	60	0.0254	0.0371
	3	39	0.0208	0.0226
1990	River	42	0.2143	0.2691
	1	70	0.1485	0.2736
	2	52	0.0639	0.1262
	3	23	0.0144	0.0076
1991	River	33	0.0806	0.0947
	1	55	0.0336	0.0401
	2	39	0.0197	0.0059
	3	24	0.0283	0.0183
1992	River	39	0.225	0.1946
	1	64	0.079	0.0965
	2	50	0.0195	0.0173
	3	23	0.0186	0.019
1993	River	21	0.2054	0.2506
	1	33	0.2047	0.2781
	2	22	0.1655	0.2237
	3	10	0.1393	0.1331
1994	River	33	0.1375	0.1125
	1	55	0.0573	0.0705
	2	41	0.0136	0.0111
	3	21	0.0725	0.2133

YEARS 1995 TO 2003

Year	Zone	N	NO_3 Mean (mg/L)	Std Dev
1995	River	21	0.075	0.0507
	1	35	0.0219	0.0308
	2	25	0.0119	0.008
	3	13	0.0284	0.025
1996	River	27	0.1994	0.1814
	1	36	0.1135	0.2201
	2	27	0.0597	0.1262
	3	17	0.0494	0.0401
1997	River	28	0.3398	0.4221
	1	37	0.154	0.2656
	2	27	0.0457	0.041
	3	14	0.0437	0.0482
1998	River	21	0.073	0.0585
	1	28	0.0482	0.0796
	2	14	0.0211	0.0294
	3	0		
1999	River	39	0.1133	0.1064
	1	61	0.0639	0.096
	2	48	0.0226	0.0211
	3	19	0.0234	0.0155
2000	River	30	0.2489	0.4385
	1	44	0.1529	0.3315
	2	35	0.0472	0.0782
	3	12	0.0091	0.0062
2001	River	36	0.1103	0.1299
	1	42	0.0704	0.122
	2	39	0.0516	0.0791
	3	16	0.057	0.0501
2002	River	24	0.3738	0.4808
	1	40	0.3316	0.4757
	2	29	0.1809	0.2041
	3	20	0.1307	0.089
2003	River	21	0.2975	0.229
	1	28	0.1553	0.2393
	2	23	0.0889	0.0884
	3	12	0.1451	0.0591

YEARS 2004 TO 2012

Year	Zone	N	NO_3 Mean (mg/L)	Std Dev
2004	River	25	0.4905	0.6641
	1	38	0.3825	0.5719
	2	29	0.1652	0.2704
	3	10	0.2032	0.1289
2005	River	34	0.2376	0.2933
	1	59	0.0951	0.154
	2	43	0.0368	0.0391
	3	30	0.0395	0.0343
2006	River	33	0.1546	0.1947
	1	51	0.0798	0.1286
	2	44	0.0649	0.0949
	3	21	0.0631	0.062
2007	River	37	0.1653	0.2522
	1	41	0.037	0.0767
	2	49	0.0161	0.026
	3	26	0.0238	0.0278
2008	River	41	0.3241	0.3321
	1	41	0.2128	0.2985
	2	52	0.1483	0.2676
	3	30	0.097	0.0931
2009	River	34	0.3201	0.4069
	1	39	0.1495	0.2692
	2	52	0.0693	0.0928
	3	34	0.0679	0.0516
2010	River	29	0.3978	0.313
	1	28	0.1133	0.1456
	2	41	0.0338	0.0295
	3	21	0.0376	0.0272
2011	River	28	0.3054	0.1606
	1	32	0.1236	0.2052
	2	44	0.0745	0.1192
	3	31	0.0818	0.0554
2012	River	35	0.0763	0.1402
	1	38	0.0321	0.094
	2	57	0.0108	0.0159
	3	40	0.0247	0.0319

Table A-3: Mean and standard deviation for NO_2.

YEARS 1986 TO 1994

Year	Zone	N	NO_2 Mean (mg/L)	Std Dev
1986	River	56	0.0071	0.0059
	1	90	0.0069	0.0045
	2	68	0.0093	0.0344
	3	36	0.0033	0.0017
1987	River	27	0.008	0.0054
	1	45	0.0056	0.0046
	2	35	0.0031	0.0016
	3	22	0.0024	0.0012
1988	River	33	0.011	0.0017
	1	55	0.01	0.0001
	2	44	0.01	0
	3	29	0.01	0
1989	River	45	0.0121	0.0059
	1	75	0.0115	0.0041
	2	60	0.0102	0.0008
	3	39	0.01	0
1990	River	42	0.0146	0.0143
	1	70	0.01	0.0117
	2	52	0.0042	0.0051
	3	23	0.0017	0.0008
1991	River	33	0.0138	0.0176
	1	55	0.0052	0.0065
	2	40	0.0013	0.0005
	3	25	0.002	0.0025
1992	River	39	0.0265	0.0208
	1	65	0.0118	0.0121
	2	50	0.0026	0.0018
	3	23	0.002	0.0012
1993	River	21	0.0254	0.0101
	1	33	0.0295	0.0139
	2	22	0.02	0.0118
	3	10	0.016	0.0055
1994	River	33	0.0186	0.0144
	1	55	0.0106	0.0087
	2	41	0.0049	0.0015
	3	21	0.0044	0.0027

YEARS 1995 TO 2003

Year	Zone	N	NO_2 Mean (mg/L)	Std Dev
1995	River	21	0.0073	0.0025
	1	35	0.0041	0.0018
	2	25	0.003	0.0011
	3	13	0.0035	0.0018
1996	River	27	0.0202	0.0152
	1	36	0.0137	0.017
	2	27	0.0083	0.0079
	3	17	0.0056	0.0039
1997	River	25	0.0313	0.0312
	1	32	0.0137	0.0113
	2	23	0.0068	0.0022
	3	11	0.0048	0.0013
1998	River	21	0.0108	0.0043
	1	28	0.0092	0.0082
	2	14	0.0041	0.0017
	3	0		
1999	River	39	0.0124	0.0079
	1	61	0.0098	0.007
	2	48	0.0059	0.0022
	3	19	0.0056	0.0016
2000	River	30	0.0203	0.0257
	1	44	0.0139	0.0179
	2	35	0.0063	0.0058
	3	12	0.0034	0.0017
2001	River	36	0.0115	0.0069
	1	42	0.0098	0.0093
	2	39	0.0074	0.0045
	3	16	0.0088	0.0036
2002	River	24	0.0229	0.0225
	1	40	0.0218	0.0221
	2	29	0.013	0.0086
	3	20	0.0095	0.0031
2003	River	21	0.0255	0.0156
	1	28	0.0171	0.015
	2	23	0.0105	0.0053
	3	12	0.0108	0.0029

YEARS 2004 TO 2012

Year	Zone	N	NO_2 Mean (mg/L)	Std Dev
2004	River	25	0.0329	0.0406
	1	38	0.0261	0.0346
	2	29	0.0124	0.0157
	3	10	0.0112	0.0022
2005	River	34	0.0299	0.0352
	1	59	0.0127	0.0146
	2	43	0.0075	0.0027
	3	30	0.0077	0.0018
2006	River	33	0.0153	0.0119
	1	51	0.0107	0.0066
	2	44	0.0083	0.0031
	3	21	0.0073	0.0009
2007	River	37	0.0213	0.0214
	1	41	0.0079	0.0052
	2	49	0.0054	0.0025
	3	26	0.0062	0.0025
2008	River	41	0.0196	0.0144
	1	41	0.015	0.0144
	2	52	0.0092	0.0118
	3	30	0.0059	0.0032
2009	River	34	0.0266	0.0173
	1	39	0.0108	0.0113
	2	52	0.0054	0.0037
	3	34	0.0047	0.0017
2010	River	29	0.034	0.023
	1	28	0.0134	0.0122
	2	41	0.0057	0.0031
	3	21	0.0039	0.0019
2011	River	28	0.0261	0.0105
	1	32	0.0111	0.0102
	2	44	0.0081	0.0064
	3	31	0.0096	0.008
2012	River	32	0.0111	0.0102
	1	38	0.0071	0.005
	2	57	0.004	0.0017
	3	40	0.004	0.0016

Table A-4: Mean and standard deviation for NH_3.

YEARS 1986 TO 1994

Year	Zone	N	NH_3 Mean (mg/L)	Std Dev
1986	River	53	0.0696	0.0761
	1	86	0.0892	0.1181
	2	65	0.0446	0.085
	3	36	0.0388	0.0552
1987	River	24	0.2296	0.1416
	1	40	0.2155	0.1292
	2	31	0.1713	0.1325
	3	19	0.1577	0.1051
1988	River	36	0.1421	0.0868
	1	60	0.0773	0.0646
	2	48	0.0688	0.0558
	3	29	0.0551	0.0323
1989	River	45	0.1024	0.0972
	1	75	0.0795	0.1224
	2	60	0.0625	0.1148
	3	39	0.0758	0.137
1990	River	42	0.1479	0.0695
	1	70	0.1136	0.076
	2	52	0.0902	0.0556
	3	23	0.0719	0.0359
1991	River	33	0.2699	0.2004
	1	54	0.1505	0.0803
	2	40	0.1146	0.0757
	3	25	0.1313	0.055
1992	River	39	0.2591	0.1465
	1	65	0.1594	0.1014
	2	50	0.1699	0.1527
	3	23	0.1437	0.0608
1993	River	25	0.0965	0.0581
	1	43	0.1216	0.0806
	2	31	0.0673	0.0393
	3	15	0.0525	0.0171
1994	River	36	0.1013	0.0729
	1	60	0.0532	0.0393
	2	45	0.0408	0.0217
	3	24	0.0371	0.0208

YEARS 1995 TO 2003

Year	Zone	N	NH_3 Mean (mg/L)	Std Dev
1995	River	36	0.109	0.0802
	1	61	0.0487	0.0342
	2	41	0.0356	0.0125
	3	25	0.0378	0.0154
1996	River	36	0.1169	0.0689
	1	49	0.0707	0.0455
	2	36	0.0553	0.0259
	3	23	0.0585	0.028
1997	River	37	0.1396	0.0787
	1	52	0.0827	0.0369
	2	37	0.077	0.0295
	3	20	0.0761	0.0219
1998	River	33	0.0625	0.0646
	1	44	0.0242	0.0291
	2	24	0.0239	0.0241
	3	4	0.0046	0.0011
1999	River	39	0.0822	0.046
	1	58	0.0589	0.032
	2	46	0.0518	0.033
	3	16	0.0495	0.018
2000	River	39	0.0782	0.068
	1	59	0.0659	0.0469
	2	44	0.0608	0.0433
	3	18	0.0556	0.0327
2001	River	42	0.0732	0.057
	1	52	0.0632	0.0441
	2	39	0.052	0.0249
	3	16	0.0471	0.016
2002	River	33	0.09	0.0745
	1	55	0.077	0.0661
	2	37	0.0708	0.0473
	3	25	0.0652	0.0333
2003	River	33	0.0912	0.0716
	1	48	0.0544	0.0265
	2	39	0.0527	0.0392
	3	24	0.0573	0.0261

YEARS 2004 TO 2012

Year	Zone	N	NH_3 Mean (mg/L)	Std Dev
2004	River	28	0.1019	0.0582
	1	39	0.0841	0.0504
	2	33	0.0687	0.0315
	3	12	0.076	0.0198
2005	River	34	0.1639	0.1423
	1	59	0.0914	0.0696
	2	43	0.0725	0.0342
	3	30	0.0708	0.033
2006	River	33	0.1019	0.0665
	1	51	0.0618	0.0347
	2	44	0.064	0.0349
	3	21	0.0477	0.0217
2007	River	37	0.0981	0.0983
	1	41	0.0565	0.0418
	2	49	0.0452	0.0249
	3	26	0.0383	0.0199
2008	River	41	0.0735	0.0565
	1	41	0.0595	0.0504
	2	52	0.0476	0.0368
	3	30	0.0364	0.0106
2009	River	36	0.1542	0.0991
	1	39	0.0448	0.0675
	2	52	0.0211	0.0234
	3	34	0.0201	0.0218
2010	River	29	0.1161	0.1122
	1	28	0.0522	0.0509
	2	41	0.0225	0.0161
	3	21	0.0187	0.006
2011	River	28	0.0678	0.0495
	1	32	0.0572	0.0458
	2	44	0.0472	0.0298
	3	31	0.0395	0.0242
2012	River	35	0.1141	0.0952
	1	38	0.0522	0.0109
	2	57	0.0501	0.0078
	3	40	0.0596	0.0721

Table A-5: Mean and standard deviation for TSS.

YEARS 1991 TO 1998

Year	Zone	N	TSS Mean (mg/L)	Std Dev
1991	River	33	46.02	14.73
	1	55	34.77	13.45
	2	40	13.54	7.37
	3	25	7.78	3.48
1992	River	39	37.90	11.72
	1	65	32.65	11.33
	2	50	13.29	6.16
	3	23	6.54	2.81
1993	River	25	42.80	11.23
	1	43	35.24	12.93
	2	31	13.90	6.76
	3	15	5.47	2.11
1994	River	36	39.92	15.97
	1	60	23.59	10.34
	2	45	9.34	3.25
	3	24	4.96	1.21
1995	River	39	31.26	13.31
	1	65	24.72	10.25
	2	45	10.87	5.88
	3	27	6.26	2.87
1996	River	36	35.67	11.13
	1	49	23.81	12.45
	2	36	8.50	4.32
	3	23	4.57	1.07
1997	River	40	34.30	11.77
	1	57	25.11	14.60
	2	43	12.27	11.17
	3	23	4.50	3.19
1998	River	33	37.35	15.82
	1	44	24.88	9.71
	2	24	8.52	4.24
	3	4	3.25	1.89

YEARS 1999 TO 2006

Year	Zone	N	TSS Mean (mg/L)	Std Dev
1999	River	45	29.41	7.29
	1	68	22.05	7.42
	2	54	9.05	5.69
	3	22	4.82	2.53
2000	River	39	46.22	16.45
	1	59	37.29	14.20
	2	44	16.44	9.08
	3	18	8.50	3.33
2001	River	42	52.06	23.14
	1	54	43.58	20.26
	2	43	16.66	10.15
	3	17	5.76	2.48
2002	River	33	39.85	10.44
	1	64	24.83	10.94
	2	49	9.35	5.85
	3	30	4.77	2.30
2003	River	33	45.39	12.22
	1	48	39.53	12.89
	2	39	14.21	6.34
	3	24	4.90	2.20
2004	River	33	37.37	11.99
	1	45	29.77	14.07
	2	40	14.21	8.27
	3	13	6.97	5.34
2005	River	34	59.59	29.48
	1	59	36.88	14.88
	2	43	11.83	9.96
	3	30	5.50	1.34
2006	River	33	43.42	21.99
	1	51	29.85	14.41
	2	44	9.70	5.39
	3	21	4.28	2.06

YEARS 2007 TO 2012

Year	Zone	N	TSS Mean (mg/L)	Std Dev
2007	River	37	58.08	26.30
	1	41	30.77	14.08
	2	49	9.13	5.47
	3	26	3.83	1.33
2008	River	41	33.72	12.12
	1	41	28.92	10.20
	2	52	10.70	6.26
	3	30	4.71	2.72
2009	River	36	24.60	6.91
	1	38	16.50	7.74
	2	52	4.96	2.54
	3	34	2.71	1.49
2010	River	29	24.72	10.58
	1	28	17.45	7.26
	2	41	6.27	3.06
	3	21	2.48	0.80
2011	River	28	22.50	5.79
	1	32	21.68	10.01
	2	44	8.04	4.46
	3	31	3.08	1.05
2012	River	35	53.11	26.39
	1	38	.4.23	18.69
	2	57	9.28	5.51
	3	40	4.54	2.03

Table A-6: Mean and standard deviation for Chla.

YEARS 1990 TO 1997

Year	Zone	N	Chla Mean (ug/L)	Std Dev
1990	River	42	64.1034	21.5498
	1	70	58.3446	18.8765
	2	52	27.6427	10.8728
	3	23	13.916	5.5396
1991	River	33	154.4583	93.6663
	1	55	85.2049	39.279
	2	40	32.448	21.684
	3	25	15.725	7.8868
1992	River	38	92.584	34.1915
	1	65	68.0457	21.0624
	2	50	30.2631	17.2679
	3	23	13.542	7.288
1993	River	25	69.4422	31.3476
	1	43	61.5517	25.8726
	2	31	28.3442	15.3663
	3	15	11.9754	5.8354
1994	River	33	49.5893	30.6207
	1	55	32.3543	19.6387
	2	42	13.7783	10.2763
	3	24	5.2152	4.056
1995	River	33	24.792	16.8351
	1	56	20.5074	12.5627
	2	39	5.7225	7.1622
	3	27	1.8813	4.2516
1996	River	30	48.7339	26.6935
	1	43	48.3823	29.4562
	2	31	15.7167	11.7761
	3	20	8.4444	4.6916
1997	River	40	89.1392	50.0097
	1	57	45.3709	30.5862
	2	41	18.0004	10.5218
	3	23	8.735	4.5901

YEARS 1998 TO 2005

Year	Zone	N	Chla Mean (ug/L)	Std Dev
1998	River	33	53.0865	12.7991
	1	44	44.6358	22.385
	2	24	14.705	8.6063
	3	4	4.195	3.3998
1999	River	45	55.2482	18.7542
	1	68	44.6083	20.3786
	2	53	16.0252	9.1278
	3	22	6.9703	3.7625
2000	River	39	84.3904	32.1658
	1	59	63.1564	30.9706
	2	44	21.0185	13.6126
	3	18	12.9302	6.3924
2001	River	42	66.0111	53.3457
	1	54	61.0251	37.1374
	2	43	23.2134	16.0939
	3	17	8.42	4.3985
2002	River	33	60.7221	47.1889
	1	63	41.575	25.2209
	2	48	10.9014	8.8288
	3	30	5.5151	3.5009
2003	River	33	73.6852	35.2023
	1	48	57.362	23.7286
	2	39	20.2379	11.0447
	3	24	9.5165	5.3088
2004	River	33	51.9277	40.9046
	1	45	40.932	25.9921
	2	40	25.3559	17.0652
	3	13	7.6735	7.7013
2005	River	34	96.6912	39.9153
	1	59	69.489	28.4257
	2	43	21.7265	16.1356
	3	30	10.4422	3.4623

YEARS 2006 TO 2012

Year	Zone	N	Chla Mean (ug/L)	Std Dev
2006	River	33	76.4106	30.8582
	1	51	58.0824	22.4302
	2	44	18.2487	9.2477
	3	21	8.8324	4.3486
2007	River	37	109.6973	43.0808
	1	41	57.4848	36.6608
	2	49	17.9896	13.5566
	3	26	10.1267	10.6241
2008	River	38	46.9039	23.3596
	1	38	51.3618	29.3372
	2	48	23.8665	16.6741
	3	27	9.9852	4.6488
2009	River	36	56.475	39.4163
	1	39	34.2128	16.0916
	2	52	11.5481	5.6088
	3	34	7.0588	3.1537
2010	River	29	45.3672	35.6309
	1	28	45.6786	20.4898
	2	41	22.0146	13.9861
	3	21	8.5143	3.6488
2011	River	28	43.8982	37.1589
	1	32	53.9078	28.9099
	2	44	25.6409	17.516
	3	31	10.1413	3.7752
2012	River	35	112.4543	45.69
	1	38	80.24	47.89
	2	57	26.93	18.14
	3	40	15.05	12.21

Table A-7: Mean and standard deviation for Secchi depth.

YEARS 1986 TO 1994

Year	Zone	N	Secchi Mean (m)	Std Dev
1986	River	48	0.55	0.07
	1	77	0.72	0.16
	2	60	1.63	0.61
	3	36	2.72	0.55
1987	River	26	0.51	0.05
	1	45	0.66	0.20
	2	35	1.47	0.66
	3	22	2.25	0.98
1988	River	36	0.51	0.11
	1	58	0.69	0.35
	2	48	1.70	0.50
	3	29	2.40	0.73
1989	River	45	0.43	0.11
	1	75	0.51	0.17
	2	59	1.30	0.43
	3	39	2.37	0.58
1990	River	42	0.51	0.09
	1	68	0.52	0.11
	2	52	0.99	0.29
	3	23	1.83	0.36
1991	River	33	0.28	0.07
	1	54	0.39	0.15
	2	40	1.06	0.41
	3	25	1.70	0.59
1992	River	39	0.33	0.07
	1	70	0.39	0.13
	2	54	1.02	0.53
	3	26	1.88	0.71
1993	River	25	0.32	0.08
	1	43	0.32	0.10
	2	31	0.85	0.38
	3	15	1.61	0.41
1994	River	38	0.35	0.12
	1	63	0.50	0.16
	2	51	1.24	0.41
	3	24	2.15	0.57

YEARS 1995 TO 2003

Year	Zone	N	Secchi Mean (m)	Std Dev
1995	River	37	0.49	0.13
	1	64	0.65	0.29
	2	43	1.66	0.70
	3	27	2.63	0.75
1996	River	36	0.47	0.11
	1	48	0.61	0.19
	2	36	1.68	0.58
	3	21	2.49	0.54
1997	River	39	0.51	0.14
	1	57	0.77	0.42
	2	42	1.73	0.93
	3	23	2.76	1.46
1998	River	27	0.47	0.13
	1	36	0.69	0.37
	2	16	1.78	0.70
	3	4	3.15	1.31
1999	River	45	0.55	0.09
	1	68	0.64	0.15
	2	53	1.58	0.75
	3	20	2.41	0.63
2000	River	39	0.46	0.15
	1	59	0.56	0.23
	2	42	1.15	0.47
	3	18	1.93	0.65
2001	River	42	0.35	0.11
	1	54	0.40	0.13
	2	43	1.10	0.61
	3	17	2.06	0.43
2002	River	33	0.30	0.07
	1	64	0.53	0.26
	2	49	1.88	0.97
	3	30	2.84	0.86
2003	River	33	0.32	0.15
	1	48	0.35	0.14
	2	39	1.19	0.78
	3	24	1.98	0.73

YEARS 2004 TO 2011

Year	Zone	N	Secchi Mean (m)	Std Dev
2004	River	33	0.39	0.19
	1	45	0.45	0.24
	2	40	1.04	0.51
	3	12	2.48	0.94
2005	River	34	0.22	0.13
	1	58	0.43	0.48
	2	43	1.58	0.74
	3	29	2.64	0.81
2006	River	31	0.23	0.11
	1	51	0.37	0.27
	2	44	1.58	0.96
	3	21	2.60	1.34
2007	River	35	0.20	0.16
	1	39	0.29	0.18
	2	45	1.33	0.67
	3	26	2.36	0.69
2008	River	41	0.24	0.12
	1	42	0.38	0.26
	2	52	1.31	0.69
	3	30	2.31	0.77
2009	River	36	0.28	0.10
	1	39	0.55	0.38
	2	52	2.08	0.86
	3	34	3.06	1.23
2010	River	28	0.39	0.23
	1	27	0.54	0.50
	2	40	1.68	1.20
	3	21	3.30	1.77
2011	River	31	0.38	0.13
	1	34	0.42	0.22
	2	43	1.22	0.57
	3	30	2.17	0.61

Table A-8: Mean and standard deviation for chloride.

YEARS 1986 TO 1994

Year	Zone	N	Cl Mean (mg/L)	Std Dev
1986	River	54	18.182	5.29
	1	87	19.4855	3.93
	2	66	14.6265	2.62
	3	36	12.0417	2.03
1987	River	27	29.2852	4.40
	1	45	24.1056	5.48
	2	35	16.9886	2.25
	3	22	15.3114	1.45
1988	River	36	40.4444	7.34
	1	60	26.9833	7.52
	2	48	16.7813	1.70
	3	29	15.3448	1.75
1989	River	45	31.3333	6.55
	1	75	28.8067	6.76
	2	60	19.9417	3.28
	3	39	17.3846	2.42
1990	River	42	27.8452	3.97
	1	70	27.5286	4.70
	2	52	22.2885	2.73
	3	23	19.3261	1.61
1991	River	33	34.6364	5.17
	1	55	30.8545	5.95
	2	40	21.3125	3.63
	3	25	19.56	2.59
1992	River	39	32.4744	4.66
	1	65	30.4462	4.98
	2	50	22.14	3.65
	3	23	19.087	2.93
1993	River	25	20.42	4.33
	1	43	21.0349	4.06
	2	31	18.3226	4.44
	3	15	17.1333	3.40
1994	River	36	25.0556	5.15
	1	60	23.575	4.61
	2	45	16.5556	2.53
	3	25	14.18	1.53

YEARS 1995 TO 2003

Year	Zone	N	Cl Mean (mg/L)	Std Dev
1995	River	39	27.8769	6.75
	1	65	24.32	6.29
	2	44	14.8386	3.96
	3	27	12.0759	2.38
1996	River	33	21.4242	5.27
	1	44	20.875	3.96
	2	32	14.5469	2.97
	3	22	12.7273	2.25
1997	River	40	24.025	4.14
	1	57	21.1667	4.51
	2	41	14.5976	2.43
	3	19	12.6053	1.51
1998	River	30	27.8833	5.60
	1	40	24.4563	5.05
	2	22	15.7159	1.88
	3	3	12.8333	0.29
1999	River	45	26.2222	5.26
	1	68	25.4559	4.10
	2	54	16.9259	3.00
	3	22	14.0455	1.14
2000	River	36	28.5417	6.08
	1	54	28.1667	6.48
	2	40	19.975	4.42
	3	17	16.7353	1.57
2001	River	42	33.0714	7.16
	1	54	29.9259	6.66
	2	43	20.3721	2.83
	3	17	17.4412	2.07
2002	River	33	28.0606	5.62
	1	55	25.7545	6.19
	2	37	17.2568	2.88
	3	26	15.1731	4.46
2003	River	30	30.5983	6.56
	1	43	29.2058	6.30
	2	35	17.07	2.62
	3	21	14.5238	1.72

YEARS 2004 TO 2012

Year	Zone	N	Cl Mean (mg/L)	Std Dev
2004	River	33	24.1864	4.79
	1	45	23.9989	3.75
	2	40	18.9588	3.24
	3	13	17.3462	1.09
2005	River	31	31.65	4.02
	1	54	25.887	5.88
	2	39	15.4551	2.28
	3	27	13.0963	1.34
2006	River	33	33.8939	4.94
	1	51	28.9157	6.39
	2	44	17.8489	2.92
	3	21	15.2929	1.64
2007	River	37	40.0541	4.23
	1	41	26.5573	6.84
	2	49	17.1367	3.54
	3	26	14.3596	1.06
2008	River	38	24.6289	2.41
	1	38	25.3237	3.30
	2	48	19.4344	2.70
	3	27	16.2981	1.54
2009	River	36	32.7222	6.50
	1	39	23.6026	5.49
	2	52	16.7212	4.30
	3	34	14.1324	1.36
2010	River	29	27.6724	6.09
	1	28	25.8036	5.23
	2	41	19.7805	3.55
	3	21	16.5952	1.35
2011	River	28	23.6071	3.03
	1	32	21.7344	3.53
	2	44	16.8182	2.59
	3	30	14.3333	0.98
2012	River	35	30.4457	7.23
	1	38	24.2657	7.12
	2	57	16.0877	2.89
	3	40	13.8938	2.10