

Appendix 9.2: Green Bay Open Water East

Written by Erin Giese and Dr. James Horn

| Location (centroid) | Lat. 44.557768°, Lon. -87.951764° ¹ (NAD 1983, UTM Zone 16N) | | | | | | | | | | | | | | | | | | |
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| Total Area (ha) | 3,207.07 ha | | | | | | | | | | | | | | | | | | |
| Area Public Land (ha) | The boundaries of the Green Bay Open Water East priority area are located within the coastal zone/waters of the bay of Green Bay and are thus entirely publicly owned. Depending on lake levels, parts of the east shore (e.g., Bay Shore Woods and Beach) may overlap with the boundaries of the Green Bay Open Water East priority area. | | | | | | | | | | | | | | | | | | |
| Area of Habitat Types Present (ha) and Percent of Each Habitat Type | <p>Dominant Habitat Types: These habitat types were documented during a July 2015 habitat mapping effort led by the University of Wisconsin-Green Bay Cofrin Center for Biodiversity (CCB) across the Lower Green Bay and Fox River Area of Concern (LGB&FR AOC)². Habitat types within Green Bay Open Water East are displayed as a static map at the bottom of this document. Note that the extent of submergent marsh was refined by the CCB's 2017 submerged aquatic vegetation field surveys. There is a total of 3,207.07 ha of natural habitat in Green Bay Open Water East.</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th>Habitat Type</th> <th>Area (ha)</th> <th>Percent</th> </tr> </thead> <tbody> <tr> <td>Emergent Marsh (High Energy Coastal)</td> <td>4.20</td> <td>0.13</td> </tr> <tr> <td>Great Lakes Beach</td> <td>5.94</td> <td>0.19</td> </tr> <tr> <td>Green Bay Open Water</td> <td>3182.92</td> <td>99.25</td> </tr> <tr> <td>Other Forest</td> <td>0.18</td> <td>0.01</td> </tr> <tr> <td>Submergent Marsh</td> <td>13.83</td> <td>0.43</td> </tr> </tbody> </table> <p><i>Disclaimer! Because this priority area is located within the Great Lakes coastal zone, the amount of habitat types can vary drastically across years and even within years (or months) due to changing Great Lakes water levels, precipitation, and seiche. Within this priority area specifically, the amounts of emergent and submergent marsh and Great Lakes beach are known to fluctuate significantly from year to year and within years. The habitat types listed above and mapped below are based on a field effort conducted in July 2015. Plants recorded in the "Natural Habitat Communities and Significant Plants" section were primarily documented in July 2015 and late summer/fall 2016 and 2017. Great Lakes water levels were much higher in 2016 and 2017 than in July 2015.</i></p> | Habitat Type | Area (ha) | Percent | Emergent Marsh (High Energy Coastal) | 4.20 | 0.13 | Great Lakes Beach | 5.94 | 0.19 | Green Bay Open Water | 3182.92 | 99.25 | Other Forest | 0.18 | 0.01 | Submergent Marsh | 13.83 | 0.43 |
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| General Description | The Green Bay Open Water East priority area consists of the eastern half of the open water/pelagic zone of the lower bay of Green Bay, which is the western arm of Lake Michigan. It is somewhat arbitrarily distinguished and separated from the Green Bay Open Water West priority area by the shipping channel, though there are some distinct differences between the eastern and western halves of the bay. Shallower areas along the eastern shoreline, Point Sable Bar (drowned sandbar that extends from Point Sable nearly reaching Longtail Point), and where Grassy Island used to reside (former island across from present day Cat Island Wave Barrier and by Lone Tree Island) can range from 0.30 m to 1.83 m (1-6 ft) in depth ^{3,4} . The remainder of Green Bay Open Water East can get as deep as 3.05 m (10 ft) with the exception of the shipping channel, which can be up to 7.32-7.92 m (24-26 ft) deep ^{3,4} . The Fox River empties into the lower bay, and the water currents move in a counterclockwise direction starting by | | | | | | | | | | | | | | | | | | |

¹ File "AOC_PriorityAreas.v09_20171212.shp"

² LGB&FR AOC 2015 habitat field mapping effort

³ Depths based on 1988 NOAA bathymetry survey

⁴ U.S. Army Corps of Engineers Map of the Head of Green Bay, including Fox River below De Pere, Wisconsin, Chart No. 725 from August 1966

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| | <p>traveling up the eastern shore to Sturgeon Bay, at which point the currents turn west⁵. Sediments largely consist of sand and silt⁶. Unfortunately, water quality in the lower bay has been poor for decades. The LGB&FR AOC was originally listed as a Great Lakes Area of Concern in 1988 due to poor water quality, contaminated sediments, and degraded or lost habitat. Waters within the LGB&FR AOC regularly report high concentrations of total phosphorus, total suspended solids, nitrates/nitrites, and toxic chemicals, leading to poor overall water quality^{7,48}. It can also be turbid and experience summer and late fall blooms of harmful algae⁷.</p> <p>Despite water quality issues, a great number of fish and wildlife still use the lower bay's pelagic zone. The Green Bay Open Water East (and West) priority area is extremely well studied and may in fact be one of the most studied priority areas in the LGB&FR AOC. Over the past several decades, scientists from agencies, non-profit organizations, universities, and other organizations have conducted dozens of research projects and collected data on fish, water quality, invertebrates, birds, and plants. Like other Great Lakes, large ships and freighters regularly use the pelagic zone of the bay of Green Bay via the shipping channel for importing and exporting products and goods. Residents and visitors of Green Bay regularly use the waters of the lower bay for fishing, hunting, boating, swimming, diving, water sports, and nature viewing. Therefore, improving the quality of lower Green Bay waters and associated habitats would improve the livelihood and economics of both wildlife and people.</p> |
| <p>Special Features</p> | <ul style="list-style-type: none"> • Provides critical open water and nearshore fish habitat (e.g., woody debris) as well as spawning reefs around Renard Island, the McDonald Marina (eastern shore of the mouth of the Fox River), and Joliet Park. • Provides habitat for open water and nearshore aquatic invertebrates, including freshwater mussels, aquatic insects, arthropods, annelids, etc. • Contains Great Lakes beach, which is rare to both the state of WI and the LGB&FR AOC, and nearshore and submergent marsh habitats. • Important waterfowl migratory bird stopover site⁸. |
| <p>Natural Habitat Communities and Significant Plants (ordered in terms of ecological importance and size/amount)</p> | <p>Nearly 3,200 ha of the Green Bay Open Water East priority area is Green Bay open water with little to no plant life, except for a few small stretches of submergent marsh^{2,9}. Behind Renard Island is a submergent marsh that is dominated by sago pondweed (<i>Stuckenia pectinata</i>) and coontail (<i>Ceratophyllum demersum</i>)⁹; great duckweed (<i>Spirodela polyrrhiza</i>) and common waterweed (<i>Elodea canadensis</i>) also occur infrequently here⁹. An even smaller submergent marsh across from Scottwood Drive on the east shore is dominated by sago pondweed with a small amount of invasive Eurasian water-milfoil (<i>Myriophyllum spicatum</i>)⁹. The open water zone of this priority habitat often experiences harmful algal blooms in the late summer and early fall⁷.</p> <p>There is also nearly 6 ha of Great Lakes beach habitat, which is significant since it is a habitat that is both rare within the LGB&FR AOC and across the state^{2,10}. Along the Bay Beach Amusement Park Shoreline (behind Renard Island) is highly modified Great Lakes beach that consists of large rock, small cobble, or sand and is mostly vegetated by common reed (<i>Phragmites australis</i>; hereafter referred to as <i>Phragmites</i>)^{2,10}. Narrow stretches of Great Lakes beach extends from the Bay Beach Amusement Park Shoreline and private housing to the UW-Green Bay campus^{2,10}. Campus Great Lakes beach consists of sand, shells (including zebra mussel [<i>Dreissena polymorpha</i>] shells), and rock (in some cases rip-rap) and is partially vegetated with cottonwood, sandbar</p> |

⁵ Klump et al. 1997: Sedimentary phosphorus cycling and a phosphorus mass balance for the Green Bay, Lake Michigan ecosystem

⁶ Wisconsin's Historical Markers: <http://www.wisconsinhistoricalmarkers.com/2012/09/grassy-island-range-lights.html>

⁷ Qualls et al. 2013: State of the Bay 2013:

<http://www.seagrant.wisc.edu/Home/Topics/HabitatsandEcosystems/Details.aspx?PostID=1840>

⁸ Epstein et al. 2002: "A data compilation and assessment of coastal wetlands of Wisconsin's Great Lakes"

⁹ LGB&FR AOC Submerged Aquatic Vegetation Mapping; led by Dr. Amy Wolf and Dr. James Horn

¹⁰ LGB&FR AOC Plant Biodiversity Hotspot Field Effort led by Dr. Amy Wolf, Dr. Robert Howe, and Dr. James Horn

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| | <p>willow (<i>Salix interior</i>), box elder, green ash, gray dogwood (<i>Cornus foemina</i>), and common cocklebur (<i>Xanthium strumarium</i>)^{2,10}. Invasives present along the beach include <i>Phragmites</i>, glossy buckthorn, dame's rocket (<i>Hesperis matronalis</i>), and others^{2,10}. Rather thin stretches of Great Lakes beach line the eastern shore up until Point au Sable, which has a significant amount of Great Lakes beach around its perimeter. Point Sable's beaches primarily consist of zebra and quagga mussel shells with some sand and matted dead <i>Phragmites</i> stems^{2,10}. However, several important native plants inhabit these shorelines, such as cocklebur, American red raspberry (<i>Rubus idaeus</i> subsp. <i>strigosus</i>), beach rocket (<i>Cakile edentula</i> var. <i>lacustris</i>), a state special concern species, and late goldenrod (<i>Solidago gigantea</i>)^{2,10}.</p> |
| <p>Significant Animals</p> | <p>Birds:</p> <ul style="list-style-type: none"> • >100 bird species have been reported using the open water of the bay of Green Bay and nearshore habitats, including ducks, waterfowl, waterbirds (e.g., gulls, grebes, terns), herons, egrets, shorebirds, and some raptors during migration, the breeding season, and winter¹¹: <ul style="list-style-type: none"> ○ Ducks, waterfowl, and waterbirds, including, but not limited to: <ul style="list-style-type: none"> ▪ Congregate in large groups during migration in the Green Bay Open Water East priority area (based on recent 2016-2017 LGB&FR AOC Migratory Waterfowl Study; surveys done by Tom Prestby): <ul style="list-style-type: none"> • Bonaparte's Gull (<i>Chroicocephalus philadelphia</i>) • Common Goldeneye (<i>Bucephala clangula</i>), state special concern species • Greater Scaup (<i>Aythya marila</i>) • Lesser Scaup (<i>Aythya affinis</i>), state special concern species, listed as a Wisconsin Wildlife Action Plan Species of Greatest Concern, and regional priority species from the North American Waterfowl Management Plan • Red-breasted Merganser (<i>Mergus serrator</i>) • Ruddy Duck (<i>Oxyura jamaicensis</i>), state special concern species ▪ Other migratory waterfowl species include: <ul style="list-style-type: none"> • Bufflehead (<i>Bucephala albeola</i>) • Canada Goose (<i>Branta canadensis</i>), regional priority species from the North American Waterfowl Management Plan • Common Loon (<i>Gavia immer</i>) • Forster's Tern (<i>Sterna forsteri</i>), state endangered and listed as a Wisconsin Wildlife Action Plan Species of Greatest Concern • Herring Gull (<i>Larus smithsonianus</i>) • Horned Grebe (<i>Podiceps auritus</i>), state special concern species and listed as a Wisconsin Wildlife Action Plan Species of Greatest Concern • Ring-billed Gull (<i>Larus delawarensis</i>) ○ Herons/egrets, including, but not limited to: <ul style="list-style-type: none"> ▪ Great Egret (<i>Ardea alba</i>), state threatened and listed as a Wisconsin Wildlife Action Plan Species of Greatest Concern ▪ Great Blue Heron (<i>Ardea herodias</i>) ○ Shorebirds, including, but not limited to: <ul style="list-style-type: none"> ▪ Spotted Sandpiper (<i>Actitis macularius</i>) ▪ Wilson's Phalarope (<i>Phalaropus tricolor</i>), state special concern species, listed as a Wisconsin Wildlife Action Plan Species of Greatest Concern, and listed on the regional/continental |

¹¹ LGB&FR AOC Biota Database: file "AOCBiota_DB_ShareableVersion_20171213.accdb"

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| | <p>priorities from the Upper Mississippi/Great Lakes Joint Venture Shorebird Plan</p> <ul style="list-style-type: none"> ○ Raptors, including, but not limited to: <ul style="list-style-type: none"> ▪ Bald Eagle (<i>Haliaeetus leucocephalus</i>), state special concern species and listed as a Wisconsin Wildlife Action Plan Species of Greatest Concern ▪ Osprey (<i>Pandion haliaetus</i>), listed as a Wisconsin Wildlife Action Plan Species of Greatest Concern ○ During the breeding season and migration, swallows use nearshore habitats and open water for foraging ○ Great Egrets, Herring Gulls, and Double-crested Cormorants currently nest on Lone Tree Island¹² <p>Fish:</p> <ul style="list-style-type: none"> • >80 fish species have been recorded in the pelagic zone of the lower bay, including¹¹: <ul style="list-style-type: none"> ○ One federally endangered species: chinook salmon (<i>Oncorhynchus tshawytscha</i>) ○ Three state special concern species, including: American eel (<i>Anguilla rostrata</i>), banded killifish (<i>Fundulus diaphanus</i>), and lake sturgeon (<i>Acipenser fulvescens</i>) ○ One International Union for Conservation of Nature-listed species as “vulnerable” (bloater [<i>Coregonus hoyi</i>]) and one as “endangered” (American eel) ○ Two globally list species (G3 = vulnerable): redbside dace (<i>Clinostomus elongatus</i>) and lake sturgeon (<i>Acipenser fulvescens</i>) ○ Walleye (<i>Sander vitreus</i>), which use spawning reefs around Renard Island, the McDonald Marina (mouth of the Fox River), and Joliet Park ○ Bluegill sunfish (<i>Lepomis macrochirus</i>) ○ Burbot (<i>Lota lota</i>) ○ Gizzard shad (<i>Dorosoma cepedianum</i>) ○ Lake trout (<i>Salvelinus namaycush</i>) ○ Largemouth bass (<i>Micropterus salmoides</i>) ○ Longnose gar (<i>Lepisosteus osseus</i>) ○ Muskellunge (<i>Esox masquinongy</i>) ○ Northern pike (<i>Esox lucius</i>) ○ Pumpkinseed (<i>Lepomis gibbosus</i>) ○ Shortnose gar (<i>Lepisosteus platostomus</i>) ○ Smallmouth bass (<i>Micropterus dolomieu</i>) ○ Yellow perch (<i>Perca flavescens</i>) <p>Mammals:</p> <ul style="list-style-type: none"> • Although ~50 mammal species are known to or are expected to occur along the west shore (as noted in Roznik 1979)¹³, only a small few likely use parts of the Green Bay Open Water East, including muskrat (<i>Ondatra zibethicus</i>), North American river otter (<i>Lontra canadensis</i>), and American mink (<i>Neovison vison</i>)^{14,15} • Bats also use nearshore airspace for foraging¹⁶ <p>Mollusks:</p> <ul style="list-style-type: none"> • Within the pelagic zone of the lower bay, the following has been recorded¹¹: <ul style="list-style-type: none"> ○ Freshwater clams: fingernail clam (<i>Sphaerium</i> sp.), pea clam (<i>Pisidium</i> sp.). |
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¹² Personal communication with Thomas Prestby

¹³ Green Bay West Shores Master Plan Concept Element 1979 by Roznik et al.

¹⁴ Wisconsin Department of Natural Resources Technical Report PUB-LF-073.

¹⁵ Wisconsin Department of Natural Resources 2015 muskrat house survey

¹⁶ Jeremiah Shrovnal's LGB&FR AOC Bat Study 2016

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| | <ul style="list-style-type: none"> ○ Three snails: mud bithynia (<i>Bithynia tentaculata</i>), river snail species (<i>Campelema</i> sp.), and valve species (<i>Valvata</i> sp.) <p>Arthropods:</p> <ul style="list-style-type: none"> ● Several species have been recorded in the pelagic zone of the lower bay in the 1990s, including: <ul style="list-style-type: none"> ○ Long-horn caddisfly (<i>Oecetis</i> sp.)¹¹ ○ Buzzer midge (<i>Chironomus plumosus</i>)¹¹ ○ Green midge (<i>Tanytarsus</i> sp.)¹¹ ○ Riffle beetle species (<i>Ordobrevia</i> sp.) from 2007¹¹ <p>Annelids:</p> <ul style="list-style-type: none"> ● Aquatic oligochaete worms have been recorded in the pelagic zone of the lower bay in the early 1990s, including¹¹: <ul style="list-style-type: none"> ○ <i>Aulodrilus americanus</i> ○ <i>Dero digitata</i> ○ <i>Nais pardalis</i> ○ <i>Potamothrix moldaviensis</i> ○ <i>Nais communis</i> |
| Habitat Quality | <p>Overall, the ecological quality of the entire lower bay of Green Bay is relatively poor. The LGB&FR AOC was originally listed as a Great Lakes Area of Concern in 1988 due to poor water quality, contaminated sediments, and degraded or lost habitat.</p> <p>Qualls et al. (2013) assessed the status of the bay of Green Bay using several water quality parameters and a few other elements as described in their 2012 Green Bay Indicator Assessment from their 2013 “State of the Bay” report⁷. On a scale ranging from “poor” to “good,” elements that received a “poor” rating include total phosphorus (unchanging trend), total suspended solid (unchanging trend), Chlorophyll a (unchanging trend), water clarity (unchanging trend), toxic contaminants, aquatic invasive species (deteriorating trend), and benthic macroinvertebrates (undetermined trend)⁷. Nitrates received a “fair-good” rating with a deteriorating trend. Ammonia earned a “good” rating with an unchanging trend⁷. The lower bay also experiences summer and late fall blooms of harmful algae⁷.</p> <p>Between 1986 and 2013, NEW Water reported that the LGB&FR AOC's total phosphorus and total suspended solids were nearly always above the total maximum daily load (TMDL) targets, while water clarity (using secchi) was lower than the TMDL target¹⁷.</p> |
| Significant Invasive Species Issues | <p>Invasive Plant Species: Each of these species outcompetes and crowds out native plants^{2,9,10}:</p> <ul style="list-style-type: none"> ● Eurasian water-milfoil (<i>Myriophyllum spicatum</i>) <ul style="list-style-type: none"> ○ Found within some of the submergent marsh ● Common reed (<i>Phragmites australis</i>) <ul style="list-style-type: none"> ○ Occurs along Great Lakes beach habitat along the Bay Beach Amusement Park and Bay Shore Woods and Beach (i.e., UW-Green Bay campus shoreline) ● Glossy buckthorn (<i>Frangula alnus</i>) <ul style="list-style-type: none"> ○ Occurs along segments of the UW-Green Bay campus Great Lakes beach ● Dame’s rocket (<i>Hesperis matronalis</i>) <ul style="list-style-type: none"> ○ Occurs along segments of the UW-Green Bay campus Great Lakes beach |

¹⁷ NEW Water: Report on Water Quality for Lower Green Bay Fox River and East River for Field Year 2013: http://newwater.us/media/167545/Annual-Report-2013_Final-Draft_11-17-16.pdf

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| | <p>Invasive Animal Species:</p> <ul style="list-style-type: none"> • <i>Fish</i>¹¹ <ul style="list-style-type: none"> ○ Alewife (<i>Alosa pseudoharengus</i>)¹⁸ <ul style="list-style-type: none"> ▪ Poses a threat to native fish species by consuming zooplankton and disturbing the natural food web; not currently being managed ○ Common carp (<i>Cyprinus carpio</i>)¹⁹ <ul style="list-style-type: none"> ▪ Destroy vegetation by uprooting plants and increasing cloudiness of water; not currently being managed ○ Rainbow smelt (<i>Osmerus mordax</i>)²⁰ <ul style="list-style-type: none"> ▪ Negatively affect uncommon to rare native fish species; not currently being managed ○ Round goby (<i>Neogobius melanostomus</i>)²¹ <ul style="list-style-type: none"> ▪ Prey on small native fish and eggs (e.g., darters) and outcompete similarly sized native fish; not currently being managed ○ White perch (<i>Morone americana</i>)²² <ul style="list-style-type: none"> ▪ Prey on native fish eggs, such as walleye; not currently being managed • <i>Freshwater mussels</i> <ul style="list-style-type: none"> ○ Zebra mussel (<i>Dreissena polymorpha</i>)²³ <ul style="list-style-type: none"> ▪ Poses threat to native freshwater mussels; not currently being managed |
| <p>Management and Restoration Recommendations</p> | <ul style="list-style-type: none"> • Control introduced plant species (e.g., Eurasian watermilfoil) and maintain extensive and high quality submerged aquatic vegetation with native plants. • Develop or restore important fish spawning and nursery habitats, such as rocky reefs, gravel, cobble, woody debris, and sandy areas, for shoreline fish, along the shoreline and around Renard Island. • Control woody successional and invasive plant species, remove accumulated zebra/quagga mussel shells, and restore native vegetation at undeveloped east shore beaches (e.g., Point au Sable, UW-Green Bay campus, Joliet Park, Bay Beach region). • Conduct biotic inventories along AOC shoreline and if necessary re-establish populations of native turtle species and other beach specialists. • Continue efforts to re-introduce <i>Hexagenia</i> (mayfly). • Conduct inventory for remnant freshwater mussel beds and translocate/reintroduce populations at favorable locations. Use published studies (e.g., Morales et al. 2006) to identify optimal sites for re-introduction. • Identify critical buffer habitats and shorelines with potential den sites for mink, otter, and other shoreline wildlife species. • Implement Upper Fox, Wolf, and Lower Fox basin's total maximum daily loads (TMDL) to improve water quality. |

¹⁸ Fuller, P., E. Maynard, D. Raikow, J. Larson, A. Fusaro, and M. Neilson. 2016. *Alosa pseudoharengus*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. <https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=490> Revision Date: 9/25/2015. Accessed 17 Oct 2016

¹⁹ Nico, L., E. Maynard, P.J. Schofield, M. Cannister, J. Larson, A. Fusaro, and M. Neilson. 2016. *Cyprinus carpio*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. <https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=4> Revision Date: 7/15/2015. Accessed 17 Oct 2016

²⁰ Fuller, P., E. Maynard, J. Larson, A. Fusaro, T.H. Makled, and M. Neilson. 2016. *Osmerus mordax*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. <https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=796> Revision Date: 9/29/2015. Accessed on 17 Oct 2016

²¹ Fuller, P., A. Benson, E. Maynard, M. Neilson, J. Larson, and A. Fusaro. 2016. *Neogobius melanostomus*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. <https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=713> Revision Date: 1/7/2016. Accessed on 17 Oct 2016

²² Fuller, P., E. Maynard, D. Raikow, J. Larson, A. Fusaro, and M. Neilson. 2016. *Morone americana*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. <https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=777> Revision Date: 1/15/2016. Accessed on 17 Oct 2016

²³ Wisconsin Department of Natural Resources Technical Report PUBL ER-818 2010

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| | <ul style="list-style-type: none"> • Promote best management practices and innovative nutrient management measures in Fox River watershed. • Reduce unimpeded flow of toxins, nutrients, and sediments from urban/suburban storm water discharge pipes. • Implement effective non-point source pollution management plans in smaller watersheds and drainages. • Designate sensitive coastal landscapes at UW-Green Bay's Bay Shore Woods and Beach and Point Sable. |
| <p>Reference Links and Documents</p> | <p>Web Links:</p> <ul style="list-style-type: none"> • Fox 11 video on Green Bay poor water quality (including interview with Dr. Val Klump): <ul style="list-style-type: none"> ◦ http://fox11online.com/news/fox-11-investigates/fox-11-investigates-poor-water-quality-plaguing-green-bay • NEW Water's Aquatic Monitoring Program: http://newwater.us/programs-initiatives/aquatic-monitoring-program/ • WDNR's Surface Water Data Viewer: https://dnrgis.wi.gov/H5/?Viewer=SWDV • NOAA's Lake Level Viewer: https://coast.noaa.gov/digitalcoast/tools/llv.html • TMDL and Watershed Management Plan for Total Phosphorus and Total Suspended Solids in the Lower Fox River Basin and Lower Green Bay: http://www.uwgb.edu/watershed/REPORTS/Related_reports/TMDLs/LFR_TMDL_EPA_Submittal_Aug_2011.PDF • "Dead zones haunt Green Bay as manure fuels algae blooms" (article by the <i>Journal Sentinel</i>): http://archive.jsonline.com/news/wisconsin/dead-zones-haunt-green-bay-as-manure-fuels-algae-blooms-die-offs-b99344902z1-274684741.html/ • Lower Fox Demonstration Farms Network: implementing farming best management practices in the lower Fox River watershed: https://fyi.uwex.edu/foxdemofarms/about-us/where-we-work/ • 1845 Map of Green Bay, which shows the historic barrier islands: http://s3.amazonaws.com/labaye/data/1845%20Head%20Of%20Green%20Bay.pdf <p>Reference Documents:</p> <ul style="list-style-type: none"> • Cedillo, P.E. 2015. Hydrodynamic Modeling of the Green Bay of Lake Michigan Using the Environmental Fluid Dynamics Code. UW-Milwaukee Master's Thesis. Major Advisor: Dr. Hector Bravo. <ul style="list-style-type: none"> ◦ https://dc.uwm.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=2047&context=etd • Chow-Fraser P. 2006. Development of the wetland Water Quality Index for assessing the quality of Great Lakes coastal wetlands. In: Simon TP, Stewart PM (eds) Coastal wetlands of the Laurentian Great Lakes: health, habitat and indicators. Indiana Biological Survey, Bloomington, IN, pp 137-166. • Disterhaft, K. 2013. Changes in fish assemblages of Lake Michigan's Green Bay following the introduction of Dreissenid mussels and round goby (<i>Neogobius melanostomus</i>) during 1980-2010. Master's thesis from the University of Wisconsin-Green Bay. • Hamidi, S.A., H.R. Bravo, J.V. Klump, and J.T. Waples. 2015. The role of circulation and heat fluxes in the formation of stratification leading to hypoxia in Green Bay, Lake Michigan. <i>Journal of Great Lakes Research</i> 41:1024-1036. • Harris, V.A. 1998. Waterfowl use of lower Green Bay before (1977-78) and after (1994-97) zebra mussel invasion. Master's thesis from the University of Wisconsin-Green Bay. • Klump, J.V., D.N. Edgington, P.E. Sager, and D.M. Robertson. 1997. Sedimentary phosphorus cycling and a phosphorus mass balance for the Green Bay (Lake Michigan) ecosystem. <i>Canadian Journal of Fisheries and Aquatic Sciences</i> 54:10-26. |

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| | <ul style="list-style-type: none"> • Qualls, T., H.J. Harris, and V. Harris. 2013. The State of the Bay: The Condition of Green Bay/Lake Michigan 2013. University of Wisconsin Sea Grant Institute. • Wisconsin Department of Natural Resources. 2014. Green Bay Planning Group Master Plan. Technical Report PUB-LF-075. |
| <p>Site History (e.g., original vegetation, past conservation projects)</p> | <p>In the early 1630s, Frenchman Jean Nicolet first arrived in lower Green Bay when it was primarily inhabited by Native American tribes²⁴. Lower Green Bay consisted of large beds of wild rice (<i>Zizania</i> sp.) and wild celery (<i>Vallisneria americana</i>), extensive emergent marsh (<i>Schoenoplectus</i> sp., cattail), sedge meadows (<i>Calamagrostis canadensis</i>), shrub carr (e.g., <i>Cornus</i> spp., <i>Salix</i> spp.), swamps, and wet conifer forest (black spruce [<i>Picea mariana</i>], balsam fir [<i>Abies balsamea</i>])^{25,26,27,28,29}. Between the late 1600s and 1800s, European fur trade, duck hunting, fishing, logging, shipping, and agriculture were important early industries in lower Green Bay^{30,31,32}. In the early 1800s, there were a few small settlements and farms of Europeans and Native Americans in the lower Bay³¹. Similar to the fur trade and logging, commercial fishing was an important industry in Green Bay, in which most fishermen primarily harvested whitefish, lake trout, and lake herring^{7,33}. Other fish caught in Brown County in 1888 included perch, pike pickerel, suckers, catfish, muskellunge, and many others^{7,34}. Unfortunately, significant anthropogenic changes, such as water pollution caused by the paper industry, led to the decline of many fish species as well as widespread overfishing^{7,33}.</p> <p>Historically, there was a chain of barrier islands, called the Cat Island Chain, which extended off the west shore of the bay of Green Bay. Grassy Island (also called Grassy Point) was the easternmost of these islands that used to occur within present day Green Bay Open Water East³⁷. Grassy Island had a small forest of cottonwood (<i>Populus deltoides</i>) and willow (<i>Salix</i> sp.) as well as a bulrush/sedge (<i>Scirpus-Eleocharis</i>) marsh³⁵. Lone Tree Island was the only other island east of the present day shipping channel. In low water years, a cattail marsh formed in between Lone Tree Island and Grassy Island³⁶. There used to be a shallow sand bar called Point Sable Bar and Frying Pan Shoal that extended from Point au Sable on the eastern shore to Longtail Point on the west shore^{27,37,41}. In low water years, Native Americans used to walk on foot from Point Sable to the west shore⁴¹. It was so shallow in fact that willows and cottonwoods grew on Frying Pan Shoal⁴¹.</p> |

²⁴ Jean Nicolet: French Explorer. By The Editors of Encyclopaedia Britannica. Available: <https://www.britannica.com/biography/Jean-Nicolet> (accessed on 24 Oct 2016)

²⁵ Arthur C. Neville's Map of Historic Sites on Green Bay, Wisconsin 1669-1689. Available: <http://s3.amazonaws.com/labaye/data/Bay%20Settlement%20Map%20WI%20Historical%20Bulletin%201926.pdf> (accessed on 24 Oct 2016)

²⁶ Survey of the N.W. Lakes: East Shore of Green Bay 1843. Available: <http://s3.amazonaws.com/labaye/data/1843%20East%20Shore%20of%20Green%20Bay.jpg> (accessed on 24 Oct 2016)

²⁷ 1845 Chart of Green Bay. Available <http://s3.amazonaws.com/labaye/data/1845%20Chart%20of%20Green%20Bay.pdf> (accessed on 24 Oct 2016)

²⁸ 1820s Fox River Military Road Map to Ft. Crawford. Available: <http://s3.amazonaws.com/labaye/data/1820s%20Fox%20River%20Military%20Road%20Map%20to%20Ft.%20Crawford.pdf> (accessed on 24 Oct 2016)

²⁹ Personal communication with Thomas Erdman

³⁰ City of Green Bay's History Webpage: <http://www.ci.green-bay.wi.us/history/1800s.html> (accessed on 20 Oct 2016)

³¹ Excerpt from "Recollections of Green Bay in 1816-17" by James W. Biddle. Available: <http://s3.amazonaws.com/labaye/data/Recollections%20of%20Green%20Bay%20in%201816-1817.pdf> (accessed on 24 Oct 2016)

³² The Early Outposts of Wisconsin: Green Bay for Two-Hundred Years, 1639-1839. Available: <http://labaye.org/item/70/2810> (accessed on 25 Oct 2016)

³³ Qualls et al. (2013) cited Kraft, C. 1982. Green Bay's Yellow Perch Fishery. Wisconsin Sea Grant Publication. WIS. SG.82-725

³⁴ Qualls et al. (2013) cited Smith, H.M. & M.M Snell. 1891. Review of the fisheries of the Great Lakes in 1885. U.S. Commission of Fish & Fisheries.

³⁵ Howlett 1974: The rooted vegetation of west Green Bay with reference to environmental change

³⁶ Herdendorf et al. 1981: Fish and Wildlife Resources of the Great Lakes Coastal Wetlands within the United States Vol 5: Lake Michigan, Part 3

³⁷ NOAA Navigational Chart: http://www.charts.noaa.gov/BookletChart/14910_BookletChart.pdf

Because of these shallow areas in the lower bay and extensive miles-long sand bars, ship navigation was extremely challenging and in some cases nearly impossible³⁸. Therefore, in an effort to improve Green Bay shipping access and navigation, Congress provided \$30,500 in funding in 1866 to construct a shipping channel 60.96 m (200 ft) wide and 3.66 m (12 ft) deep that traversed through Grassy Island and in between Longtail Point and the western edge of Point Sable Bar/Frying Pan Shoal^{38,39}. Construction began in May the following year and was quickly finished by September 1867³⁸. Over the next several decades, the channel was widened and made deeper: June 1896: increased depth to 4.57 m (15 ft); June 1902: increased depth to 5.49 m (18 ft) in the northern channel; June 1910: created a ship turning area that was 4.57 m (15 ft) deep; September 1902: increased depth to 6.10 m (20 ft) in northern channel; March 1925: increased depth of southern channel to 5.49 m (18 ft); and January 1927: increased northern channel depth to 6.40 m (21 ft)³⁸. By the early 1930s, the channel was widened again and increased depth to 6.71 m (22 ft)³⁸. Today, the channel is anywhere between 7.32 m (24 ft) and 7.92 m (26 ft) and around 152.4 m (500 ft) wide. There used to be a lighthouse on Grassy Island that was first lit on 15 November 1872, though eventually it was relocated to the mainland by the Green Bay Yachting Club Harbor in 1966⁴⁰. A break wall was constructed on the western edge of Lone Tree Island, which makes up the shipping channel's eastern edge and is visible on Brown County's 1938 air photo, with a house⁴¹.

In June 1969, UW-Green Bay's Thomas Erdman and WDNR's Harold Mathiak conducted breeding bird censuses in the islands of the lower bay⁴¹. They found Black-crowned Night-Heron (*Nycticorax nycticorax*), Mallard (*Anas platyrhynchos*), Canada Goose, and Herring Gull nesting on Grassy Island⁴¹. The neighboring island, Lone Tree, which still exists today, provided nesting habitat for Common Tern (*Sterna hirundo*), Ring-billed Gull, and Spotted Sandpiper⁴¹. During extremely high lake levels and a series of damaging storms in the 1970s, nearly all of these barrier islands washed away. Grassy Island largely washed away though some of it still survived and provided nesting habitat for Double-crested Cormorant (*Phalacrocorax auritus*) and Black Tern (*Chlidonias niger*) in the 1970s⁴². Today, Grassy Island is gone, and it is unknown whether any underwater fish habitat is available from the remains of this island.

During the 1960s, sediment from the Bay was dredged to continue maintaining the shipping channel of Green Bay and was subsequently dumped back into open water in areas north of the Cat Island Chain (these dredge dumping areas are visible on the 1938 air photo from the Brown County Online GIS Portal) as well as north of Point Sable Bar^{43,44}. In 1974, this practice was banned since the dredge material contained toxic PCBs (polychlorinated biphenyls); therefore, an island-based confined disposal facility was constructed in 1979, called Renard Island (aka Kidney Island), where this dredge material was stored⁴³. A causeway was later built that connects the mainland to Renard Island on the island's westernmost section for convenient access and that has two culverts under the causeway⁴⁶. Both the island and causeway changed the shoreline overtime, in which Great Lakes beach and emergent marsh expanded behind Renard Island, though they are now invaded by *Phragmites*. The causeway and Renard Island also altered sediment transport (per UW-Sea Grant's Julia Noordyk)⁴⁶.

³⁸ *Green Bay Press Gazette* article from 1934 on increasing the depth of the Green Bay shipping channel; available in David A. Cofrin Library's Special Collections

³⁹ U.S. Army Corps of Engineers Map of the shipping channel from 1898 and 1898; provided by Tom Erdman

⁴⁰ Wisconsin's Historical Markers: <http://www.wisconsinhistoricalmarkers.com/2012/09/grassy-island-range-lights.html>

⁴¹ Personal communication with Thomas Erdman

⁴² Bertrand et al. 1976: *The Green Bay Watershed: Past/Present/Future*

⁴³ U.S. Army Corps of Engineers 2011: Available: <http://www.lre.usace.army.mil/Portals/69/docs/PPPM/PlanningandStudies/GBDMMP/GreenBayDMMP2.pdf>.

⁴⁴ U.S. Army Corps of Engineers map from 1966

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| | <p>While Renard Island is capped and covered by some short vegetation, it has provided poor quality terrestrial habitat⁴¹. Tom Erdman witnessed a botulism outbreak on Renard Island, which slowly killed infected waterbirds. Renard Island has also leached PCBs and caused high mortality to nesting birds⁴¹. Unfortunately, because the perimeter is built out of large rock, chicks have also fallen and become trapped in between the cracks in the rock during the breeding bird season⁴¹. That being said, the waters surrounding Renard Island are regularly used by many fish species. In fact, there is a spawning reef for walleye as well as woody debris for fish habitat⁴⁵. Further improvements of fish habitat could be made around the waters of Renard Island, though very minimal terrestrial improvements are recommended.</p> <p>Over the past several decades, the entire bay of Green Bay has been heavily studied by scientists from agencies, non-profit organizations, universities, and other organizations. The amount of knowledge accrued is truly significant. Below is a selected listing of relatively recent projects:</p> <ul style="list-style-type: none"> • WDNR's Tammie Paoli leads a long-term bottom trawling fish monitoring project in the bay of Green Bay that dates back to the 1980s⁴⁸. • WDNR's Steven Hogler has conducted fyke net fish sampling along the east shore and fall electroshocking for young-of-year walleye and other species⁴⁶. • In 2012, Steve Hogler also led a fish habitat restoration project around the waters of Renard Island by placing woody debris and building a spawning reef⁴⁷. • In collaboration with the WDNR, UW-Green Bay graduate student, Katherine Disterhaft, investigated changes in fish assemblages in the bay of Green Bay since the introduction of invasive zebra and quagga mussels and round gobies between 1980 and 2010 for her master's thesis project. Disterhaft used fish data collected by WDNR's Tammie Paoli⁴⁸. • Dr. Patrick Forsythe and Dr. Christopher Houghton have been leading an investigation of coastal wetland-nearshore linkages of Green Bay sport fishes, which also includes invertebrate sampling⁴⁸. They plan to estimate the coastal wetland habitat that is used by sport fish species and to build habitat food webs⁴⁸. They are also looking at spatial and temporal distributions of larval fish in the upper and lower bay⁴⁸. • The U.S. Fish and Wildlife Service (FWS) coordinates an early detection and monitoring program of aquatic invasive species in Lake Michigan, and many of their sampling locations are in the LGB&FR AOC, including sites in Green Bay Open Water East⁴⁸. They survey for ichthyoplankton, carp, macroinvertebrates, and nearshore fishes⁴⁸. • FWS' Steve Choy conducted sampling for smallmouth bass around Renard Island in 2012. • NEW Water leads a long-term aquatic monitoring program with multiple sampling locations within the LGB&FR AOC as well as other parts of the bay of Green Bay and Fox River. They collect data on water temperature, dissolved oxygen, pH, phosphorus, nitrogen, turbidity, total suspended solids, and many others⁴⁹. • Aquatic invertebrate data were collected in the bay of Green Bay in 1978, 1988, and 1994 with three sampling locations in Green Bay Open Water East (Rades, D.L. and D.F. Sanders. Lower Fox River/Bay of Green Bay Biological Water Quality Study-1994. 1995. Project 5073. Report 1: a report to Group Project 5073 Members and the Wisconsin Department of Natural Resources-Lake Michigan District. Appleton, Wisconsin: Integrated Paper Services, Inc.). • In 2014-2016, UW-Milwaukee's Dr. Jerry Kaster and graduate student Christopher Groff released 120 million eggs of <i>Hexagenia</i> (mayfly) into the bay of Green Bay in an attempt to reintroduce mayflies into the Green Bay ecosystem. In 2016, adult exuviae were found in 2016 at Longtail Point, Little Tail Point, and Sturgeon Bay. |
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⁴⁵ Personal communication with WDNR's Steve Hogler

⁴⁶ LGB&FR AOC Stakeholder Meeting on 23 June 2015

⁴⁷ AOC Conservation Project Catalogue

⁴⁸ Green Bay Fish Working Group Annual Meetings on 20 March 2015, 6 January 2016, and 4 January 2017

⁴⁹ NEW Water Aquatic Monitoring Program: <http://newwater.us/programs-initiatives/aquatic-monitoring-program/>

- In the fall of 2017, the UW-Green Bay's Cofrin Center for Biodiversity's (CCB) Dr. Amy Wolf, Dr. James Horn, and Dr. Robert Howe mapped submerged aquatic plant beds throughout the LGB&FR AOC⁹.
- For her UW-Green Bay master's thesis project (completed 1998), Vicky Harris investigated waterfowl use of lower Green Bay both before (1977-1978) and after (1994-1997) the zebra mussel invasion in the 1990s.
- In 2016-2017, under the guidance of CCB's Dr. Howe, Dr. Wolf, and Erin Giese, Tom Prestby surveyed migratory waterfowl within the LGB&FR AOC and mapped rafts.
- In the 1990s, UW-Green Bay's Thomas Erdman conducted nesting surveys at Renard Island on Common Tern, Forster's Tern (*Sterna forsteri*), Ring-billed Gull (*Larus delawarensis*), Black-crowned Night-Heron, and Herring Gull.
- Terrence Lychwick conducted a walleye study between 1983 and 1987, in which he stocked walleye fingerlings and conducted surveys along the east shore of Green Bay between Pt. Sable and Henderson's Point (Little Sturgeon Bay) and the west shore between Duck Creek and Menominee River⁵⁰.
- Surface Water Integrated Monitoring System (SWIMS): holds chemistry (water, sediment, fish tissue), physical, and biological (macroinvertebrate, aquatic invasives) data: <http://dnr.wi.gov/topic/surfacewater/swims/>
- Dr. Val Klump has spent a significant part of his career studying Green Bay water quality issues.
 - http://waterbase.uwm.edu/docs/Klump_Fermanich_2017_FinalReport_NA10NOS4780139_26Jan2017.pdf
- UW-Extension is leading the Lower Fox Demonstration Farms Project, whose goal is to implement agricultural best management practices to reduce nutrient runoff that is carried into the Fox River and ultimately lower bay⁵¹.
- The Northeast Wisconsin Land Trust's Green Bay and Lower Fox Project involves identifying high priority land parcels that could potentially improve water quality through conservation easements, etc⁴⁷.
- Green Bay Ecosystem Modeling, UW-Extension's Chad Cook⁴⁷.
- Management Analysis Tool, which looks at how climate and landscape conservation can impact Green Bay water quality (Dr. Kevin Fermanich)⁴⁷.

The bay of Green Bay provides significant and in most cases rather critical habitat for many fish species, aquatic invertebrates, waterfowl, waterbirds, and freshwater mussels that reside within the LGB&FR AOC. Water quality, which affects wildlife species differently, is relatively poor due to high nutrient and sediment loadings in the bay and pollution. Like other bodies of water, the bay has experienced (and in some cases still experience) harmful algal blooms, fish kills, and avian botulism^{7,52,53,54}. However, despite poor water quality, other structural improvements, restoration efforts, and in some cases monitoring and species re-introductions are needed in the bay. Restoration of shoreline fish spawning and nursery habitats, such as rocky reefs, gravel, cobble, woody debris, and sandy areas, are needed. Reintroductions of freshwater mussels and possibly native turtle species will also be needed. Improvements to shoreline habitat and den sites for mink and otter could furthermore be made. Efforts should continue to be made to re-introduce *Hexagenia* in the bay, one of several bottom of the food chain-species. To improve water quality, implementing best management practices for agriculture and TMDLs for the Upper Fox, Wolf, and Lower Fox basins will be necessary.

There is no doubt a significant amount of work is needed in the bay, however, thankfully there is a large cohort of scientists, biologists, policy makers, land managers, and concerned citizens actively seeking ways to improve the Green Bay ecosystem.

⁵⁰ Personal communication with WDNR's Steve Hogler

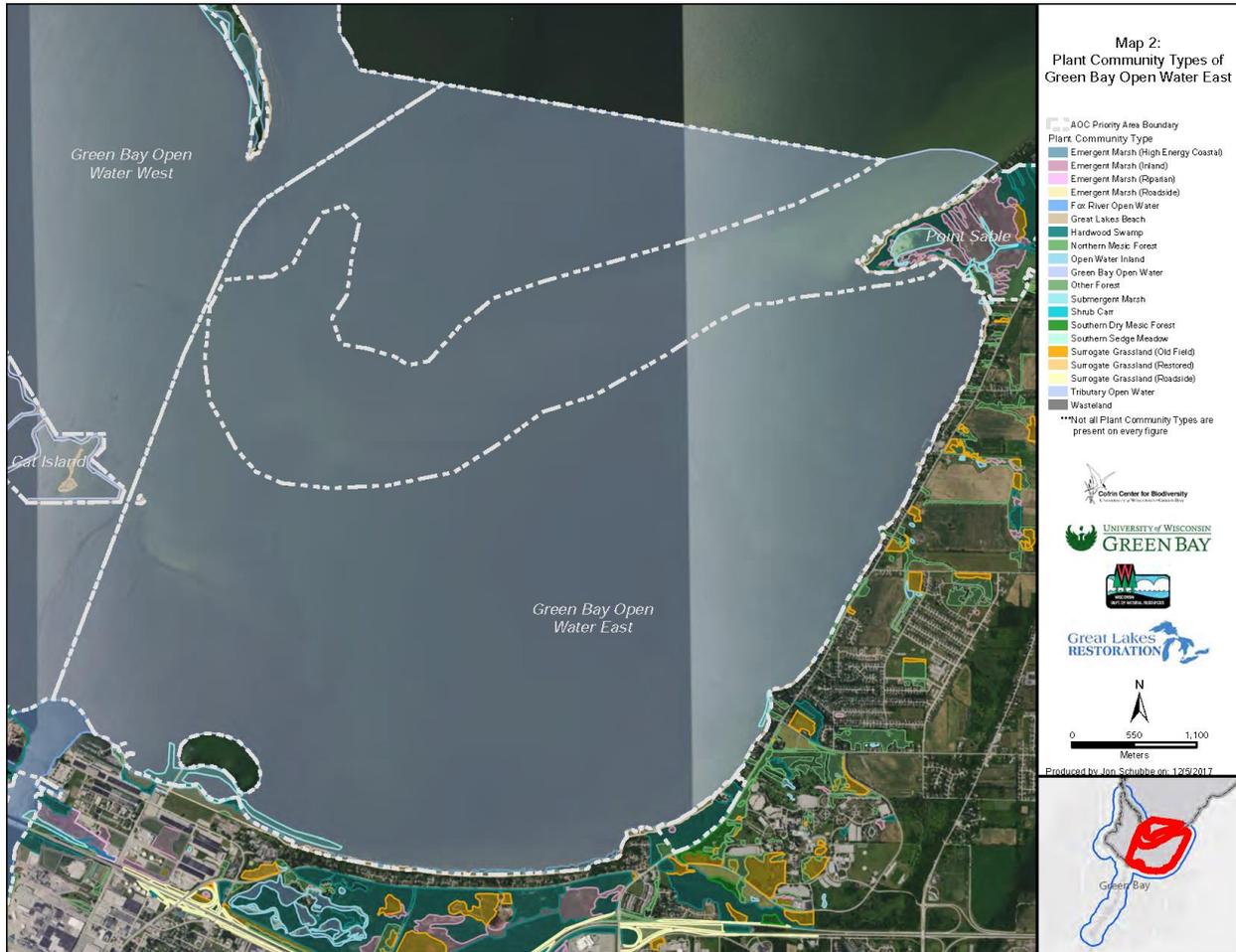
⁵¹ Lower Fox Demonstration Farms Network: <https://fyi.uwex.edu/foxdemofarms/about-us/where-we-work/>

⁵² Silliman et al. 2001: "A hypothesis for the origin of perylene based on its low abundance in sediments of Green Bay, Wisconsin"

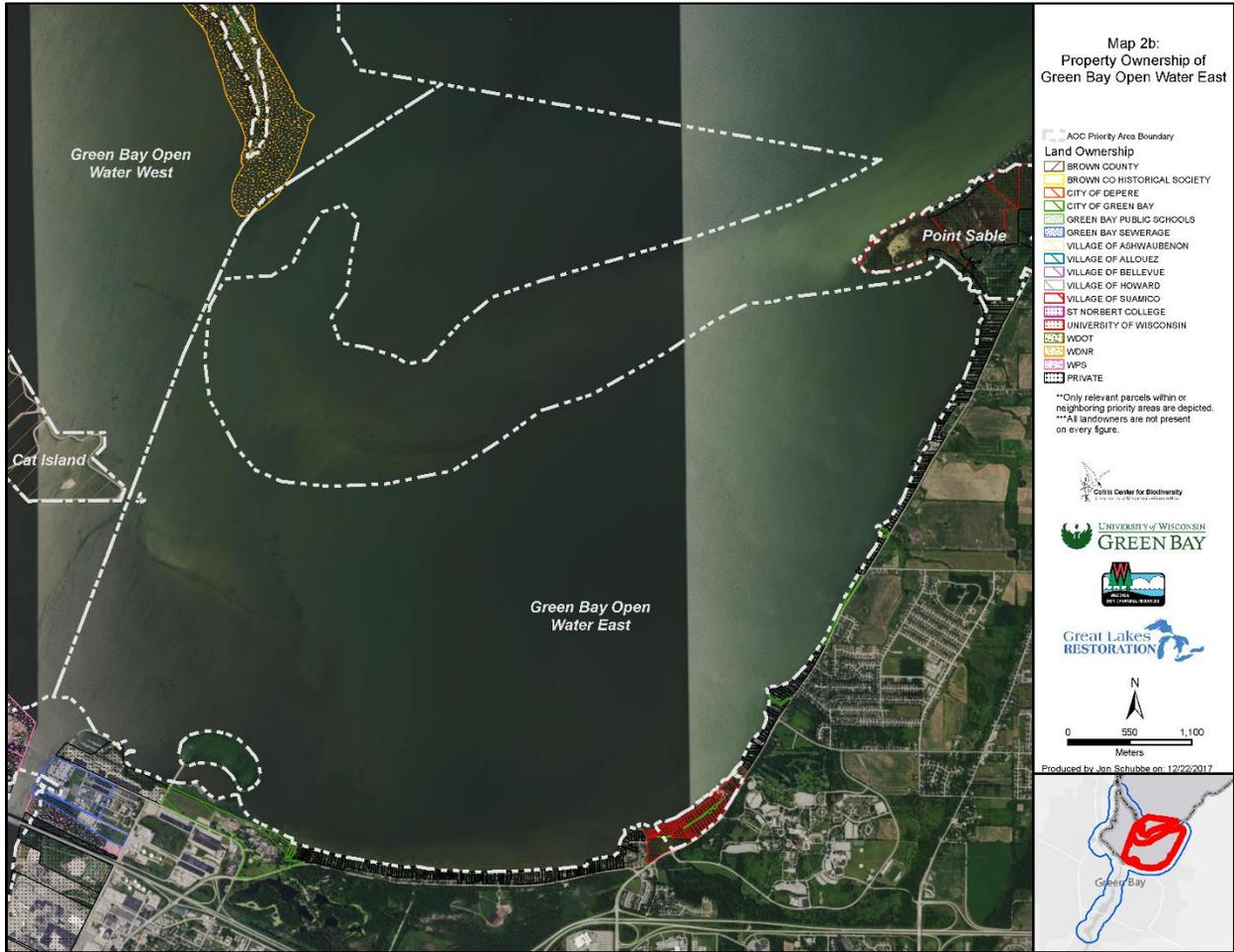
⁵³ Smith et al. 1988: "Estuary Rehabilitation: The Green Bay Story"

⁵⁴ Brand et al. 1983: Waterbird mortality from botulism type E in Lake Michigan: an update"

Map of Green Bay Open Water East plant communities, which are delineated based on the UW-Green Bay 2015 habitat mapping effort and 2017 submerged aquatic vegetation surveys. Map made by UW-Green Bay's Jon Schubbe.



Map of land ownership for Green Bay Open Water East. Map made by UW-Green Bay's Jon Schubbe.



Photograph of the southern portion of Green Bay Open Water East facing east. Photograph taken by Erin Giese on 2 December 2016.



The shipping channel is located in between the easternmost “cell” of the Cat Island Wave Barrier and Lone Tree Island. Photograph taken by Erin Giese on 2 December 2016 facing west.

