LAKE MICHIGAN'S TRIBUTARY AND NEARSHORE FISH HABITATS

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Background

The importance of preserving and restoring habitat for fish was implicitly recognized in the guiding principles and goals of the Great Lakes Water Quality Agreement (GLWQA) (International Joint Commission 1988), in A Joint Strategic Plan for Management of Great Lakes Fisheries (hereafter, Joint Plan) (Great Lakes Fishery Commission 1997), and most recently in the Great Lakes Regional Strategy (Great Lakes Regional Collaboration 2005). The GLWQA of 1978 called for an ecosystem approach to restore and maintain the chemical, physical, and biological integrity of waters within the Great Lakes basin (Bertram et al. 2005) and recognized the interdependence of living organisms with their physical and chemical habitats (Trudeau 2005). Lake management plans (LaMPs) were established to address critical pollutants and other stresses to each lake and included development of remedial action plans for Areas of Concern (AOCs) that have serious pollution problems impairing beneficial use by humans, fish, or wildlife (U.S. EPA 2004a). In 2000, the Lake Michigan LaMP was developed to comply with provisions in the GLWQA and to guide management practices to maximize achievement of ecosystem goals and restore beneficial use impairments cited in the GLWQA. Many of the subgoals of the management plan (and the environmental indicators used to evaluate those subgoals) address restoration and protection of fish health, biotic integrity, and habitat productivity. Progress towards meeting the goals is reported on a biennial basis (e.g., U.S. EPA 2004b). The Great Lakes Regional Strategy (Great Lakes Regional Collaboration 2005) is a recent wide-ranging, cooperative effort to design and implement a strategy for the

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restoration, protection, and sustainable use of the Great Lakes, with specific suggestions for addressing impairments to fish communities in tributary, coastal wetland, and nearshore habitats.

The Joint Plan called for the development of FCOs for each of the Great Lakes, the identification of environmental issues that may impede achievement of FCOs, and the development of clearly articulated and quantifiable environmental objectives (EOs) to address fish habitat issues. For Lake Michigan, it was recognized that the health and integrity of physical and chemical habitats were critical for protecting or restoring healthy fish populations and sustainable fisheries and for maintaining the biological integrity of the fish community (Eshenroder et al. 1995). The habitat FCOs for Lake Michigan are:

- Protect and enhance fish habitat and rehabilitate degraded habitats
- Achieve no net loss of the productive capacity of habitat supporting Lake Michigan's fish communities; high priority should be given to the restoration and enhancement of historic riverine spawning and nursery areas for anadromous species
- Pursue the reduction and elimination of toxic chemicals, where possible, to enhance fish survival rates and allow for the promotion of human consumption of safe-to-eat fish

Status

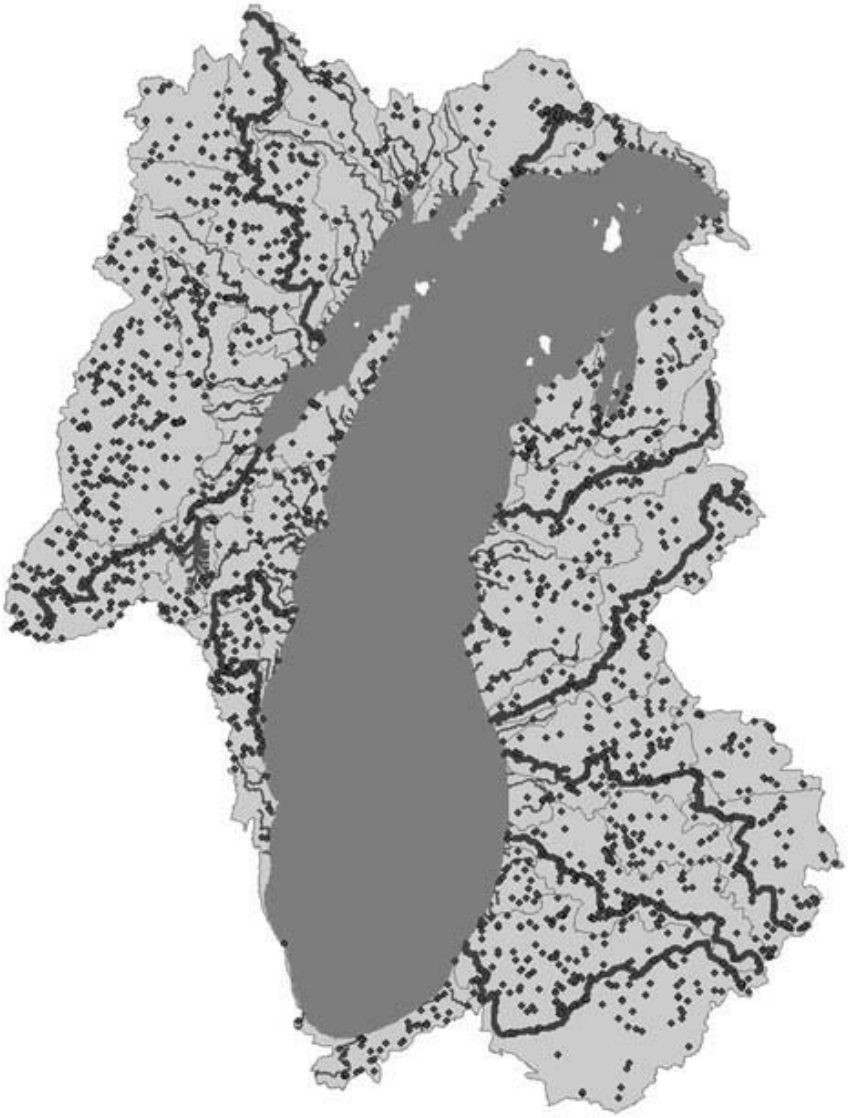
A continuum of habitats stretching from tributaries to the nearshore zone serves as important spawning and nursery habitat for one or more life stages of most Lake Michigan fishes (Wei et al. 2004). High-gradient tributary habitats are used for spawning and nursery areas by salmonines, as well as by native walleye, lake sturgeon (hereafter, sturgeon) and suckers (Catostomidae). Coastal wetland habitats support spawning and early life stages of basses (Centrarchidae), sunfishes (Centrarchidae), northern pike, muskellunge, walleye, and yellow perch, while the nearshore zone provides spawning and nursery habitat for yellow perch, smallmouth bass, and important forage fishes (cyprinids, alewife, bloater, and rainbow smelt) that fuel the growth of piscivorous fishes. Thus, natural and anthropogenic threats that degrade or permanently alter any of these habitats will severely affect fish production.

Tributaries

Most tributaries in the Lake Michigan basin have been significantly impaired through instream activities, such as damming, impoundment, channelization, sedimentation, dredging, eutrophication, and toxic contamination (U.S. EPA 2004b). These impairments have altered tributary hydrology, flow stability, and thermal regimes, thereby compromising their suitability as spawning and nursery habitats. Other physical alterations that have degraded riverine habitats result from various watershed land-use activities and changes, including timber harvest, agriculture, urban development, mining, and removal of large woody debris. Agricultural and urban land uses impose great demands for groundwater withdrawals that can reduce summer base flows and increase river temperatures and flow variability (e.g., Poole and Berman 2001; Foley et al. 2005). To prevent significant adverse impacts from water withdrawals and losses to the basin's ecosystem and its watersheds, The Great Lakes Charter (Council of Great Lakes Governors 1985) and The Great Lakes Charter Annex (Council of Great Lakes Governors 2001) agreements were enacted by the Great Lakes basin states and Canada to protect, conserve, manage, or regulate new or increased withdrawals consistent with basinwide standards (Great Lakes Basin Water Resources Compact 2005). Efforts are under way in each state to develop standards and guidelines for regulating water withdrawals.

Dams currently cause the most-obvious impairments to fish habitat in Lake Michigan tributaries. Nearly every stream draining into the Lake Michigan basin has been dammed (Fig. 1), and all of Lake Michigan's major tributaries (with mean annual discharges exceeding approximately 30 $m^3 \cdot s^{-1}$) are impounded, reducing nearly 30,000 km of available stream habitat to only 5,311 km (Rutherford et al. 2004). Dams interrupt the natural physical processes of a river by altering the flow of water, sediment, nutrients, energy, and biota, all of which affect survival and growth of individual fish and fish-community processes (e.g., Lessard 2001; Hart et al. 2002; Mistak et al. 2003).

Fig. 1. Dams (dots) in the Lake Michigan basin. Major tributaries are indicated with heavy lines.



Limited information exists to relate dam removal or fish passage with habitat and fish-population responses within a river. A geographical information system (GIS)-based, spatially explicit dam database has been compiled for the basin using dam information from state agencies and non-profit groups (e.g., the River Alliance of Wisconsin). Of the estimated 1,947 dams in the Lake Michigan basin, only 19 have some sort of fish-passage structure, and most of these are in Michigan. Dexter and LeDet (1997) summarized fish-passage information at two fish ladders in the St. Joseph River, MI. From 1918 to 2003, 67 dams have been reported removed, 58 in Wisconsin and 9 in Michigan. Wisconsin researchers have shown that the diversity of fishes in the Milwaukee River (see frontispiece for location of rivers) has increased since the removal of the North Avenue Dam in 1997 and the Chair Factory Dam in 2000 (U.S. EPA 2004b; Hirethota et al. 2005). The long-term effects of dam removal on physical attributes and the fishery of the Pine River, a high-gradient tributary of the Manistee River, continue to be studied (e.g., Bednarik 2001; Mistak et al. 2003).

Comprehensive surveys are needed to describe the fish communities and habitats in the lower reaches of Lake Michigan's tributaries. These areas are predominantly non-wadeable and hard to sample. An important but poorly studied feature of lower tributary habitats is occurrence of lateral flow and nutrient transport into and off of flood plains during high-water periods. The benefits of flood-plain habitats for fish foraging and survival are unknown but are potentially large.

Coastal Wetlands and Nearshore Zones

Coastal wetlands make a large contribution to fish health and fisheries productivity despite their relatively small size. Wetlands comprise less than 1% of Lake Michigan's total surface area of 57,800 km^2, yet provide spawning, nursery, or foraging habitat for 40-90% of Great Lakes fish species during some stage of their life cycle, and more than 75 fish species have been documented using wetlands during summer months (Jude et al. 2005a). In particular, the young-of-the-year (YOY) life stages of important forage and commercial/game fishes utilize wetland habitats and adjacent nearshore areas. Wetlands also contribute to primary productivity; provide habitat for other biota; serve as flood storage, groundwater recharge, shoreline anchoring; and assimilate and cycle nutrients and contaminants. Wetlands also serve as conduits for material transported between tributary and nearshore and offshore waters.

Coastal wetlands have been altered naturally and anthropogenically. Variability in lake hydrology is likely the most-dominant form of natural disturbance that wetlands encounter (Jude et al. 2005a). Wetlands experience natural fluctuations in water level at weekly, seasonal, and inter-annual scales. Although wetland communities are well adapted to these natural fluctuations, some natural perturbations, such as storm seiches, can be quite severe and can dramatically alter or destroy wetland communities. Inter-annual fluctuation in lake levels can dramatically change plant communities, which promotes plant and fish habitat diversity.

Coastal wetland loss has been extensive and widespread in Lake Michigan. Along the southern and western shores of Green Bay, coastal wetlands have been reduced by 60-75%, and the extensive network of wetlands along the eastern shore also has experienced dredging, ditching, draining, and backfilling (Wilcox 2005). Despite this loss, wetlands in the Green Bay area are recognized as the most-extensive fringing coastal wetland habitat in the Great Lakes basin (Jude et al. 2005a). Anthropogenic factors contributing to wetland loss or degradation include dredging, dyking, ditching, filling, shoreline hardening (i.e., sea walls, riprap), artificial manipulation of water levels, contamination, beach grooming, and increased nutrient and sediment loadings from watersheds. Beach grooming during periods of low lake levels may significantly reduce potential fish recruitment when lake levels rise.

Development-related hardening of shorelines and contamination of waters may negatively affect fish-community diversity and relative abundance (Brazner 1997). Turbidity and its negative effects on plant diversity and structure are the primary disturbance factors influencing fish and invertebrate assemblages in coastal wetlands (Uzarski et al. 2005). Turbidity lowers macrophyte cover, reduces invertebrate diversity and biomass, and decreases water clarity.

Wetlands also have been severely impacted by invasions from non-indigenous plant species but less so from non-indigenous fishes. Disruption of natural hydrologic cycles favors monocultures of plants intolerant of water-depth change (i.e., purple loosestrife) that result in lower fish biomass and species richness. Although common carp can degrade wetlands by disturbing sediments and increasing turbidity during spawning, other species including zebra mussels (*Dreissena polymorpha*), ruffe, and round goby do not appear to have impacted wetland habitats, as they are not as abundant in these habitats as in nearshore or tributary habitats.

Contaminants

Understanding the processes controlling the cycling of nutrients, sediment, and contaminants has been the focus of several studies in Lake Michigan. The Lake Michigan Mass Balance (LMMB) study has measured and modeled contaminant cycling and availability in biota and habitats within the Lake Michigan ecosystem, including fishes. Results from the LMMB study show that the greatest external inputs of PCBs are from atmospheric and tributary inputs, and the greatest losses are from volatilization and deep burial in lake sediments (McCarty et al. 2004). Because of their proximity to developed areas situated on lower rivers, the ten AOCs within the drainage have the highest concentrations of contaminants and heavy metals. The Fox, Grand Calumet, and Kalamazoo Rivers still contribute the largest tributary loads of PCBs to Lake Michigan (McCarty et al. 2004). The LaMP has identified and prioritized pollutants for removal and monitoring (U.S. EPA 2004b).

Water Quality

The water quality in Lake Michigan is generally good (U.S. EPA 2004b). Nutrient concentration trends since 1983 have shown a slow and steady decline in pelagic (offshore) phosphorus and increases in chloride, nitrogen, and silica. Reductions in pelagic phosphorus have resulted from efforts to reduce loadings, while increases in chloride, nitrogen, and silica have resulted from both increased loadings and biological cycling (Warren and Kreis 2005). In nearshore waters, zebra mussels (and, more recently, quagga mussels (*D. bugensis*)) are thought to have changed the dynamics of phosphorus cycling and increased water clarity, which, with increased tributary loadings of phosphorus from agriculture and urban areas, are stimulating blooms of *Cladophora* spp., a benthic algae (Hecky et al. 2004). The potential consequence of algal blooms for fishes are degradation of nearshore spawning and nursery habitats.

Progress towards Meeting Objectives

Draft EOs have been completed for review by the Lake Michigan Committee (Rutherford et al. 2004). The EOs were developed as guidelines to protect and restore the health and function of aquatic habitats in support of achieving the FCOs. The document identifies environmental issues and their impacts on fish species and life-history stages, summarizes current and historic information on habitats, and identifies priorities and possible future

directions required to ensure achievement of the FCOs. The document is supported by the Lake Michigan GIS project (Great Lakes Fishery Commission 2005), which contains a database and map layers to assist the public, managers, and scientists in monitoring, modeling, and analyzing fish habitats. Maps and websites of interest for fishery managers include ecoregion classifications of offshore and nearshore habitats, the U.S. Fish and Wildlife Service (USFWS) spawning and nursery atlas for Lake Michigan fishes, and the Lake Michigan Fish Atlas.

Inventory, classification, and establishment of reference conditions are necessary precursors for protecting and restoring fish habitats. Since 2000, much progress has been made using GIS software and databases. Tributary habitat inventory, classification, and modeling soon will be available for nearly the entire basin through Michigan's Digital Water Atlas, the National Hydrography Database, the Michigan Rivers Inventory, and a project funded by the Environmental Protection Agency's STAR Grant program (U.S. EPA 2005). Spatial gradients in river habitats are correlated with landscape-scale variables, such as drainage area, gradient, and soil geomorphology, which structure groundwater contributions and flows (Seelbach and Wiley 2005). Such landscape-scale variables also correlate well with fish-species abundance and community composition (Zorn et al. 2002) and, as a consequence, can be used to estimate fish habitat suitability and production potential for areas not sampled, including river habitats above dams.

Restoring additional spawning habitat to adfluvial and potamodromous fishes may be accomplished by identifying specific barrier removals or fish-passage provisions that would yield the highest spawning benefits. For example, if fish passage was provided at the Croton Dam on the Muskegon River, the reach between the Croton and Hardy Dams would produce an estimated additional 4,000 brown trout, 5,700 steelhead, 2,200 white suckers, and 21,500 Chinook salmon (Creque 2002). Providing passage on the Manistee River from Tippy to Hodenpyle Dams would produce an estimated additional 20,400 brown trout, 29,700 steelhead, 11,500 white suckers, and 109,000 Chinook salmon (Creque 2002). While potentially important, the benefits of fish passage must be balanced against the negative impacts of increased nursery habitat for sea lamprey and increased contaminant transport upstream by migrating Great Lakes fishes (Creque 2002).

Progress is being made on classification of wetland and nearshore habitats and development of indices of biotic integrity and anthropogenic disturbance. Albert and Minc (2001) identified ecoreaches of coastal Lake

Michigan using wetland types, geomorphology, and floral composition. Simon et al. (2005) and Wilcox (2005) reported classification schemes for Lake Michigan wetlands based on hydrologic influence with further sub-classification based upon geomorphic features and shoreline processes. The Great Lakes Environmental Indicators project (http://glei.nrri.umn.edu/default/) classified wetland types based on hydrology and geology and developed a suite of physical and biological indicators of ecosystem health, including fish. Recently, Uzarski et al. (2005) developed a fish-based index of biotic integrity and anthropogenic disturbance for wetlands.

Monitoring of coastal wetlands is critical for assessing wetland losses from development and is the basis for protecting wetlands. In 2000, the Great Lakes Wetlands Consortium was established to develop and begin implementation of protocols to monitor wetland status and trends. Efforts are ongoing to establish bio-indicators of wetland health. Wetland restoration efforts are concentrating on reducing sources of turbidity and increasing macrophyte production, which should result in more-diverse biotic communities. Future work must assess the potential impacts of exotic species, cultural development, and climate change on wetland function and area. Basic work remains to be done on quantitative sampling and monitoring of habitat characteristics and fish communities in nearshore areas.

Technology exists for continuous monitoring of physical, chemical, and biological components of aquatic habitats at temporal and spatial scales appropriate for fishes (http://www.glerl.noaa.gov/res/Programs/eos/). Aerial photography can provide measures of habitat change, and satellite imagery can provide estimates of surface temperature, turbidity, and chlorophyll *a* (http://www.glerl.noaa.gov/pubs/brochures/coastwatch/coastwatch.pdf). Acoustics can provide maps of gradient, depth, substrate composition, and sediment transport (Cochrane and Lafferty 2002); in-situ and towed cameras (Sprules et al. 1998) and hydroacoustics can estimate biomass of fishes and their prey in horizontal and vertical dimensions (http://www.glerl.noaa.gov/pubs/brochures/fishecology/fishacoustics.pdf). Fish otoliths also may provide a record of water chemistry and temperature, thus providing clues to habitat dependence. Using these techniques, Brazner et al. (2004) were able to distinguish wetland vs. nearshore habitat dependence for yellow perch in Lake Superior. Dufour et al. (2005) documented thermal histories and habitat use of alewife recruits in Lake Michigan, while Wurster et al. (2005) documented thermal histories of Chinook salmon in Lake Ontario. Analysis of stable isotope geochemistry in fish otoliths has been used to determine

natal habitats of steelhead juveniles in Lake Michigan watersheds (ESR, unpublished data).

Additional inventory work is needed to address the large data gaps that exist for fish communities and habitats in most coastal areas outside of the AOCs. In addition to establishment of habitat reference conditions, much work is needed to quantify fish habitat quality. Traditional measures of habitat quality have documented presence/absence or relative abundance of fish, but an understanding of habitat importance to fish growth, survival, and reproduction is also required (Brandt et al. 1992; Minns et al. 1996). Recent examples of comprehensive survey and modeling approaches to habitat quality and importance include the Muskegon River Mega Model Project, a multi-university modeling-based framework for integrated fish habitat management of watershed, wetland, and nearshore fisheries habitats (Wiley 2005).

Significant progress has been made towards reducing and eliminating toxic substances. Thousands of kilograms of contaminated sediments have been removed from the AOCs in Lake Michigan under sponsored projects identified in Annex 2 of the GLWQA. Financial support for cleanup was increased by recent passage of the Great Lakes Legacy Act (U.S. EPA 2006), which provides funding for contaminant removal and remediation of the AOCs. In the Fox River, cleanup is being funded by paper mill companies through the Superfund process. Detailed descriptions of remediation activities completed for each AOC can be found at http://www.epa.gov/glnpo/aoc/. Although significant progress has been made in removal of contaminants from the ten AOCs in Lake Michigan, as of 2004, all AOCs were still plagued by low water quality, high suspended solids, and contaminant loads, especially of PCBs and dieldrin.

Progress has been made in the reduction of contaminant loadings and burdens in fishes and other indicator species. Murphy and Whittle (2004) reported consistent declines in total DDT and total PCB concentrations in lake trout tissues from Lake Michigan starting in the 1970s, although there has been very little change in recent years. While total DDT concentrations have remained near or below the GLWQA criteria since 1986, total PCBs in lake trout remain above the criteria. Agreements have been reached to reduce mercury concentrations entering Lake Michigan by 50% (U.S. EPA 2004b). Concentrations of atrazine, an herbicide used to control weeds in agriculture, have increased but still are well below regulatory limits for human health concerns and proposed criteria for ambient water quality (Brent and Warren 2005).

The presence of new persistent toxics represents an emerging threat to the health of the Great Lakes ecosystem. These compounds include the brominated flame retardants (BFRs), which are heavily used globally in the manufacturing of a wide range of consumer products and building materials. Flame retardants are bioaccumulating in Great Lakes fish and in breast milk of North American women (Murphy and Whittle 2004; Environmental Working Group 2006). Assessment of the occurrence and fate of these new compounds has recently been incorporated into surface water, suspended sediment, and bottom-sediment monitoring programs (Murphy and Whittle 2004). Levels of polybrominated diphenyl ethers (PBDEs), which are a major class of BFRs, have increased since the late 1980s, a trend also seen for PBDEs in lake trout in the Great Lakes (Murphy and Whittle 2004).

In summary, significant progress has been made towards addressing the habitat-related objectives within the FCOs. Efforts are under way to restore and protect critical habitats in tributary, nearshore, and wetland habitats. Reduction of contaminant burdens has occurred in many key indicator species, and work continues on rehabilitating degraded habitats in the AOCs. Recognition of the importance of watershed connectivity to lake health and function has focused efforts on watershed management and dam removal. Future work should improve habitat monitoring and surveying and lead to improved understanding of habitat function and its importance to fisheries. Efforts also should focus on quantifying habitat alterations caused by exotic species and separating effects of anthropogenic sources from natural environmental changes.

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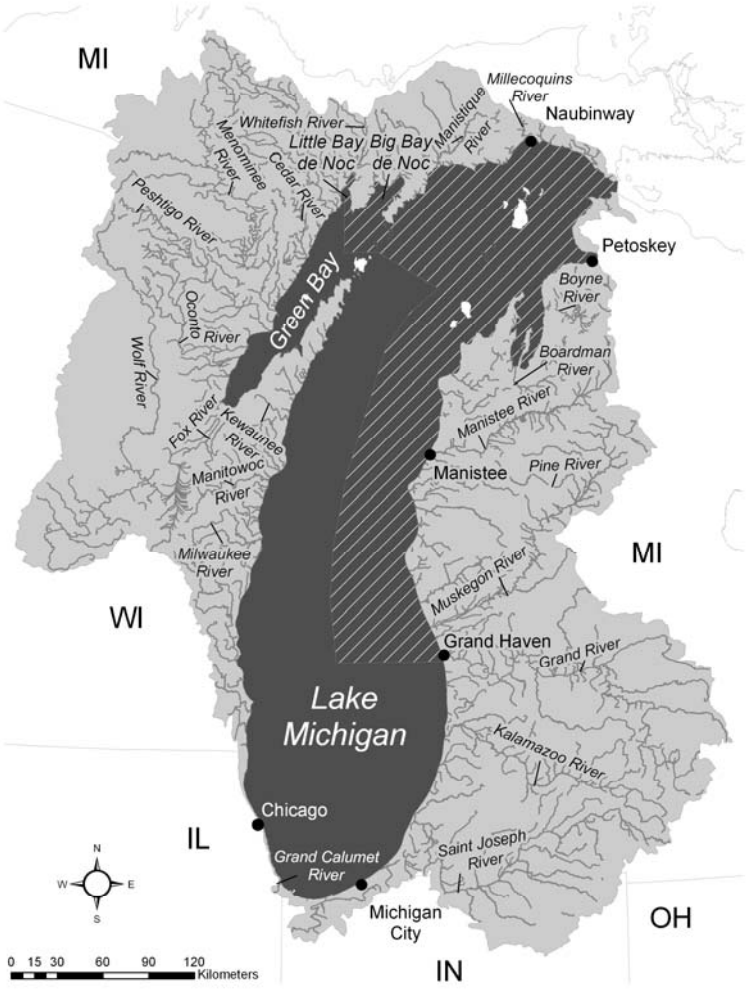

Lake Michigan depicting locations not otherwise identified in this publication. The lake basin is in grey, and treaty-ceded waters are depicted by diagonal lines.

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