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A Product of the Great Lakes Restoration Initiative

# Great Lakes Restoration Success through Science

## U.S. Geological Survey Accomplishments 2010 through 2013


Circular 1404


U.S. Department of the Interior
U.S. Geological Survey

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## *Dear Reader,*

*The Great Lakes Restoration Initiative (GLRI), implemented in 2010, brought together stakeholders from across the region in an effort to restore the Great Lakes and protect them for future generations. The U.S. Geological Survey (USGS) is proud to be a partner in this unprecedented restoration effort by providing scientific information and monitoring data needed to address many of the issues facing the Great Lakes. The USGS has a long history of conducting scientific research in the Great Lakes Basin, and the resulting knowledge and information is the foundation of our GLRI science strategy.*

*We have structured our science to meet the goals and objectives of each of the five GLRI Focus Areas described in the GLRI Action Plan, and are working closely with our Tribal, Federal, State, and local agencies and other stakeholders to achieve these goals. We are also strategically looking ahead to ensure that we continue to meet the science needs of resource managers and advance the new GLRI Action Plan for 2015. As GLRI begins its sixth year of restoration work, the issues being addressed are becoming more complex and need greater input from the scientific community to achieve successful restoration.*

*Our scientists have been gathering data on the Great Lakes and the rivers and streams that flow into them to assess water quality and availability; providing the science to restore fish habitat in Areas of Concern to create healthier aquatic ecosystems; examining food web changes and effects on the health of the Great Lakes; developing cutting-edge technologies to control invasive species; and taking numerous other science actions to contribute to the restoration efforts.*

*We are excited to share this publication with you, which highlights many of our science accomplishments and describes how new science findings, data, tools, and technologies can help restore and revitalize the Great Lakes for the people of the Great Lakes region and the Nation!*

*— Leon Carl,*
*Regional Director, Midwest Region,*
*U.S. Geological Survey*

# Contents



**(Photo left) Collecting water samples from the Nemadji River in Wisconsin. Water samples have been collected from 59 major tributaries to the Great Lakes, including the Nemadji River, to locate the sources of contaminants and to estimate the amount of the contaminants flowing into the Great Lakes. Photograph by Austin Baldwin, USGS.**

**Multitudes of prey fish are using the restored habitat at Crane Creek wetland (Lake Erie) now that they have access. Photograph by Kurt Kowalski, USGS.**

# Introduction

*The Great Lakes (Superior, Michigan, Huron, Erie, and Ontario) are the largest group of freshwater lakes on Earth and serve as an important source of drinking water, transportation, power, and recreational opportunities for the United States and Canada. They also support an abundant commercial and recreational fishery, are crucial for agriculture, and are essential to the economic vitality of the region. The Great Lakes support a wealth of biological diversity, including over 200 globally rare plants and animals and more than 40 species that are found nowhere else in the world. However, more than a century of environmental degradation has taken a substantial toll on the Great Lakes. To stimulate and promote the goal of a healthy Great Lakes region, President Obama and Congress created the Great Lakes Restoration Initiative (GLRI) in 2009. The GLRI is an interagency collaboration that seeks to address the most significant environmental problems in the Great Lakes ecosystem. The GLRI is composed of five focus areas that address these issues:*

- *Cleaning up toxic substances and Areas of Concern,*
- *Preventing and controlling invasive species,*
- *Promoting nearshore health,*
- *Protecting and restoring habitat and wildlife*
- *Tracking progress and working with partners.*

*As of August 2013, the GLRI had funded more than 1,500 projects and programs of the highest priority to meet immediate cleanup, restoration, and protection needs. These projects use scientific analyses as the basis for identifying the restoration needs and priorities for the GLRI. Results from the science, monitoring, and other on-the-ground actions by the U.S. Geological Survey (USGS) provide the scientific information needed to help guide the Great Lakes restoration efforts. This document highlights a selection of USGS projects for each of the five focus areas through 2013, demonstrating the importance of science for restoration success. Additional information for these and other USGS projects that are important for Great Lakes restoration is available at http://cida.usgs.gov/glri/glri-catalog/.*

Researchers inspect egg mats that had been placed in the St. Clair River to determine whether fish successfully used the new reefs for spawning. This buoy-less method for sampling fish eggs and spawning activity using egg mats deployed on the river bottom was developed by the USGS for sampling early life stages of lake sturgeon and other fish.

# Highlights

## Cleaning Up Toxic Substances and Areas of Concern

*Although many sources of contamination have been reduced, legacy contamination remains in the Great Lakes area. "Legacy contamination" is contamination largely left over from past practices but that continues to recirculate through the environment. These legacy contaminants often are persistent toxic substances, such as mercury, banned pesticides, polycyclic aromatic hydrocarbons (otherwise known as PAHs and are components in asphalt and coal tar), and polychlorinated biphenyls (otherwise known as PCBs). These legacy contaminants continue to be present in the environment at levels above those considered safe for humans and wildlife, sometimes warranting fish consumption advisories in the Great Lakes and connecting channels. In addition to the legacy contaminants, contaminants of emerging concern, such as pharmaceuticals, have been detected in the Great Lakes in recent years and also pose potential but unknown threats to the ecosystems. Altered or destroyed habitats in Areas of Concern—places in the Great Lakes with the largest legacies of toxic contamination—also affect Great Lakes ecosystems, causing degraded fish and wildlife populations, which is one of 14 Beneficial Use Impairments (BUIs) in Areas of Concern. A BUI is a change in the chemical, physical, or biological integrity of the Great Lakes system sufficient to cause any of 14 use impairments (http://epa.gov/greatlakes/lakeerie/buia/index.html). Progress in cleaning up toxic substances and enhancing habitat in Areas of Concern is critical to public health, and to the health of fish and wildlife. Efforts to clean up toxic substances and to address BUIs are underway in the 30 U.S. Great Lakes Areas of Concern as part of the GLRI. As part of this effort, the USGS is working with others to improve the health of the Great Lakes fisheries by enhancing fish habitat for the Huron-Erie Corridor; identifying the types and locations of legacy contaminants and contaminants of emerging concern in major tributaries to the Great Lakes; examining mercury processes including how mercury enters the food chain, how it affects the fish, and how that affects public health; using birds as indicators of contaminant exposure in the Great Lakes; and supporting restoration of beneficial uses in Areas of Concern by using measures of plankton and benthos condition.*

# Enhancing Fish Habitat in the Huron-Erie Corridor


The Huron-Erie Corridor is the international waterway that connects Lake Huron and Lake Erie, including the St. Clair River, Lake St. Clair, Detroit River, and western Lake Erie. The Huron-Erie Corridor supports more than 65 species of fish, of which 16 are classified as threatened or endangered, and is one of the busiest navigation centers in the United States. Historically, the Huron-Erie Corridor supported a highly productive fishery, providing spawning and nursery habitat for 80 fish species including lake trout, lake sturgeon, lake whitefish, lake herring, walleye, and yellow perch. Fish productivity in the Huron-Erie Corridor was dramatically reduced over the last century due to construction of shipping channels, which has severely altered fish habitat, including spawning grounds and nursery habitats. The St. Clair River and Detroit River are Areas of Concern for the Great Lakes.

The USGS and partners are supporting restoration and enhancement of native fish habitat and populations in the Huron-Erie Corridor as part of the GLRI. The USGS and Huron-Erie Corridor Initiative partners (*http://huron-erie.org/*) are developing science-based adaptive management strategies to help restore habitats and native fish in the corridor, ultimately providing societal, economic, and environmental benefits to the Great Lakes region. Adaptive management is a systematic approach for improving resource management by learning from management outcomes. Guided by a science-driven adaptive management framework, researchers are identifying, assessing, and prioritizing sites for fish spawning habitat construction and fish and nursery habitat restoration to address beneficial use impairments (BUIs) in the Detroit River and St. Clair River Areas of Concern and to help define what constitutes adequate restoration in the Areas of Concern. A BUI is a change in the chemical, physical, or biological integrity of the Great Lakes

**More than 14,000 samples of fish eggs and larvae have been collected at sites throughout the Huron-Erie Corridor (map, lower left) and across many habitat types. Pre- and post-construction monitoring near constructed spawning reefs (photo, upper left) demonstrated an immediate response by more than 14 native fish species, including lake sturgeon.**

system sufficient to cause any of 14 use impairments (*http://epa.gov/greatlakes/lakeerie/buia/index.html*). Restoration of functional spawning habitat in the Huron-Erie Corridor is critical to allowing fish populations to reproduce and maintain sustainable populations of sport and commercial fish.

The USGS is providing vital information to define restoration targets in Areas of Concern and is measuring restoration success through assessments of pre- and post-habitat construction. Monitoring information collected for this project indicate that restored habitats are attracting a variety of fish species, including multiple threatened species. Ongoing sampling is providing information on the timing and spatial distribution of fish spawning, abundance and survival of fish eggs, and production of larvae necessary for restoration efforts. Data gathered from this project also are used to validate and improve models used to predict spawning areas for lake sturgeon, walleye, and lake whitefish that would be suitable for spawning reef construction. Seven additional fish spawning habitat projects are planned for construction in the St. Clair and Detroit Rivers by 2015. With funding support from the GLRI, more than 20 acres of fish spawning habitat will be restored in the Huron-Erie Corridor by 2015. Habitat assessment and restoration techniques developed in the Huron-Erie Corridor through this project could be applied to other Great Lakes connecting channels, such as the St. Marys River (connecting Lakes Superior and Huron) and the Niagara River and Welland Canal (connecting Lakes Erie and Ontario). To ensure that information generated through this project is accessible by local communities, an outreach partnership with Michigan Sea Grant was developed. Ultimately, this project will enhance ecologically and economically valuable fish populations in the Huron-Erie Corridor, and contribute to the revitalization of the region.

**Researchers capturing a lake sturgeon (lower right) and collecting a lake sturgeon on restored spawning grounds in the lower St. Clair River (page 6). Pre- and post-construction monitoring near constructed spawning reefs demonstrated an immediate response by more than 14 native fish species, including spawning by lake sturgeon, listed as a threatened species in both Michigan and Ontario.**

**Researchers sampling larval fish using bongo nets to collect larvae drifting along the river bottom (below) and lake whitefish sac fry larvae (above). Ongoing sampling provides information on the timing and spatial distribution of fish spawning, fish eggs, and larvae necessary for restoration efforts.**

*“This work is assisting resource management agencies in developing science-based restoration criteria in the Areas of Concern. Both the restoration of important fish spawning habitat and evaluation of those projects are improving fish populations throughout the Huron-Erie Corridor, as well as improving future projects by using an adaptive approach.”*

*—Jim Francis, Lake Erie Basin Coordinator for the Michigan Department of Natural Resources, Fisheries Division*

## Early Successes

- Two techniques were developed for sampling early life stages of lake sturgeon and other fish in the Detroit River, which is a deep, flowing Great Lakes connecting channel: (1) buoy-less method for sampling fish eggs and spawning activity using eggs mats deployed on the river bottom and (2) a D-frame drift net system to assess larval lake sturgeon for use in the deeper Detroit River using an anchor and buoy system (*http://dx.doi.org/10.1111/j.1439-0426.2011.01828.x*). The techniques are now being widely used by USGS in collaboration with Federal and State partners to assess habitat restoration efforts in the St. Clair and Detroit Rivers.

- USGS scientists identified nine sites for fish spawning habitat restoration in the Detroit River and in the St. Clair River with deep, fast-flowing water suitable for spawning by native fish species. These sites were identified by using monitoring data collected for this project in conjunction with a geographic, hydrodynamic model (*http://dx.doi.org/10.1016/j.jglr.2014.02.002*).

- Spawning reefs were constructed in the Detroit and St. Clair Rivers. The positive response of lake sturgeon to a spawning reef constructed in 2008 in the Detroit River was documented in a 2011 journal article (*http://dx.doi.org/10.1111/j.1439-0426.2011.01829.x*)

- Since 2010, nine northern madtoms (a freshwater catfish), which are considered endangered in Lakes Michigan and Ontario and globally rare, have been captured in the Detroit River. Assessment data have revealed that the madtoms use the constructed reefs created in the Detroit River (*http://dx.doi.org/10.1016/j.jglr.2014.01.005*).

## 2013 Successes

- The construction of three additional spawning reefs was completed in 2013. These fish spawning reefs are used by at least 14 species of native fish, including economically important walleye, lake sturgeon (threatened in Michigan and Ontario), and lake whitefish.

- Four years of intensive field sampling was completed in 2013 at sites throughout the Huron-Erie Corridor and across many habitat types to evaluate fish spawning and nursery habitats. This work provides new and critical information for measuring the success of the restored spawning reefs to inform future habitat restoration efforts.

- Physical habitat characterization efforts that began in 2012 continued in 2013. The habitat data from these efforts are being used to evaluate potential sites for restoration efforts. A total of 71 sonar transects were run at 1 site in the Detroit River and 4 sites in the St. Clair River. These transects totaled more than 106 kilometers in length. More than 70 underwater video drift transects also were completed.

- An article was published describing the diet, age, and growth of larval (age-0) deepwater sculpin (a deepwater fish), transport of larvae through the St. Clair-Detroit River system, and the potential for larvae to drift from Lake Huron through the Huron-Erie Corridor and help restore populations in the lower Great Lakes (*http://dx.doi.org/10.1016/j.jglr.2013.07.004*). Deepwater sculpins are a preferred prey of lake trout and burbot (a cod-like fish) that reside in the deep offshore waters of the Great Lakes.

- An article describing results of fish habitat assessments and fish use of nearshore habitats in the Detroit River was published (*http://dx.doi.org/10.1016/j.jglr.2013.10.001*). Results of diet, age, and growth analyses are presented for native fishes as well as for the invasive round goby (a small, soft-bodied fish). Rehabilitation and maintenance of nearshore embayments in efforts to provide adequate resources for larval and juvenile fishes will result in enhanced recruitment of larval fishes and add resilience to populations.

**This northern madtom (*Noturus stigmosus*) was captured in a minnow trap near a constructed spawning reef in the Detroit River. Since 2010, nine northern madtoms, which are endangered in Michigan and Ontario and are considered globally rare, have been captured in the Detroit River. Assessment data have revealed that madtoms use the constructed reefs for habitat, indicating that these reefs are contributing to the recovery plan for this rare and valuable native fish. Photograph by Andrew Muir, Great Lakes Fishery Commission.**

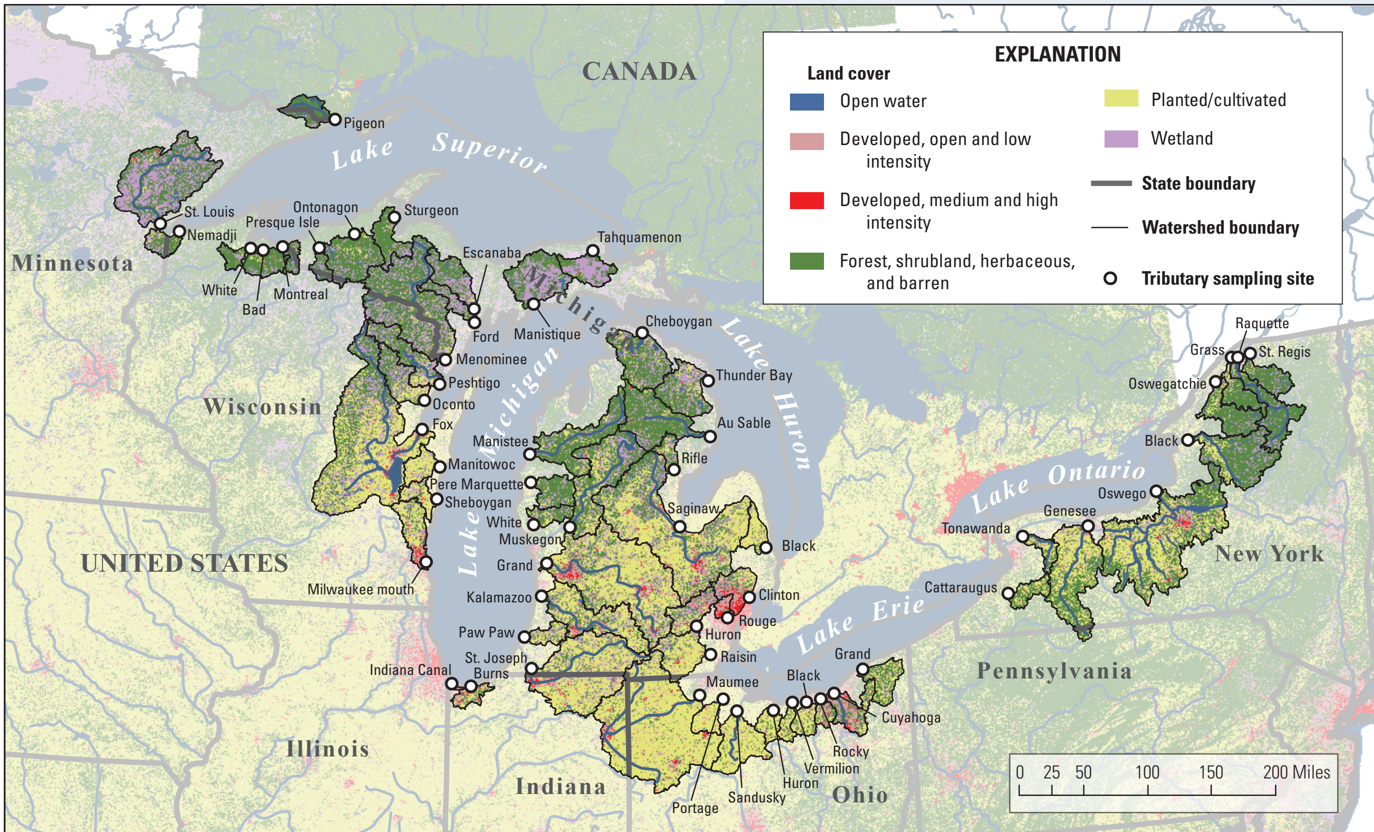
# Identifying Sources of Toxic Contaminants

Monitoring site at the Clinton River at Mount Clemens, Michigan, with custom automatic sampling system for monitoring waterborne pathogens, human-specific bacteria, mercury, and trace organic chemicals. Photograph by Peter Lenaker, USGS.

The USGS is analyzing water and sediment samples for legacy contaminants and contaminants of emerging concern at 59 tributaries to the Great Lakes, including many sites in Areas of Concern (places in the Great Lakes with the largest legacies of toxic contamination), to locate sources of these contaminants and to estimate the amount of these contaminants flowing into the Great Lakes. Monitoring at tributary sites provides important baseline information that can be used to measure progress towards restoration goals and assess new threats. This information also provides an understanding of how these contaminants reach the Great Lakes and where they originate, so that future restoration actions can be assessed. This work is coordinated with the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, individual States, many local agencies, and other monitoring and modeling entities.

Preliminary monitoring information indicates that the toxic substances found most frequently in water samples include polycyclic aromatic hydrocarbons (PAHs), pesticides, fragrances, flame retardants, and chemicals used in the manufacture of other substances. The legacy contaminants polychlorinated biphenyls (PCBs) in sediment samples from several tributaries were found at concentrations likely to affect aquatic life. Concentrations of legacy pesticides, such as DDT, were present in watersheds with a variety of land cover ranging from mostly urban to mostly agricultural. Human waste indicators, such as human-specific viruses and bacteria, and wastewater-specific trace organic compounds, were detected in all tributaries monitored, with the greatest concentrations in urban streams, followed by agricultural streams, and, at lower concentrations, in forest streams. Genetic markers of one or more pathogenic (disease-causing) bacteria were detected in 74 percent of all water samples analyzed for these genes. Knowing which contaminants are most problematic and where they are found provides important information to decision makers to help prioritize watersheds for restoration, develop strategies to reduce contaminants, and measure the success of those efforts in meeting restoration goals.

(Below left) The USGS is identifying the types and spatial distribution of legacy contaminants and contaminants of emerging concern in the water and sediments in the Great Lakes at Area of Concern sites. Decision makers can use this information to prioritize watersheds for restoration, develop strategies to reduce contaminants, and measure the success of those efforts in meeting restoration goals.




## Early Successes

- Initial monitoring effort was completed at 59 major tributary sites in fall 2010 to provide critical information for restoration efforts.
- Water samples were collected in 2010 and 2011 at 57 sites and analyzed for 69 legacy contaminants (such as mercury) and contaminants of emerging concern (such as pharmaceuticals).
- Passive samplers were deployed at 55 sites in the fall of 2010. These samplers passively accumulated contaminants from the water column over a period of 1 month and were analyzed for more than 170 legacy contaminants (such as PCBs and pesticides) and contaminants of emerging concern (such as pharmaceuticals and flame retardants).
- A total of 165 water samples collected from 22 tributary sites during the recreational season in 2011 were analyzed for fecal indicator bacteria and pathogenic bacteria including *Shigella*, *Campylobacter*, and *Salmonella*.

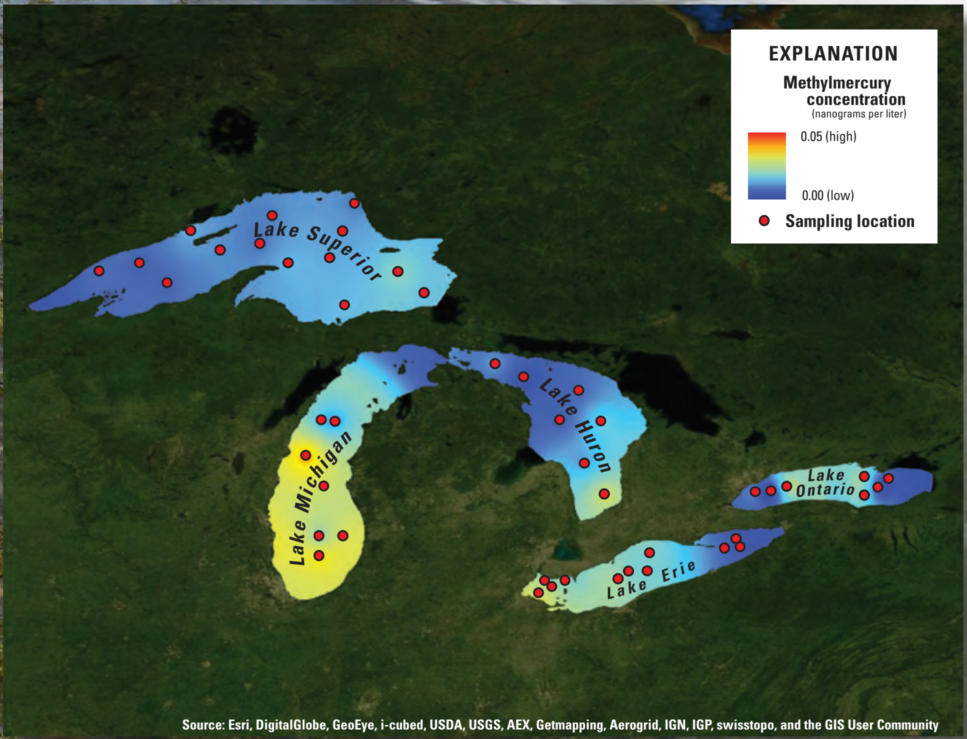
**(Above map) Water and sediment samples from 59 tributaries to the Great Lakes are being analyzed for toxic contaminants.**

## 2013 Successes

- Intensive sampling was performed at 17 monitoring sites to characterize variability in the types and concentrations of toxic contaminants by season and flow. Water samples were collected approximately monthly and during high-flow events and analyzed for 69 chemicals including pesticides, flame retardants, solvents, PAHs, and fuels. This monitoring provides information on which contaminants are most problematic and where they are found—important information to decision makers to help prioritize watersheds for restoration, develop strategies to reduce contaminants, and measure the success of those efforts in meeting restoration goals.
- Samples from eight of the intensive sampling sites were analyzed for mercury and waterborne pathogens (organisms capable of causing disease, such as enteric viruses, that may be transmitted through water and acquired through ingestion, bathing, or by other means), including human viruses, bovine viruses, pathogenic bacteria, protozoa, and human-specific bacteria. Analysis of data is in progress to provide important baseline information that can be used to measure progress towards restoration goals and assess new threats.
- At 15 Area of Concern sites, sediment samples were collected and analyzed for legacy contaminants (such as PCBs and pesticides) to provide a baseline for measuring restoration outcomes.

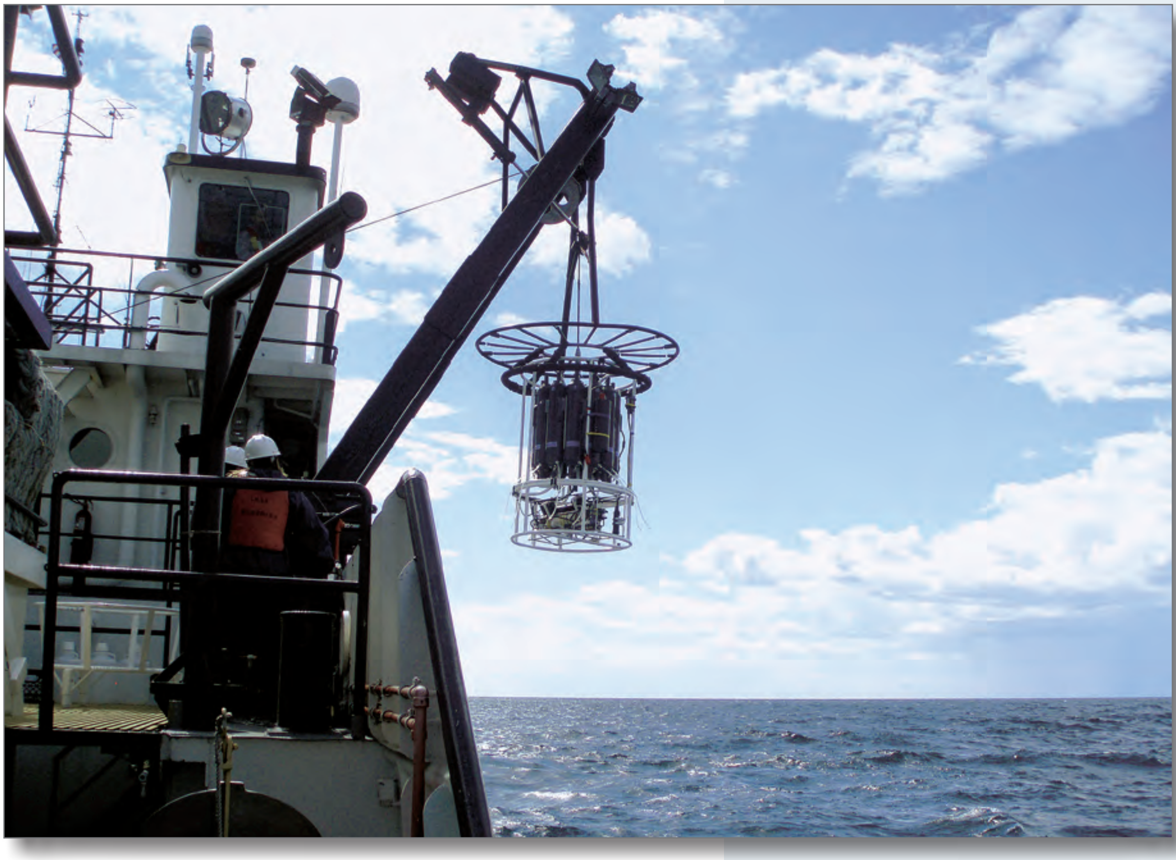
# Studying Mercury Processes

Mercury is a highly toxic substance that is found naturally in the environment but can also be released into the air through industrial activity, such as from coal-burning power plants. Mercury falls from the air and can accumulate in streams, wetlands, and oceans, where it can be transformed into methylmercury (the type of mercury that can be most harmful to humans) through chemical processes in the environment. Fish absorb the methylmercury as they feed in contaminated waters, and it builds up in the fish because it is not easily excreted. Humans, especially pregnant women and young children, risk ingesting dangerous levels of mercury when they eat contaminated fish. As of 2006, mercury was responsible for 80 percent of the fish consumption advisories posted in the United States, and high levels of mercury are still found in sport and commercial fish across the Great Lakes Basin. Understanding the sources and processes that control the formation and movement of methylmercury is critical to reducing fish mercury levels and improving the overall health of the Great Lakes and its ecosystems. The USGS is working to improve the health of the Great Lakes sport and commercial fisheries by studying the processes that result in mercury entering the food chain, determining how mercury affects the fish, and helping to evaluate the implications for public health. As part of this effort, USGS scientists in collaboration with the U.S. Environmental Protection Agency are sampling throughout the Great Lakes and establishing the relations between the

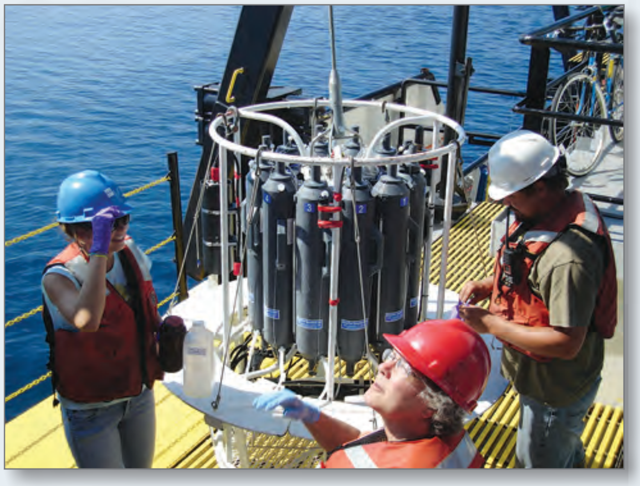



**Large patches of *Cladophora*, a genus of green algae, line the shore of Lake Michigan in Chicago, Illinois. Significant methylmercury formation occurs in the Great Lakes in the nearshore zone when large masses of *Cladophora* wash ashore. Background photograph by Ashley Spoljaric, USGS.**

**(Map, right) Spatial distribution of methylmercury concentrations in surface water across the Great Lakes. Results show differences among the lakes and regions within each lake where more or less methylmercury is present. Lake Michigan has some of the highest concentrations of methylmercury whereas Lake Superior has some of the lowest.**



(Three photos this page) Sampling is facilitated with a special sampling device called a rosette that was purchased through the GLRI effort to upgrade capabilities of the U.S. Environmental Protection Agency's Research Vessel *Lake Guardian*. The device allows 12 samples to be collected at different depths for a single cast.




various chemical forms of mercury and their concentrations in the water column (from the water surface to the bottom sediments) and where mercury is found in the food web.

Monitoring for this study has produced new data on total mercury and methylmercury in the water column of the Great Lakes to help evaluate mercury in sediment, plant, and animal life. In addition, two previously unrecognized sources of methylmercury were identified. The first source is the formation of methylmercury within the lakes themselves, deep in the lake's water column near the thermocline (the point where warm and cold water meet). The thermocline is a location of significant importance for biological production and fish foraging. The second source identified is in the nearshore zone where large masses of a certain type of algae (*Cladophora*) accumulate and wash ashore every year. The comprehensive dataset and the new understanding of methylmercury sources for the Great Lakes will help inform decision makers and restoration managers on effective steps toward reducing mercury contamination in fish.

Sample of sediment collected from Lake Michigan during a biannual monitoring cruise that was analyzed for mercury and methylmercury. Photograph by John Walker, USGS.

USGS researchers lower a submersible light profiler into the water. This instrument measures how fast sunlight dissipates through the water column. This monitoring information is important because light penetration affects mercury processes and is crucial for algae production.

USGS researchers collect a sediment sample from Lake Superior.

## Early Successes

- Samples of water, sediment, fish, and other aquatic organisms were collected during April and August 2010–2012 during biannual (April and August) monitoring cruises of all five Great Lakes and were analyzed for mercury and methylmercury.
- A journal article (*http://dx.doi.org/10.1007/s00244-012-9767-2*) was published in 2012 that increases the understanding of factors controlling methylmercury and inorganic mercury in lake trout from the Great Lakes. Results indicate that methylmercury elimination rates for fish have been overestimated in previous studies; thus, the fish have a much harder time ridding themselves of toxic methylmercury than previously thought.

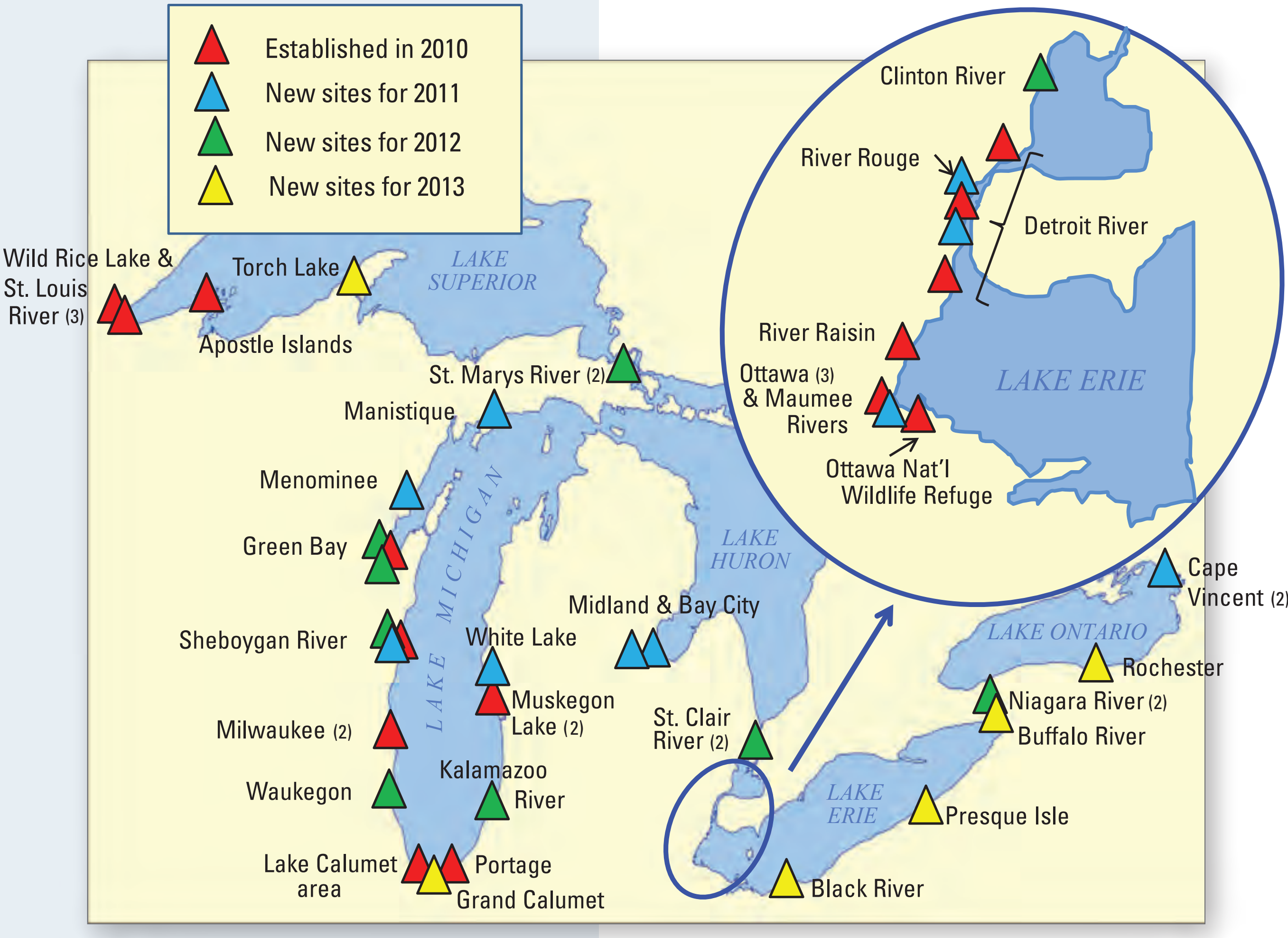
## 2013 Successes

- The seventh and eighth sampling surveys across the entire Great Lakes Basin were completed to provide important information on the water column, bottom sediments, benthic fauna (organisms found on and within the bottom of a water body), and zooplankton (microscopic animals found in water bodies) at about 80 sites during each survey.
- Two previously unrecognized sources of methylmercury were identified: (1) within the lakes themselves, deep in the lake's water column near the thermocline and (2) in the nearshore zone where large masses of a certain type of algae (*Cladophora*) accumulate and wash ashore every year.

# Using Birds as Indicators of Toxic Exposure

The USGS is quantifying effects of legacy (historical) and newly emerging contaminants on select Great Lakes food chains and is evaluating exposure and effects of these contaminants on sentinel indicator species—specifically, selected species of birds, such as colonial waterbirds (herons and cormorants) and tree swallows. Results of this study are being used by State agencies and the U.S. Environmental Protection Agency in their assessments of beneficial use impairments (BUIs; *http://epa.gov/greatlakes/lakeerie/buia/index.html*) and remedy effectiveness assessments. Birds are ideal sentinel species (a species whose presence, absence, or relative well-being in a given environment is a sign of the overall health of its ecosystem) because of their sensitivity to the presence of and changes in chemical concentrations in the environment. The monitoring results from this study are used to identify important sources and effects of legacy contaminants (polychlorinated biphenyls or PCBs, mercury, dioxins, and furans) and newly emerging toxic contaminants (such as chemicals that resist sticking or staining and flame retardants) to the Great Lakes ecosystem through broad surveillance and laboratory and field research of sentinel bird species. Because cleaning up contaminated areas is an important component of the GLRI program, the monitoring results from this study will not only contribute to assessments of Great Lakes ecosystem health and science-based decision-making but also provide a baseline for future trend analysis, including a determination of the effectiveness of recently remediated Areas of Concern and other known hotspots. This study is a close collaboration with the U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration, U.S. Fish and Wildlife Service, State and Tribal agencies, and others.

**Reduced hatching or fledging success is one measurement that is being quantified at all sites to determine population viability. Photograph by Christine Custer, USGS.**




Map showing study sites where detailed monitoring information on avian health has been collected through 2013 in 25 Areas of Concern across all five Great Lakes.

(Above) USGS researcher processes field samples. Nest boxes were installed in Areas of Concern. At each active nest box at the sites, 14 different measures of toxic exposure and effects of legacy contaminant and emerging contaminants are being monitored, including genetic damage and reproduction effects. Photograph by Christine Custer, USGS.

Through 2013, detailed monitoring information on avian health has been collected at 52 study sites encompassing 25 Areas of Concern across all five Great Lakes. This monitoring information can be used to determine whether exposures to certain toxic chemicals are at or above levels of concern for reproductive problems and population viability. Additionally, reproductive effects and genetic damage are directly measured as part of this study, which has resulted in the most comprehensive set of avian data available for the Great Lakes. The monitoring data collected for this study are already being used by several States in their assessments of and potential removal of BUIs, which were the basis for the designation of specific locations as Areas of Concern. The two BUIs where these data are especially useful are “Bird or Animals Deformities or Reproductive Problems” and “Degradation of Fish and Wildlife Populations.” The monitoring data are used to indicate increases or decreases in contaminants, and the association, if any, with reproductive impairments, which can be used by managers to determine whether the two BUIs can be removed. The monitoring information also can be used by decision makers to prioritize watersheds for future restoration and provides important baseline information to measure the success of restoration and remediation activities that are ongoing or planned.

(Above) USGS researcher checks a tree swallow nest box. The swallow's diet consists primarily of aquatic insects that they eat within about 1 kilometer of their nest box, so contamination in their tissues is closely tied to sediment contamination and the cleanup of those sediments. Photograph by Christine Custer, USGS. (Below) Nest box in the Connor Creek landscape. Photograph by Thomas W. Custer, USGS.

## Early Successes

- Baseline contaminant information was collected from sites at all five Great Lakes at a total of 20 Areas of Concern during 2010 to 2012. Samples were analyzed for legacy and emerging contaminants. This information is critical for measuring progress of remediation efforts in Areas of Concern and BUI assessment.

- A web site was established to provide information and preliminary findings: (*http://www.umesc.usgs.gov/wildlife_toxicology/glri_project80.html*).

- Several presentations, posters, handouts, and video were presented at meetings for the public and partners. Public meetings are an important venue to reach a diverse audience and provide important access to preliminary information about this project.

- USGS co-led the Bird or Animal Deformity or Reproductive Problem BUI workshop for the U.S. Areas of Concern meeting in Cleveland, Ohio, in 2012.

## 2013 Successes

- Collection of baseline contaminant information began at five new Areas of Concern in 2013 and continued at sites established previously. Samples were analyzed for legacy and emerging contaminants.

- At each active tree swallow nest box at the sites, 14 different measures of toxic exposure and effects of legacy contaminant and emerging contaminants are being measured, including genetic damage and reproduction effects.

# Supporting Restoration of Beneficial Uses in Areas of Concern by Using Measures of Plankton and Benthos Conditions


Efforts to clean up contaminants from past industrial discharges are underway in the 30 U.S. Great Lakes Areas of Concern (AOCs) as part of the GLRI. Cleanup actions for AOCs are directed toward restoring beneficial uses that have been impaired. "Degradation of benthos" and "degradation of phytoplankton and zooplankton" are 2 of 14 beneficial use impairments (BUIs; *http://epa.gov/greatlakes/lakeerie/buia/index.html*) identified in many Great Lakes AOCs and refer to the negative impairment in the structure or function of the communities of benthic invertebrates (benthos) in sediments and plankton in water. Benthic invertebrates are macroscopic insect larvae and crustaceans that live on or in the bottom sediments. Plankton are microscopic plants (phytoplankton) and animals (zooplankton). The benthos and plankton communities are strongly affected by their environment and can serve as biological indicators of the overall condition of the aquatic environment. Many benthic invertebrates and plankton also are important components of fish diets and constitute an important link in the food chain.

Recent investigations indicated that sediment and water-quality conditions may have improved and that benthos and plankton communities may have recovered substantially in the Rochester Embayment and Massena AOCs in New York. The USGS, in cooperation with the U.S. Environmental Protection Agency, New York State Department of Environmental Conservation, and others, is collecting data to characterize the toxicity of sediments and the condition or health of the benthos and plankton communities in the Rochester Embayment AOC and the St. Lawrence River and its tributaries in the Massena AOC. The measures will be used by the local Remediation Action Planning committees to determine whether water and bed sediments meet established criteria for removing the benthos and plankton BUIs in both AOCs.

Community composition and toxicity results from the New York sites generally indicate that water and sediments in both AOCs currently are not toxic and should not significantly impair the health of resident benthos and plankton communities. The findings from relatively simple, standardized toxicity and community assessments generally show that most criteria for removing plankton and benthos BUIs can be attained in multiple AOCs across New York. Assessments of community composition and toxicity of water and sediments are critical to decisions regarding the potential removal of benthos and plankton BUIs in many AOCs.

## Early Successes

- Water samples from nine St. Lawrence River tributary sites inside the Massena AOC and five control sites outside the AOC were collected during May, August, and October 2011 and used to quantify potential toxicity of these whole waters to the green algae *Selenastrum capricornutum* and to the water flea *Ceriodaphnia dubia*. Data from the three water surveys were published in a journal article in 2012 (*http://dx.doi.org/10.1016/j.jglr.2012.09.008*) that provides important information that managers need for BUI removal.
- Sediment surveys were done at AOC and control sites on the St. Lawrence River and its tributaries in the Massena AOC in August 2012 to evaluate the composition of benthic invertebrate communities and toxicity of sediments.

## 2013 Successes

- Bed sediments were collected at seven sites inside the Rochester Embayment AOC and at seven control sites outside the AOC during summer 2013 to evaluate differences in the composition of benthic macroinvertebrate communities and toxicity of bed sediments.
- The toxicity of bed sediments in the Rochester Embayment and Massena AOCs was assessed with standard (U.S. Environmental Protection Agency) 10-day survival and growth toxicity tests using the midge (small two-winged fly) *Chironomus dilutus*. Percent survival and weight of midges after exposures were evaluated to determine the significance of differences between control and AOC sites.
- Water surveys began in the Rochester Embayment AOC at sites inside the AOC and control sites outside the AOC during August 2013, and will continue through 2014.
- Acute and chronic toxicity of waters at AOC and control sites are being assessed by using the growth of the green algae *Selenastrum capricornutum* and the survival and reproductive capacity of the water flea *Ceriodaphnia dubia* in standard U.S. Environmental Protection Agency toxicity tests.
- Planning began in 2013 to conduct comparable assessments of sediment toxicity and composition of benthic communities at AOC and control sites in the Eighteenmile Creek AOC and Niagara River AOC during 2014–15.
- The assessments of community composition and toxicity of water and sediments listed above are critical to decisions regarding the potential removal of benthos and plankton BUIs in the AOCs.

**The midge *Chironomus dilutus* was used as a surrogate to determine impacts to survival and growth of resident benthic invertebrates when exposed to sediments from sites inside Areas of Concern compared to exposure to sediments from control sites outside the Area of Concern.**

**(Photos above and far left) Water samples were collected from sites inside and outside the Rochester Embayment and Massena Areas of Concern. Acute and chronic toxicity of waters from sites inside Areas of Concern and from control sites outside Areas of Concern were assessed by using the growth of the green algae *Selenastrum capricornutum* and the survival and reproductive capacity of the water flea *Ceriodaphnia dubia* in standard toxicity tests.**


**Researcher with the New York State Department of Environmental Conservation sifting debris from a benthic invertebrate sample in the Rochester Embayment Area of Concern in Rochester, New York.**

Invasive quagga mussels. Photograph by Dan Schrimsher, California Department of Fish and Game.

# Highlights

## Preventing and Controlling Invasive Species

*Enhanced prevention and control efforts are critical to halting new invasive (non-native) aquatic, wetland, and terrestrial species from becoming established in the Great Lakes. More than 180 aquatic nuisance species now exist in the Great Lakes. By rapidly reproducing and spreading, invasive species can degrade habitat, harm native species, and jeopardize food webs. Prevention is the most cost-effective approach to dealing with organisms that have not yet arrived and could potentially threaten the Great Lakes. New invasive species can be introduced into the Great Lakes region through various pathways, including commercial shipping, canals and waterways, trade of live organisms, and activities of recreational and resource users. Once invasive species establish a foothold in the Great Lakes, they are virtually impossible to eradicate; however, invasive species still need to be controlled to maintain the health of the Great Lakes ecosystem. The GLRI is supporting efforts to prevent and control invasive species. As part of this effort, the USGS is working with others to help prevent and control Phragmites (common reed), Asian carp, and dreissenid mussels.*

# Developing Innovative Control Strategies for Phragmites

> ***"Through their leadership in the Great Lakes Phragmites Collaborative, the USGS has brought both strategic vision and scientific rigor to the complexity of issues surrounding non-native Phragmites research and management. The USGS has spearheaded innovative research on biological control while simultaneously, encouraging a regional dialogue on the ecological, economic and philosophical implications of invasive species management, to maximize the collective impact of this growing natural resource challenge."***
>
> *—Heather Braun, Great Lakes Commission*

The common reed (*Phragmites australis*) is a tall, invasive wetland grass that continues to spread throughout the Great Lakes. *Phragmites* alters the soil, produces copious seeds, forms very dense stands, and has unfavorable impacts on coastal resources, including critical fish and wildlife habitat and coastal views. Current control strategies of manipulating water levels, applying herbicides, mowing, and burning are time, labor, and resource intensive and require multiple years of follow-up to prove success. A recent survey from 2005 to 2009 found that managers spend roughly $4.6 million per year on *Phragmites* management in the United States with no clear idea of the relation between size of the investment and management success (*http://dx.doi.org/10.1007/s12237-013-9593-4*). These findings highlight the need for new, innovative tools to control the spread of *Phragmites*.

USGS scientists are testing strategies to reduce the invasive properties of *Phragmites* and minimize its competitive advantage. This effort includes two lines of research, gene silencing and microbiome manipulation. Gene silencing is a molecular genetic technique whereby specific traits, such as photosynthetic ability or flower development, can be minimized by blocking the genetic codes for proteins that express the traits. This technology takes advantage of a widely-known natural defense mechanism in cells known as RNA interference in which cells degrade suspicious-looking code that resembles viral RNA. The USGS Great Lakes Science Center has partnered with researchers at Wayne State University to develop technology to silence the genes in *Phragmites* that allow it to reproduce and grow. For example, if researchers target and silence the genetic code essential for photosynthesis, a plant will not be able to harness the sun's energy and growth will be stunted. Gene silencing is a species-specific approach that could provide managers with new treatment options for invasive species without having detrimental effects on non-target plant or animal species.

Researchers at the USGS are also exploring *Phragmites* control through microbiome manipulation. This research stems from the fact that all plants have relationships with microbes. Some of these relationships are mutually beneficial and can confer benefits (such as increased growth rate and stress tolerance) to the host plant. Such benefits may help *Phragmites* gain a competitive edge over other species. Therefore, opportunities exist to identify and disrupt these relationships as a form of control. The USGS, with partners at Indiana University and Rutgers University, is creating

**(Left) Stands of *Phragmites* are invading a Great Lakes coastal wetland near Oak Harbor, Ohio. This tall wetland grass was introduced from Europe in the early 19th century and aggressively displaces native vegetation, causing plant diversity to decline and critical habitat for fish and other wildlife to be altered. Photograph by Kurt Kowalski, USGS.**



(Above) A USGS researcher in an invasive *Phragmites* stand in the Great Lakes area. The species is rapidly invading the few remaining marshes in the Great Lakes, but USGS scientists and their colleagues are using cutting-edge research to try to fight back. Photograph by Kurt Kowalski, USGS. (Right) Fungal microbes cultured from *Phragmites* seeds. Photograph by Zack Shearin, Indiana University.

a microbial inventory around the *Phragmites* microbiome and beginning to identify the roles played by the members of the microbial community as part of a strategy to develop management approaches that both decrease the competitive advantage of *Phragmites* and increase the competitive abilities of native species in restoration projects. The innovative strategies being developed for *Phragmites* will provide additional tools for managers in fighting invasive *Phragmites* and could have broad applications for controlling other invasive species as well.

To further increase effectiveness of *Phragmites* management, the USGS formed a critical partnership with the Great Lakes Commission to launch the Great Lakes *Phragmites* Collaborative (GLPC) in 2012. The GLPC is a regional partnership to improve communication and lead to more coordinated, efficient, and strategic approaches to *Phragmites* management, restoration, and research across the Great Lakes Basin. The GLPC serves as a communication conduit via an interactive Web site (*http://greatlakesphragmites.net/*), a webinar series, and social media outlets to facilitate access to information and resources and to encourage technology transfer and network building among habitat managers, governmental agencies, and private landowners. The GLPC embraces the idea of collective impact as a framework for solving the complex problem of *Phragmites* management. By linking researchers, managers, and decision makers in a coordinated way, establishing a common agenda, establishing shared metrics, and fostering mutually reinforcing activities, the GLPC is in a position to improve the level of success of *Phragmites* management regionwide.

## Early Successes

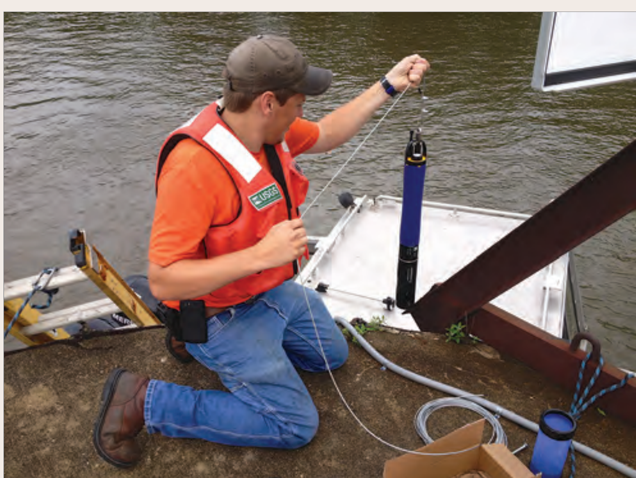
- A study conducted in 2012 indicated that treatment of fungal endophytes (microbes that live in all parts of plants) with a general use fungicide can decrease the number of new *Phragmites* stems.

## 2013 Successes

- In partnership with the Great Lakes Commission, the USGS developed the Collaborative for Microbial Symbiosis and *Phragmites* Management composed of an international group of microbial ecologists focused on identifying the key players in the microbial community surrounding *Phragmites*. The group meets regularly and is preparing a science agenda manuscript for publication.
- Researchers at Wayne State University were able to sequence and analyze a *Phragmites* transcriptome (a genetic road map) and use results from experiments with model plants similar to *Phragmites* (such as maize) to expand laboratory testing of gene silencing techniques in *Phragmites*.
- The Great Lakes *Phragmites* Collaborative (GLPC) continued to add content to its Web site, share information via social media, and host several well-attended (greater than 150 people) webinars on high-profile research and management topics.

# Developing Control Tools and Strategies for Asian Carp

Asian carp control technologies were demonstrated in August 2013 near Morris, Illinois, at a backwater pond of the Illinois River. State and Federal partners were invited to visit an application of Integrated Pest Management to Asian carp control. Water guns, algal feeding attractant, acoustic fish tracking, and commercial fishing were implemented in a coordinated manner to reduce the Asian carp population of the backwater pond. Photograph by Jon Amberg, USGS.



A USGS scientist prepares to collect data to assess how flow and water quality affect Asian carp movement, spawning, and recruitment from the Illinois River near Seneca, Illinois. Monitoring is providing a greater understanding of the preferred habitat of Asian carp with regards to flow and water-quality characteristics and insight into how habitat may be altered to deter them from spreading into new areas. Photograph by Jon Amberg, USGS.

Asian carp were originally imported from Asia to the southern United States to control algae and unwanted plants in controlled settings such as water treatment lagoons. Flooding allowed these fish to escape into the Mississippi River system and migrate into the Illinois River, which is connected to the Great Lakes (Lake Michigan) by the Chicago Sanitary and Ship Canal. Asian carp have harmed the ecosystem, economy, property, and boaters in the Mississippi River system, and they are now threatening the Great Lakes. Four species of Asian carp are considered invasive and a threat to the Great Lakes: the bighead, silver, grass, and black carp, but the Asian Carp Control Strategy Framework (*http://asiancarp.us/*) is primarily focused on silver and bighead carp. This Framework was developed by the Asian Carp Regional Coordinating Committee (ACRCC), a multiagency team led by the White House Council on Environmental Quality with the goal to prevent sustainable populations of Asian carp from becoming established in the Great Lakes and to reduce existing populations in the Mississippi River Basin. As a partner in these efforts, the USGS focused on developing control tools and technologies, methods for early detection, and assessing the risk of successful of Asian carp reproduction and survival. The overall strategy is to use an Integrated Pest Management approach to detect, aggregate, and remove Asian carp. Essential to these efforts is the application of the extensive knowledge of Asian carp life history that guides design, development, and application strategies.

Monitoring for the presence of Asian carp by using early detection methods is vital in determining where to focus control measures if detected and to determine the effectiveness of control methods. Other types of monitoring also are important in combating invasive species. As an example, monitoring by the USGS is providing critical hourly water-level information at an adult Asian carp barrier fence in Eagle Marsh, a high risk pathway for Asian carp to migrate from the Wabash River to Lake Erie. When flooding raises water levels at the fence, alerts are sent to State and local biologists and resource staff who respond and inspect the fence line for adult Asian carp. Collectively, the lessons learned in efforts to control the spread of Asian carp as part of the GLRI and new control technologies and methods directly transfer to invasive species outside the Great Lakes area.

## Early Successes

- Information on the developmental rate and behavior of early life stages of bighead carp and silver carp was published in 2011 (*http://pubs.usgs.gov/sir/2011/5076/*) and 2013 (*http://dx.doi.org/10.1371/journal.pone.0073829*).
- Studies of the effects of water hardness on hatching success of Asian carp eggs showed that the soft water of the Great Lakes is not likely to inhibit the invasion of Asian carp, as had previously been thought (*http://dx.doi.org/10.1577/T09-004.1* and *http://dx.doi.org/10.1577/M09-067.1*).
- Two successful examples of the use of dye tracing during the large-scale applications of a piscicide (a pesticide designed to kill fish) in the Chicago Sanitary and Ship Canal in 2009 and 2010 to combat invasive Asian carp were documented in the USGS report (*http://pubs.usgs.gov/sir/2013/5211/*). The use of dye allowed real-time monitoring of the piscicide plume to support application and deactivation strategies.
- Scientists field tested water guns, which use compressed air to fire a sound pressure wave into the water, to assess how silver and bighead carp respond to them and evaluate the potential use of water guns as a control tool. Preliminary results indicate that the carp move away from the water guns. Additional field tests are being conducted in 2014.

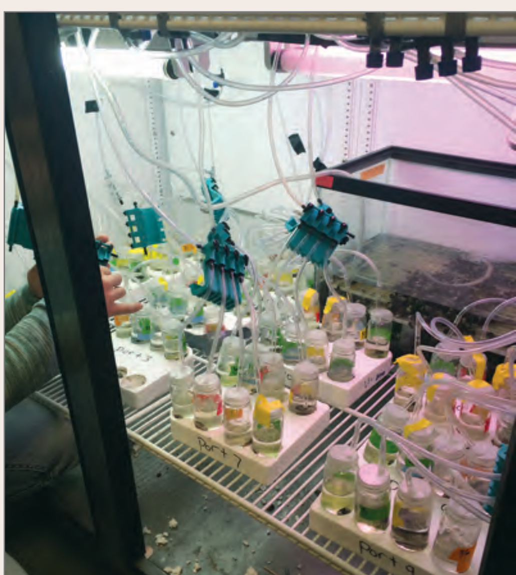

**These silver and bighead carp were collected from the Illinois River to learn more about the anatomy and physiology of Asian carp. This information is important to the development of potential biological or chemical controls as part of an Integrated Pest Management approach for resource managers. Photograph by Jon Amberg, USGS.**

## 2013 Successes

- In collaboration with the Illinois Department of Natural Resources and Southern Illinois University, an Integrated Pest Management approach to Asian carp control was used in the field, combining food attractants, water guns, hydroacoustics, and commercial fishing to capture and remove large numbers of Asian carp from an Illinois River backwater pond (see video at *http://gallery.usgs.gov/videos/813)*.
- Preliminary results of field testing of water guns are promising for altering Asian carp behavior and can be used to contain, repel, or herd carp. Initial field testing of this technology was completed in 2013 in a backwater pond of the Illinois River.
- Scientists discovered that Asian carp are strongly attracted to certain mixtures of algae and have been testing methods for using the attractants as lures to facilitate capture and removal. Testing was done in the Missouri River and Illinois River.
- Microparticles filled with a registered toxin are being designed to specifically target Asian carp. When eaten by Asian carp, the toxin is released while inside the fish, avoiding harm to native species.
- A new Tributary Assessment Tool has been developed by the USGS in collaboration with the University of Illinois to assess risk of successful Asian carp spawning in rivers based on river length, water velocity, water temperature, and egg and larval development (*http://dx.doi.org/10.1016/j.ecolmodel.2013.05.005*). The risk assessment is focused on egg and larval development, which are important knowledge for informing management control efforts. As part of this study, scientists discovered that river reaches as short as 16 miles in length may allow Asian carp eggs sufficient time to develop and hatch (*http://pubs.usgs.gov/sir/2013/5106/*).
- In collaboration with the U.S. Army Corps of Engineers and U.S. Fish and Wildlife Service, USGS scientists have developed faster methods of processing water samples to determine whether DNA of Asian carp is present in a water body. Early detection of Asian carp is of paramount importance in the battle against this invasive species. Scientists also have designed more than 20 genetic markers to identify silver carp and bighead carp DNA in water samples.
- Another early detection method being developed that complements the DNA efforts is microbial source tracking. Mapping the unique microbes present in the digestive systems of Asian carp holds promise for monitoring their presence in rivers and other water bodies.

# Preventing Spread of Dreissenid Mussels

The preliminary testing of Zequanox® indicates that this may be a promising new tool that could be used to prevent the spread of zebra and quagga mussels but that does not appear to be harmful to other organisms, including the freshwater unionids. Photograph by James Luoma, USGS.



USGS researchers are performing tests to determine the mortality and stress of dreissenid mussels in response to *Microcystis aeruginosa* algae. Photograph courtesy of Donna Kashian, Wayne State University.

The USGS is working with the U.S. Fish and Wildlife Service and other partners to find effective and safe tools to control and prevent the spread of invasive dreissenid mussels (namely zebra mussels *Dreissena polymorpha* and quagga mussels *D. rostriformis bugensis*) in and around the Great Lakes. Both the zebra and quagga mussels are small (about the size of a pistachio), non-native mussels that were transported to North America in the ballast water of transoceanic ships in the late 1980s. These mussels quickly spread to all five Great Lakes causing substantial ecological and environmental impacts including clogging of pipes in water systems, disruption of food cycles, and alteration of aquatic habitats. No methods currently exist to safely control dreissenid mussels; however, new advances in research in identifying "weak" points associated with the feeding, reproductive, and other characteristics are paving the way for development of tools to prevent the spread of these invasive mussels. Research has shown that dreissenid mussel spawning is initiated and inhibited by natural chemical cues released by algae and that these natural products can be useful for control. The USGS is currently researching one of these weak points—natural spawning inhibitors, such as compounds released by specific species of algae—which could be used to control reproduction of this invasive species.

Tools that target specific invasive species without harming other aquatic organisms, animals, or humans are needed to prevent the further spread of invasive species, such as dreissenid mussels, in the Great Lakes area. The invasive zebra and quagga mussels are an immediate threat to the survival of freshwater unionids, such as pocketbook mussels, in the Great Lakes area. One potential tool for limited open-water control of dreissenid mussels is the commercially formulated product, Zequanox®, which contains killed cells of the common soil bacterium *Pseudomonas fluorescens* (strain CL145A). Zequanox® is produced by Marrone Bio Innovations (Davis, California) and is registered by the U.S. Environmental Protection Agency for specific applications. Preliminary tests with Zequanox® indicate that this may be a promising new tool that could be used to prevent the spread of zebra and quagga mussels but that does not appear to be harmful other organisms, including the freshwater unionids. Comprehensive research is needed to determine the potential of this dreissenid management tool for use in natural aquatic habitats. Determining this potential may ultimately allow this new technology to be used to support ecosystem restoration and rehabilitation efforts in and around the Great Lakes. In addition, experiments are ongoing with *Microcystis aeruginosa* and other species of algae to discover natural product spawning inhibitors that could be used to control dreissenid mussels.

(Left) USGS researchers are performing tests on natural spawning inhibitors for quagga mussels. The male is on the left with the water clouded by sperm. The female is on the right, and a cluster of clearish-white eggs is visible on the bottom of the vial. Photograph courtesy of Donna Kashian, Wayne State University.

## Early Successes

- In 2012, the USGS completed field studies in Lake Carlos in Minnesota and Shawano Lake in Wisconsin to assess the effectiveness of Zequanox® to control dreissenid mussels in a controlled field laboratory designed to simulate open water exposures. Mortality of zebra mussels in these studies exceeded 90 percent.

## 2013 Successes

- The USGS completed a field study in the Black River in Wisconsin to assess the impacts of Zequanox® exposure to seven species of adult native mussels, including several species of concern, in a controlled field laboratory designed to simulate open water exposures. There were no detrimental impacts to native mussels.
- The USGS completed field studies to assess the effectiveness of Zequanox® to control dreissenid mussels adhering to native mussels in Lake Darling near Alexandria, Minnesota, and to bottom/rocky habitats in Lake Minnetonka near Alexandria, Minnesota. In field studies, Zequanox® treatment significantly reduced zebra mussel colonization of native mussels without increasing mortality of the native mussels relative to the untreated mussels.
- Research on natural spawning inhibitors showed that dreissenid mussels co-cultured with *Microcystis aeruginosa* algae spawned significantly less frequently than those in the absence of *Microcystis aeruginosa*, whereas experiments showed that exposure to the *Chlorella* algae enhances the rate at which dreissenid mussels spawn.
- Probes that measure eDNA (environmental DNA, such as from feces, mucus, skin, or urine, that can be used to detect aquatic organisms) have been developed to distinguish between dreissenid and native unionids. Once tested, these probes can be used to identify bodies of water where control measures are warranted.

(Right) More than 40 species of freshwater mussels, such as this pocketbook mussel, are native to the Great Lakes, and most species are endangered. Photograph by Alissa Ganser, USGS. (Below) Native freshwater mussels are threatened by invasive species such as dreissenid mussels. The faster-growing dreissenid mussels settle on the shells of the native mussels, effectively smothering them. Invasive zebra mussels in Detroit, Michigan. Photograph by Jeff Allen, USGS.


USGS

# *Highlights*

## Promoting Nearshore Health

*Nearshore and open waters provide drinking water for municipalities and habitat for numerous species of birds, fish, and other aquatic life. This is the area in which most residents and visitors experience the Great Lakes through swimming, boating, and other forms of recreation. Nearshore water quality has become degraded, as evidenced by eutrophication—the process by which a water body is enriched by nutrients such as nitrogen and phosphorus, resulting in excessive growth of algae, depletion of the dissolved oxygen that aquatic species need to survive, beach closings, and other impacts. In the nearshore zones of the Great Lakes, eutrophication has sometimes been manifested by harmful algal blooms; by unsightly, odorous rotting mats of the green algae Cladophora washed ashore on beaches; and by avian botulism. The environmental stressors causing these problems include excessive nutrient loadings (the mass of nutrients carried by water into surrounding waterways over a period of time) from both point sources (single, discrete places) and nonpoint sources (broad areas, such as runoff from drainage basins); bacteria and other pathogens responsible for outbreaks of botulism and beach closures; development and shoreline hardening that disrupt habitat and alter nutrient and contaminant runoff; and agricultural practices, which may increase nutrient and sediment loadings. Additional shoreline stresses can be traced to failing septic systems, gray-water pipes (pipes containing nonhazardous household substances like soap), inadequate pump-out stations for recreational boats, and even invasive species. The GLRI is supporting efforts to promote nearshore health. As part of this effort, the USGS is evaluating best management practices; using automated samplers and probes to monitor nutrient and sediment loadings at 30 of the Great Lakes National Monitoring Network sites; and providing beach managers with the tools necessary to make effective beach closure and advisory decisions.*

**(Left) Monitoring by USGS provides important information about the processes that affect beach contamination and helps to ensure that beaches are safe for public recreational use. Photograph by Meredith Nevers, USGS.**

# Evaluating Best Management Practices in Targeted Geographic Watersheds


The USGS is collaborating with the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) and U.S. Environmental Protection Agency (EPA) to assess the effects conservation practices have on water-quality issues as part of the Priority Watershed component of the GLRI. The goal of this effort is to improve and protect water quality and reduce the sediment and nutrients (nitrogen and phosphorus) flowing into the Great Lakes. Monitoring is being used to demonstrate the effectiveness of agricultural management practices in diverse landscapes in three priority watersheds: Fox River, Wisconsin; Maumee River, Ohio; and Saginaw River, Michigan. The monitoring work for this study ranges from the subwatershed scale to individual agricultural fields (edge-of-field scale) and involves the direct participation of local conservation groups, agricultural groups, and private landowners. Edge-of-field monitoring provides information about the amount of runoff, soil, and nutrients (such as nitrogen and phosphorus) moving off a given agricultural field into an adjacent waterway. Ongoing sampling at edge-of-field monitoring sites, as well as the subwatershed location in each of the three Priority Watersheds, is providing baseline information prior to the implementation of best management practices (BMPs) designed by the NRCS. At this scale of monitoring, the water quality, under a full range of weather conditions, can be affected immediately by land-use and management changes. Thus, the information gathered from this study will allow for a rapid assessment of implemented conservation practices.

This study will be used to develop an understanding of the effects of differing agriculture practices on the quantity and quality of runoff water from monitored farms, including edges of fields and subsurface drains, and the effect of this water on streams receiving runoff water. Volumes and losses of sediment, nutrients, and other selected constituents are being quantified through monitoring. Weather data also are collected to help establish cause-and-effect relations between agricultural practices and water quantity and quality. The monitoring information collected as part of this study can be incorporated into models or used in education on conservation practices.

**(Left upper) Map showing locations of GLRI priority watersheds.**

**(Left middle) Surface runoff at an edge-of-field monitoring site on a private farm in the Upper East River Basin, Wisconsin.**

**(Left lower) Ice and snow were removed to prepare for oncoming snowmelt at edge-of-field (left) and subsurface tile (right) monitoring sites in the Upper East River Basin in Wisconsin.**


USGS staff finishing the installation of an edge-of-field (above) and subsurface-tile (below) monitoring site on a private farm in the Saginaw River watershed in Michigan.

*"The explosion of harmful algae growth from phosphorus runoff is a clear and present danger to community, economic and ecological health. This work is driving us to target the biggest sources of phosphorus to make the biggest difference for the most people."*

*—Cameron Davis, Senior Advisor to the Administrator,*
*U.S. Environmental Protection Agency,*

USGS staff finishing installation of the wingwall at an edge-of-field monitoring site in the Blanchard River Basin in Ohio.

Finalized subsurface-tile monitoring site using solar power located on a private farm in the Blanchard River Basin in Ohio.

## Early Successes

- Selection and establishment of monitoring locations was completed, including the coordinated effort between the USGS, NRCS, EPA, and private landowners.
- Construction of four edge-of-field stations, two subsurface drains, and three streamgages was completed in water year 2012 to collect baseline data prior to BMP implementation. (A water year is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends.)
- Data collection at the monitoring sites began in water year 2012.

## 2013 Successes

- Data collection at the monitoring sites continued. Measurement devices monitor the amount of runoff from the agricultural field on a continuous basis in intervals of every 1 to 5 minutes during rainfall events and every 15 to 60 minutes at all other times. The water-quality sampler is triggered automatically by runoff or activated remotely from the USGS office.
- Collected samples are analyzed for nutrients and other constituents at the Water and Environmental Analysis Lab in Stevens Point, Wisconsin.
- Annual updates were provided to EPA and NRCS partners as well as to the local conservation staff and participating landowners on monitoring results and uses.

***"We know many conservation practices can improve water quality, and we are always looking for ways to enhance that effectiveness. Edge-of-field monitoring stations allow us to measure the benefits of conservation for improving water quality right at the edge of farm fields, rather than assume conservation effects from in-stream measurements that are subject to influences outside of the farmer's control. Such influences include legacy nutrient and sediment inputs, as well as other land uses within a watershed."***

*—Dr. Wayne Honeycutt, Deputy Chief for Science and Technology,*
*U.S. Department of Agriculture*
*Natural Resources Conservation Service*

# Estimating Real-Time and Forecasted Nutrient and Sediment Loads

(Above) Sediment and algae color the Great Lakes in this image captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua satellite on October 9, 2011. The blue in Lake Michigan and Lake Huron is sediment brought to the surface when strong winds churned the lakes. The green in Lake Erie and in Lake Huron's Saginaw Bay is toxic algae, *Microcystis aeruginosa*, that forms readily in nutrient-rich water. Image courtesy of NASA.

Nitrogen and phosphorus are essential nutrients for plant and animal growth, but overabundance of these nutrients leads to one of the most widespread, costly, and challenging contamination problems in water in the United States. Sediment is the loose sand, clay, silt and other soil particles that settle at the bottom of a body of water, and sediment generally originates as soil erosion from locations such as agricultural and construction sites. Sediment is the most common contaminant in rivers, streams, lakes, and reservoirs, according to the U.S. Environmental Protection Agency. Excessive nutrients and sediment can hamper water supplies and recreation, and can cause harm to ecosystems. USGS scientists are collecting nutrient, sediment, streamflow, and other data from 30 monitoring sites on streams that flow into the Great Lakes ("tributaries"). These data will provide baseline information on the amount of nutrients and sediment that are being transported to the lakes, enable managers to determine whether restoration and remediation projects are having the desired effect on improving water quality, and provide real-time reporting of water quality by the use of sensors. In the future, the data can be used in computer models to forecast changes in the amount of sediments and nutrients being transported to the Great Lakes.

A key component of the GLRI tributary monitoring program is the use of real-time sensors to estimate nutrient and sediment concentrations. Scientists are working to predict nutrient and sediment concentrations by the use of statistical models that are based on water-quality data transmitted from sensors. These models will enable real-time prediction of nutrient and sediment concentrations, and computer models will eventually allow predictions from unmonitored streams.

(Right) About 2,000 samples have been collected and analyzed for nutrients and suspended sediment through August 2013 for this project. Photograph by Austin Baldwin, USGS.


Map showing locations of tributaries monitored for real-time and forecasted nutrient and sediment loading.

## Early Successes

- A USGS report published in 2011 contains a list of existing watershed models that had been created for tributaries within the United States that drain to the Great Lakes (*http://pubs.usgs.gov/of/2011/1202/*).
- Thirty monitoring sites were equipped with automated samplers and real-time water-quality monitoring sensors starting in March 2011. At each site, monthly samples have been collected, and as many as six samples per year have been collected during large rainfalls.

USGS scientists are collecting nutrient and sediment samples from 30 monitoring sites on tributaries flowing into the Great Lakes. Photograph by Mark Godfrey, The Nature Conservancy.

## 2013 Successes

- Monitoring data were collected at the sites for the third year in 2013. About 2,000 samples (about 75 samples per monitoring site) had been collected and analyzed for nutrients and suspended sediment as of August 2013 to help predict nutrient concentrations.
- Real-time sensors measured dissolved oxygen, turbidity (the cloudiness of water), specific conductance (a measure of water's ability to conduct electricity, and therefore a measure of the amount of dissolved solids such as salt in the water), pH, and water temperature every 15 minutes for the third year in 2013, enabling scientists to compare data over time and look for changes. All real-time water-quality data are available at *http://waterwatch.usgs.gov/wqwatch/* for use by resource managers and other partners.
- Progress was made toward developing models for the Kalamazoo River in Michigan and Tonawanda Creek in New York. These watershed models will be used to simulate hydrology, water temperature, and phosphorus and sediment concentrations and loads.

The Bad River in northern Wisconsin is one of 30 monitoring sites where nutrient and sediment samples are being collected. Monitoring is crucial to documenting real-time changes in nutrient and sediment loads to the Great Lakes. Photograph by Eric Dantoin, USGS.

# Enhancing Water-Quality Decision-Making at Great Lakes Beaches

Water recreation and associated tourism provide numerous economic opportunities and societal benefits to the Great Lakes region with its more than 500 beaches and nearly 11,000 miles of coastline. Unfortunately, coastal areas can become contaminated with disease-causing microorganisms of fecal origin that threaten the health of people who swim in coastal waters. Some beaches have become fouled with excess quantities of the algae *Cladophora*, which may harbor human and animal pathogens and produce offensive odors that discourage use of beaches by the public. Beach advisories and closures are intended to protect swimmers from illness caused by fecal contamination. However, several problems face beach managers who issue advisories or closures or try to solve contamination problems: (1) traditional laboratory analyses for beach water quality take too long, (2) sources of fecal contamination in recreational water are often unknown, (3) recreational waters are seldom monitored for actual pathogens (disease-causing bacteria, viruses, and protozoa), and (4) monitoring strategies and storage of monitoring data are sometimes inconsistent between beaches.

The USGS has been a leader in the science of beach health with an overall mission to provide science-based information and methods that allow beach managers to more accurately make beach closure and advisory decisions, understand the sources and physical processes affecting beach contaminants, and mitigate and restore beaches and protect the public. The USGS is working in collaboration with many Federal, State, and local agencies and universities to improve beach health and enhance decision-making through real-time assessments of recreational water quality; research on the types pathogens present at beaches and use of microbial source tracking to determine potential contamination sources; and development of tools to aid in data discovery, aggregation, and processing to supplement current research needs.

**The USGS has been a leader in the science of beach health, with an overall mission to provide science-based information and methods that will allow beach managers to more accurately make beach closure and advisory decisions, understand the sources and physical processes affecting beach contaminants, and mitigate and restore beaches and protect the public. Photograph, left, by Richard Whitman, USGS.**

Water quality can change rapidly at beaches in response to varying weather conditions and other factors such as currents and waves, sewer overflows, and even the number of birds and visitors at the beach. Predictive modeling of real-time water-quality conditions (nowcasting) using environmental and water-quality data is an important tool for quickly making management decisions on beach advisories or closures. A nowcast system (for example, see *http://www.ohionowcast.info/index.asp*) estimates current water-quality conditions, and the results are posted at the beach and online to inform the public. Research efforts on pathogens and microbial source tracking for Great Lakes beaches are providing information about the types of pathogens present at Great Lakes beaches, their relations to fecal indicator bacteria, and their sources (such as humans, mammals, and birds). Coastal research by USGS scientists is providing important information about the processes that affect beach contamination. These findings help establish factors that affect fluctuations in microorganism concentrations and highlight potential approaches for beach restoration. The Great Lakes Beach Health Database currently holds more than 7,000 records from sanitary surveys from Great Lakes beaches in Wisconsin, New York, Michigan, and Ohio. (For more information on the database, see *http://pubs.usgs.gov/fs/2013/3068/*.) Data used in the study of recreational waters are sometimes inconsistent because data are compiled by numerous agencies in a variety of formats, making data discovery, compilation, and data analysis difficult. Data analyses are being aided through the use of the database and associated Web applications for standardizing output formats and data visualization.

**(Above) USGS dive team members carry an Acoustic Doppler Current Profiler (ADCP) into Lake Michigan near Portage, Indiana, to measure currents throughout the summer season in order to improve predictive modeling at recreational beaches and better predict bacteria concentrations in the water, thereby improving the safety of swimmers. Photograph by Kasia Kelly, USGS. (Photo immediately right) USGS scientists tested different filtration methods for concentrating microbial indicators and pathogens in lake water samples at Point Beach, Wisconsin. Photograph by Jeff Steuer, USGS.**

**Beaches like this one (above) on Lake Michigan in Illinois can become contaminated with disease-causing bacteria that threaten public health, disrupt water recreation, and affect the Great Lakes economies that depend on summer tourism. Photograph by Richard Whitman, USGS.**


**Similar to weather forecasts, the nowcast systems use near-real-time information to estimate water-quality conditions and bacteria concentrations at specific beaches in the Great Lakes region, such as at Edgewater Beach in Ohio. Nowcast systems use mathematical models that are developed from several years of measurements made at particular sites. The USGS is committed to helping beach managers develop and implement nowcast programs. Photograph by Donna Francy, USGS.**

## Early Successes

- USGS fact sheets on understanding beach health throughout the Great Lakes were published in 2010 and 2012 (*http://pubs.usgs.gov/fs/2010/3093/* and *http://pubs.usgs.gov/fs/2012/3113/*).
- USGS scientists have performed research to identify sources of contamination and the environmental factors that may create a situation where unhealthy bacteria or viruses can live and pose a threat to public health. Various processes investigated include sediment transport, wave heights and resuspension of contaminants from beach sands; diurnal pattern of fecal indicator bacteria (decrease through daylight hours and rebound after dark); changes in lake and groundwater levels; and tributary inputs.
- More than 300 samples were collected in 2010 from 12 Great Lakes beaches (Lake Michigan, Huron, and Erie) and analyzed for waterborne pathogens. Analyses indicate that pathogens were not uniformly distributed among the 12 beaches (*http://dx.doi.org/10.1021/es402299a*). This research helps to increase the understanding of the factors that influence fecal indicator bacteria, pathogen occurrence, and microbial sources at Great Lakes beaches.
- Real-time assessments of recreational water-quality conditions (called nowcasts) were expanded throughout the Great Lakes. During 2010–12, the USGS worked with 23 local and State agencies to improve existing operational beach nowcast systems at 4 beaches and expand the use of predictive models in nowcasts at an additional 45 beaches throughout the Great Lakes in Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania, and Wisconsin. During validation of 42 beach models in 2012, the models overall performed better than the current method to assess recreational water quality (using the previous day's *E. coli* concentration) (*http://pubs.usgs.gov/sir/2013/5166/*).
- The USGS created a Great Lakes Beach Health Database that uses a Web tool for easy access to beach health data from numerous agencies collecting data across the Great Lakes region (*http://cida.usgs.gov/enddat/*).

## 2013 Successes

- Four USGS fact sheets were published in 2013 highlighting USGS research on Great Lake beaches:
  - Real-time assessments of water quality (nowcasts) (*http://pubs.usgs.gov/fs/2013/3069/*)
  - Pathogens (*http://pubs.usgs.gov/fs/2013/3071/*)
  - Coastal processes (*http://pubs.usgs.gov/fs/2013/3070/*)
  - Tools for beach health data management (*http://pubs.usgs.gov/fs/2013/3068/*)
- A USGS report on potential sources and transport processes of fecal indicator bacteria to beach water at Murphy Park Beach on Green Bay in Wisconsin was published (*http://pubs.usgs.gov/sir/2012/5190/*). This research helps to increase understanding on transport processes affecting fecal indicator bacteria at beaches.
- A journal article comparing filtration methods for concentrating microbial indicators and pathogens in lake water samples was published (*http://dx.doi.org/10.1128/AEM.03117-12*). Different filtration methods worked best for individual microorganisms; however, the ultrafiltration method resulted in the highest recovery while maintaining low variability for the nine microorganisms tested (bacteria, viruses, and protozoa).
- A journal article was published that examines the new recreational water-quality criteria and how differences in available methods that are used to classify beach water as exceeding a "beach action value" can result in variations in how often a beach is posted with an advisory or closing (*http://dx.doi.org/10.1021/es304408y*).
- The USGS tested two rapid analytical methods to detect fecal-indicator bacteria and pathogenic organisms in beach water—quantitative polymerase chain reaction (qPCR) and immunomagnetic separation with adenosine triphosphate detection (IMS/ATP). These rapid analytical methods can provide results in 2 to 3 hours—a substantial improvement compared to traditional methods that take 18 to 24 hours. Because substantial water-quality change can occur quickly, the safety of the water can be more accurately assessed by using the rapid analytical methods, thus providing an improved tool to beach managers.
- The USGS continued to work with local agencies to improve real-time predictions and implement more nowcast systems (see *http://www.ohionowcast.info/* and *http://www.wibeaches.us/apex/f?p=BEACH:HOME*).

# *Highlights*

# Protecting and Restoring Habitat and Wildlife

*The health of Great Lakes habitats and wildlife depends upon the protection and restoration of ecosystems. Fully resilient ecosystems buffer the impacts of potential problems such as climate change. A multitude of threats—among which is competition from invasive species—affect the health of Great Lakes habitats and wildlife and have led to an altered food web, loss of biodiversity, and, in places, poorly functioning ecosystems. Scientists are researching particular human effects on the ecosystems and are applying lessons learned from past and ongoing restoration projects and programs to advance protection and restoration of habitat and wildlife. As part of the GRLI, the USGS is working with others to support the protection and restoration of critical elements of the Great Lakes ecosystem by providing the science to restore native fishes in Lake Ontario, restore coastal wetlands in the Ottawa National Wildlife Refuge and adjacent Lake Erie, develop breakthroughs in the prediction and prevention of botulism outbreaks that affect fish and fish-eating birds, and survey food-web interactions within all five Great Lakes.*

**Lake herring (left) along with Atlantic salmon smolts (page 39) are being raised at the USGS Tunison Laboratory of Aquatic Science for release into Lake Ontario and tributaries. This laboratory's state-of-the-art capabilities for holding wild-captured eggs and raising fish for release and would not have been possible without GLRI funding. Photo credits: Marisa Lubeck, USGS, and Emily Waldt, Tunison Laboratory of Aquatic Science.**

# Supporting Restoration of Native Fish in Lake Ontario

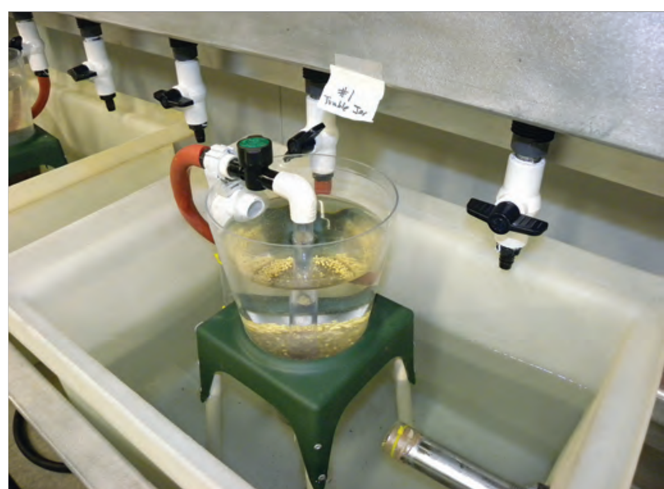
The USGS is taking an innovative approach to supporting restoration by simultaneously helping to restore native predator fish and their native food sources (prey fish) in Lake Ontario. These species are Atlantic salmon and two whitefishes. Restoring them at the same time increases the prized predator's chance of survival. Historically, the Lake Ontario population of Atlantic salmon represented the largest freshwater population of salmon in the world, but overfishing and loss of spawning habitat led to their local extinction in Lake Ontario in the late 1800s. Two whitefishes—deepwater cisco (also known as bloater) and a shallower water species, lake herring—are either extirpated (bloater) or have declined dramatically (lake herring) in Lake Ontario because of invasive species, such as alewife and rainbow smelt. Bloater and lake herring were once very abundant in Lake Ontario, serving as important prey for native salmon and lake trout, and supporting commercial fisheries. Although populations of deepwater cisco and lake herring have persisted in Lakes Superior, Michigan, and Huron, the deepwater cisco disappeared from Lake Ontario by the 1970s, and lake herring population declined dramatically by the mid-1900s.

The USGS focus on providing the science to restore Atlantic salmon, deepwater cisco, and lake herring in Lake Ontario and its tributaries, marks a first-of-its-kind effort in the region. A state-of-the-art experimental fish culture facility has been established with funds from the GLRI at the USGS Great Lakes Science Center, Tunison Laboratory of Aquatic Science in Cortland, New York, where USGS scientists are working to support restoration of these native fishes in Lake Ontario and the St. Lawrence River by raising and stocking them, and evaluating the success of these efforts. Working closely with the State of New York, the St. Regis Mohawk Tribe, and Ontario governments, the USGS is ensuring that scientifically based techniques and strategies are used to maximize rehabilitation success and avoid potential fish diseases. All stocked fish are marked with a dye that allows researchers to monitor fish survival.

Reintroduction of Atlantic salmon is expected to provide greater fishing opportunities in Lake Ontario and restore the natural balance of the Lake Ontario food web by adding more predator fish to the system. Reintroduction of deepwater cisco and lake herring is essential for increasing food choices and enhancing the natural recruitment potential of predator fish, such as Atlantic salmon and lake trout. Restoration of native fish is also expected to mitigate previous effects of invasive species, such as alewife and rainbow smelt, and reduce opportunities for new invasive species to colonize the lake by increasing food web resistance to invasion. Restoring a resilient native fish community in Lake Ontario is a critical first step not only to strengthen the local fish ecosystem, but also to guide native species restoration throughout the Great Lakes.

(Right) Stocking of Atlantic salmon will increase fishing opportunities in Lake Ontario and restore the natural balance of the food web through providing additional top predators. Thousands of young Atlantic salmon were reared at the USGS Tunison Laboratory and released into the St. Regis River system (a tributary of the St. Lawrence River) by USGS scientists and members of the Mohawk Tribe. Photograph by Tony David, St. Regis Mohawk Tribe.

An Atlantic salmon is marked with a dye that will allow researchers to evaluate poststocking success. Photograph by Emily Waldt, Tunison Laboratory of Aquatic Science.



Deepwater cisco are being raised at the USGS Tunison Laboratory of Aquatic Science for release into Lake Ontario and tributaries. Photograph courtesy of Tunison Laboratory of Aquatic Science.

*Two wild Atlantic salmon fry were captured in the Salmon River in July of 2013, which represented documented evidence of natural reproduction in the Salmon River. These successes highlight the importance of monitoring fish survival in evaluating restoration progress.*

## Early Successes

- The state-or-the art culture facility at Tunison Laboratory of Aquatic Science became operational in 2011 to enable restoration of Atlantic salmon in Lake Ontario and the St. Lawrence River through development of new and innovative restoration techniques.
- Atlantic salmon were raised at the Tunison Laboratory of Aquatic Science and multiple salmon strains were evaluated to determine their suitability for restoration. The salmon were released in Lake Ontario tributaries during 2011 and 2012 in collaboration with the St. Regis Mohawk Tribe and the New York State Department of Environmental Conservation (NYDEC).
- Deepwater cisco and lake herring also were raised at the Tunison Laboratory of Aquatic Science and were first released in 2012 in partnership with the NYDEC.

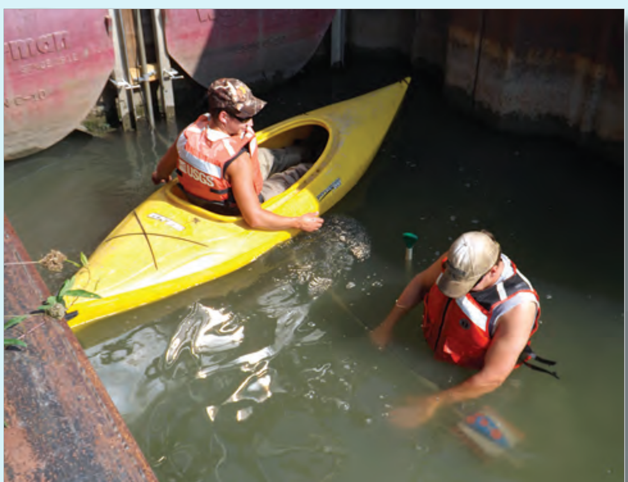
## 2013 Successes

- The following native fishes were released in 2013:
  - 17,000 yearling Atlantic salmon smolts in Lake Ontario tributaries in April,
  - 65,000 fall fingerling Atlantic salmon in Lake Ontario tributaries in September,
  - 9,000 fall fingerling lake herring into Irondequoit Bay in Lake Ontario in November, and
  - 7,200 fall fingerling deepwater cisco in Lake Ontario near Oswego, New York in November.
- In July 2013, scientists captured the first returning adult Atlantic salmon that had been released as part of the GRLI.

*"Lake Ontario's sport fisheries are a significant economic driver in New York State, and were valued at more than $113 million in 2007. Re-establishing bloaters in Lake Ontario will diversify the fish community, adding stability to the lake's ecosystem and sport fisheries."*

*—Joe Martens, New York State Department of Environmental Conservation Commissioner*

# Supporting Restoration of Coastal Wetlands in the Ottawa National Wildlife Refuge and Adjacent Lake Erie



The western shore of Lake Erie has lost more than 95 percent of its wetland habitat since the 1860s. Most of the coastal wetlands were isolated from Lake Erie by an extensive network of earthen dikes that were constructed to protect habitat from wave attack. The diked wetlands historically provided critical migratory waterbird habitat, but their isolation from Lake Erie limits certain wetland functions such as providing fish habitat and improving water quality. The few remnant coastal wetlands (that is, the wetlands still connected to Lake Erie) have been severely degraded by altered hydrology, nutrient and sediment loading, and invasive species. This collective loss of suitable coastal wetland habitat has negatively affected the habitats for about 43 species of important Great Lakes fish that depend on productive wetland habitats to feed (such as longnose gar, channel catfish, and bowfin), to spawn (such as northern pike and yellow perch), or to provide protection for juveniles (such as gizzard shad, emerald shiner, and largemouth bass).

USGS scientists are focused on supporting the restoration of natural water flow and ecological processes between diked coastal wetlands and major adjacent water bodies (Lake Erie) to improve fish and wildlife habitat. Flow reconnection and habitat restoration strategies were tested initially at the U.S. Fish and Wildlife Service (USFWS) Ottawa National Wildlife Refuge as part of the GLRI and through partnerships with the USFWS, Ducks Unlimited, and many others. A water-control structure (opened in March 2011) restored hydrologic connection for the first time in nearly 40 years between a 99-acre diked coastal wetland and Crane Creek, a tributary to Lake Erie. This control structure allows exchange of water, fish, mussels, and other wildlife and provides a unique opportunity to quantify the response of reconnected wetlands through field sampling of fish, birds, invertebrates, plants, water quality, and water levels.

Intense data collection by the USGS and close interaction with refuge managers and other partners have led to an unprecedented look at the wetland ecosystem response to a large restoration action, implementation of adaptive management practices, and recognition of water-quality improvements associated with habitat restoration

**(Left upper) Constructed water-control structure connecting a managed pool to Crane Creek wetland (Lake Erie). This water-control structure allows critical fish passage between Lake Erie and the previously diked wetland. Photograph by Kurt Kowalski, USGS.**

**(Left middle) Sampling for this study indicates water-quality improvements since the wetland was reconnected to Lake Erie. Photograph by Kurt Kowalski, USGS.**

**(Left lower) Northern pike depend on productive wetland habitats for spawning, and are an example of a fish species positively affected by the reconnection of a diked wetland to Lake Erie.**


Sampling for wetland fish provides important information on the success of habitat restoration efforts. Photograph by Kurt Kowalski, USGS.

in the Maumee River Area of Concern. The reconnection has improved habitat for commercially and recreationally important fish while maintaining high quality habitat for migratory waterbirds. Water-quality improvements (such as reduced phosphorous load to Lake Erie) associated with this type of wetland restoration were observed and provided baseline data used to support similar restoration efforts in the Maumee Area of Concern, Saginaw Bay/River Area of Concern, and other Great Lakes coastal areas. This project has developed a foundation of sustainable approaches that can be used as a model in other regions of the Great Lakes basin to restore coastal wetland function and increase ecosystem resilience.

## Early Successes

- Fish diversity and abundance in the restored wetland has increased dramatically since reconnection. Sixteen new fish species were found to be using the restored wetland.
- The availability of wetland habitat was crucial in 2012 when low water levels stranded some coastal wetlands and drought contributed to dry conditions in many diked wetlands in the area. However, the reconnected wetland held water throughout the summer and was used extensively by migrating waterfowl in the autumn.

## 2013 Successes

- Waterfowl and piscivorous (fish-eating) bird usage of the wetland increased after the reconnection to Lake Erie.
- The wetland has been serving as a nursery and breeding grounds for many species including northern pike, largemouth bass, white and black crappies, and numerous species of sunfish. High resolution sonar data have shown that fish access the wetland at all times of the day from late winter to late autumn.
- Fish species richness and abundance in the restored wetland increased substantially (more than 10 times in some cases) since wetland habitats were reconnected.
- Invasive common carp were effectively excluded from the restored wetland habitat through the use of specially designed gates in the water-control structure that allow northern pike and other native fish to pass into the wetlands but exclude mature breeding size carp.
- The reconnected wetland continues to be a sink for phosphorus, nitrogen, and sediment from Crane Creek. High levels of sediment and nutrient retention (approximately 50 percent) have been observed during the passage of storm or flood events that move large quantities of water into the wetland.

# Developing Breakthroughs in the Prediction and Prevention of Botulism Outbreaks

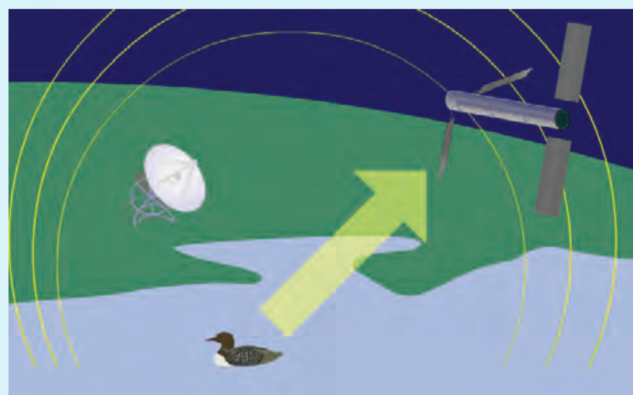
Botulism outbreaks are causing extensive mortality of fish and fish-eating birds in the Great Lakes. Botulism is a form of "food poisoning" that results from ingestion of neurotoxins produced by the naturally occurring bacterium *Clostridium botulinum*, which leads to paralysis and death of intoxicated animals. The toxin is thought to accumulate in some species of fish, which are then eaten by birds. Periodic outbreaks of type E botulism have occurred in the Great Lakes since at least the 1960s, but outbreaks have become more common and widespread since 1999, particularly in Lakes Michigan, Erie, and Ontario. Concurrent with outbreak resurgence, non-native zebra and quagga mussels and round gobies invaded the Great Lakes, but the role these invasive species play in the outbreaks has not been fully identified. Botulism has been responsible for the deaths of more than 100,000 birds and countless fish in the Great Lakes since 1999 including the federally endangered piping plover, common loons, and lake sturgeon.


The USGS is bringing together scientists with diverse areas of expertise to address botulism outbreaks in the Great Lakes through the GLRI. This team of experts, which includes the USGS, National Park Service, U.S. Fish and Wildlife Service, state wildlife agencies in Michigan and Wisconsin, and other organizations, is taking a comprehensive approach to understanding what factors need to link together to trigger a botulism outbreak, and how future outbreaks can be predicted and prevented in the Great Lakes. To accomplish this goal, scientists are developing methods to detect the presence of botulinum toxin in the environment and determining how the botulinum toxin reaches bird populations through Great Lakes food webs.

The development of a new method to test for the botulinum toxin is a major step forward in the study of botulism outbreaks in the Great Lakes and can be applied to other locations. Understanding how the botulinum toxin moves up the food chain from the lake sediments to birds is a key component to understanding how botulism outbreaks occur. Monitoring information collected for this study indicates that *Clostridium botulinum* may occur in high abundance in decomposing *Cladophora* algae. The toxin likely moves from bacteria in lakebed sediments into small invertebrates, which are then consumed by fish, which in turn, are eaten by waterbirds. Through monitoring, scientists have already demonstrated that fish communities in the area are now dominated by highly abundant and invasive round gobies. Preliminary results indicate that all of the loons that tested positive for botulism had eaten round gobies prior to death, suggesting that gobies may be a source of botulinum toxin. Another key component to understanding how birds come into contact with botulinum toxin is to better define the distribution and abundance of waterbirds during fall migration along with foraging patterns to determine where waterbirds are likely to be harmed or killed by botulism. Through monitoring efforts for this study, scientists obtained the first ever dive profiles for loons and have learned that loons dive as deep as 150 feet to feed in Lake Michigan, which indicates that botulism intoxication could be taking place at least that deep in the lake. The comprehensive approach to addressing botulism outbreaks as part of the GLRI provides important steps forward in predicting and preventing future botulism outbreaks in the Great Lakes.

**The USGS coordinator for AMBLE (Avian Monitoring for Botulism Lakeshore Events) inspects a ring-billed gull submitted for avian botulism type E testing. Some sick and dead gulls found on Lake Michigan beaches had avian botulism. Photograph by Stephanie Steinfeldt, USGS.**

(Right) Common loons were marked with a satellite transmitter and geolocator tag to study the distribution, migration movements, and foraging patterns to identify where fish-eating waterbirds are likely to be exposed to the botulinum toxin. Photographs by Luke Fara and Kevin Kenow, USGS.



## Early Successes

- The collection of lake bottom sediment began in 2010–12 near Sleeping Bear Dunes National Lakeshore on Lake Michigan. A total of 435 samples were analyzed for the presence of the botulinum toxin gene. Results from this analysis have been used to understand the ways through which birds come into contact with botulinum toxin.

- A new method to detect botulinum toxin was developed that performs as well as the traditional method. This new method is faster and cheaper than the traditional method, and is a major step forward in the study of botulism (*http://dx.doi.org/10.1128/AEM.06165-11*).

- Scientists have learned that avian botulism is the main cause of bird mortality in northern Lake Michigan. More than 950 sick or dead birds have been collected through this project. Seventy-six birds have been tested for botulinum toxin, of which 42 were positive (55% positive).

- A citizen science program (Lake Michigan Volunteer AMBLE: Avian Monitoring for Botulism Lakeshore Events) was established to collect data on bird carcasses that wash ashore near Sleeping Bear Dunes and the Upper Peninsula of Michigan, and across the lake in Door County, Wisconsin (*http://www.nwhc.usgs.gov/mortality_events/amble/*). This team effort has considerably increased our knowledge of the timing, numbers, and species affected by avian botulism.

- Links between type-E botulism outbreaks, lake levels, and surface-water temperatures in Lake Michigan indicated that avian botulism outbreaks occurred most frequently in years with low water levels and that surface-water temperature in Lake Michigan was higher in outbreak years than in other years (*http://dx.doi.org/10.1016/j.jglr.2010.10.003*).

(Above) Round goby. Photograph by S. Yavno. (Immediately right) Scientists sample fish in Lake Michigan near Sleeping Bear Dunes National Lakeshore to determine if *Clostridium botulinum* is commonly present in any particular species or locations. Photograph by Bryan Maitland, contractor to the USGS.

Botulism has been responsible for the deaths of more than 100,000 birds and fish in the Great Lakes since 1999 including the federally endangered piping plover shown in inset. The piping plover is a small migratory shorebird listed as endangered in Canada and the U.S. Great Lakes and threatened throughout the remainder of its U.S. breeding and winter range. Recent surveys indicate that only about 8,000 adult piping plovers exist. Inset photograph by Susan Haig, USGS. Background photograph by John Tracey, USGS.

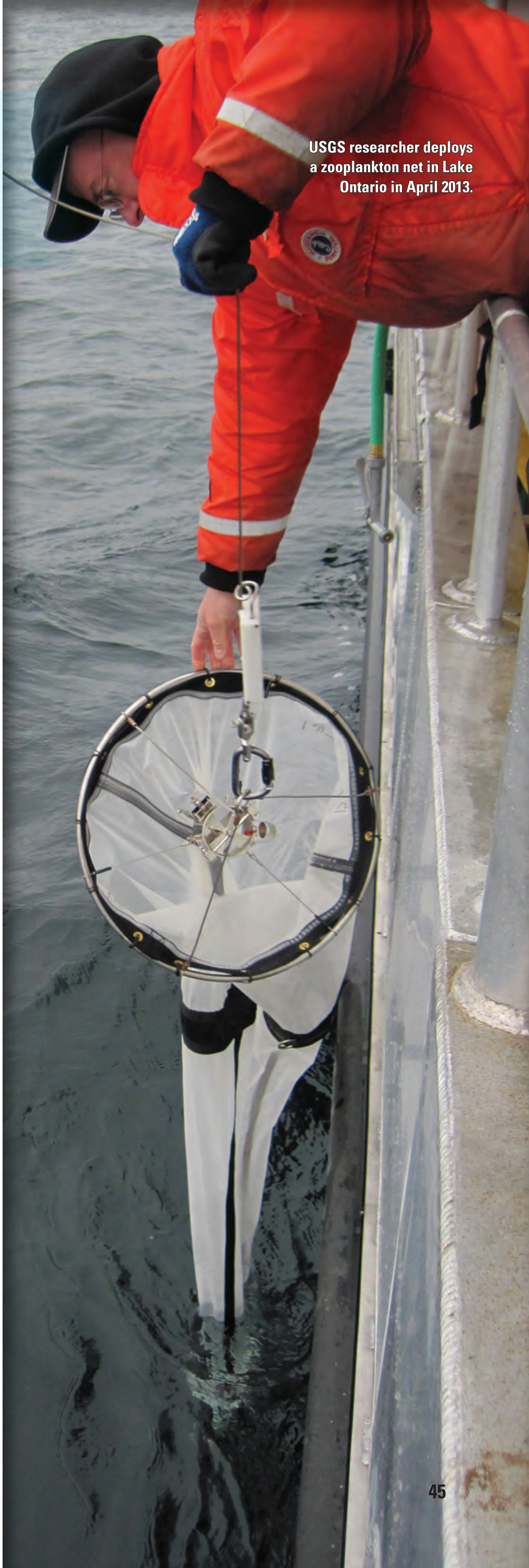
## 2013 Successes

- The distribution and relative abundance of more than 30 waterbird species were determined through aerial surveys of Lake Michigan. Movements of more than 70 common loons while on the Great Lakes were determined through the use of satellite transmitters and archival geolocator tags during the summers of 2009–13 to reveal where loons are likely to be exposed to prey fish carrying botulinum toxin. Geolocator tags also were used to capture feeding behavior. Movements of loons can be tracked by visiting the USGS loon migration Web site at *http://www.umesc.usgs.gov/terrestrial/migratory_birds/loons/migrations.html*.
- Sediment samples continued to be collected at Sleeping Bear Dunes National Lakeshore in 2013 and analyzed for the botulinum toxin gene.
- Researchers have collected fish and invertebrates, and testing is underway to determine whether *Clostridium botulinum* is commonly present in any particular species or locations. Hundreds of round goby stomachs have been analyzed to determine which invertebrates are common food items.
- Avian mortality was assessed by using data collected for this study. Large mortality events (greater than 1,000 carcasses) occurred in 2010 and 2012 (2,399 carcasses) and smaller events (fewer than 500 carcasses) occurred in 2011 and 2013.
- Scientists assessed peak carcass detection for the study years. Peak carcass detection for all study years except 2011 was in October, with mostly migratory fish-eating and diving birds reported during these peaks: 2010 (long-tailed ducks), 2012 (common loons), and 2013 (red-breasted mergansers). Peak carcass detection in 2011 occurred in August and involved primarily summer residents such as gulls and double-crested cormorants.
- Scientists are also developing carcass drift models to aid in pinpointing potential sites of botulinum toxin exposure. During 2013, current, wave, and wind force measures were determined in the laboratory to compute drag coefficients operating on portions of carcasses in air and under water. This information is being incorporated into a hydrodynamic probabilistic source tracking model to estimate the trajectory and origin of bird carcasses deposited at a given beach location.

# Surveying Food Web Interactions within All Five Great Lakes

The Great Lakes have been under persistent pressure from numerous environmental threats for more than two centuries. More than 180 invasive species now make their homes in the Great Lakes, many of which thrive at the expense of native species. Additionally, excessive nutrients (nitrogen and phosphorus) can cause harm to ecosystems. The USGS is leading the way to understand how multiple environmental threats affect Great Lakes restoration by surveying the health of food web interactions ("who-eats-what") in all five Great Lakes. With GLRI funding, scientists are sampling species throughout the food web, from top predator fishes to bottom-dwelling invertebrates, to microscopic animals (zooplankton) and plants (phytoplankton). In each year of this study, a different Great Lake is intensively sampled following the schedule of the U.S. Environmental Protection Agency's and Environment Canada's Coordinated Science and Monitoring Initiative: Lake Michigan (2010), Lake Superior (2011), Lake Huron (2012), Lake Ontario (2013), and Lake Erie (2014). This monitoring marks the largest effort ever to characterize Great Lakes food webs at broad geographic and seasonal scales, providing valuable information to restore native fish and foster the health of existing fisheries.

Knowledge generated through this project is critical to deciphering how environmental threats, such as invasive species and changes in nutrient input, ripple through food webs to ultimately affect native fish production and restoration. Scientists are creating a food web "roadmap" for each Great Lake that details the feeding linkages between species. These maps are decision support tools that allow scientists to explore how impacts of environmental threats spread through each lake's ecosystem by way of connections between species. For example, USGS scientists are using food web maps to understand how spiny water fleas—an invasive zooplankton found in all the Great Lakes—and other invasive species affect native fish. Scientists are currently using the Lake Michigan map to study how native predators such as lake trout and prey fishes such as bloater are affected by invasions of species lower in the food web, such as zebra mussels, quagga mussels, spiny water fleas, and round gobies. Through use of this tool, managers are able to make informed decisions that ultimately benefit Great Lakes restoration. In addition, this project is generating a geographically and seasonally extensive database of Great Lakes species and feeding relationships for all of the lakes. This information allows scientists to assess the current health of the Great Lakes, and it also serves as a valuable baseline from which future ecosystem changes can be monitored. Together, these studies are providing numerous insights into the structure and function of Great Lakes food webs that should substantially enhance our ability to understand how purposeful and unexpected changes affect restoration in these valuable ecosystems.



**USGS researcher deploys a zooplankton net in Lake Ontario in April 2013.**

(Above) USGS researchers filtering chlorophyll from various depths. (Below) USGS researchers pull gill nets from Lake Ontario for inshore fish diet study.


(Left) A trawl was used to collect mussels from a depth of 175 meters in Lake Ontario by USGS researchers studying food web interactions. (Below) Invasive spiny water flea (*Bythotrephes*) collected from Lake Huron. This invasive zooplankton is found in all the Great Lakes. USGS scientisits are using food web maps to understand how spiny water fleas and other invasive species affect native fish. Spiny water flea photograph by Kevin Keeler and Lynn Lesko, USGS.

## Early Successes

- Extensive sampling for three of the Great Lakes was completed: Lake Michigan, Lake Superior, and Lake Huron. This work has allowed scientists to gain in-depth knowledge of the diets of top predators, such as salmon and lake trout, and a stronger understanding of the geographic and seasonal dynamics of numerous other Great Lakes prey fish and invertebrate species.
- A decision-support tool that can explore different scenarios (for example, increased stocking of lake trout, control of invasive mussels, or reductions in phosphorus inputs) was developed for Lake Michigan. Simulation results can be used to support management decisions to restore native fish.
- Scientists studying Lake Michigan learned that a greater proportion of the Chinook salmon diet now consists of alewife (an invasive prey fish) than the diet of Chinook salmon surveyed in the 1990s, a finding that is important for determining salmon stocking targets in the changing Lake Michigan ecosystem (*http://dx.doi.org/10.1080/00028487.2012.739981*).
- Scientists studying Lake Superior have determined that the food web and water quality are currently in good condition. Scientists documented a diverse fish community living throughout the lake, even in many of the deepest areas.
- In Lake Huron, scientists observed abundant lake trout, consistent with recovery of this keystone native predator being well underway. Scientists also discovered that the spiny water flea occupies greater depths in Lake Huron than was formerly known, which demonstrated a previously unrecognized potential for this invasive species to interact with native deepwater fish and zooplankton.

## 2013 Successes

- Extensive sampling of Lake Ontario was completed. Specimens were taken to the laboratory where they were identified and counted, gut contents were examined, and chemical analyses were completed.
- An article that explores the key ecological drivers of Great Lakes food webs was published (*http://dx.doi.org/10.1093/biosci/bit001*). Water clarity increased and phytoplankton, native invertebrates, and prey fish decreased since 1998 in at least three of the five lakes. The article concluded that food was limiting several different food web levels (the position an organism occupies in a food chain) in Lake Michigan and Lake Huron, highlighting the long-term effects of varying nutrient inputs and shorter-term consequences of quagga mussel's altering of energy availability.
- A new method for analyzing data from acoustic sampling of the fish community was developed on the basis of the 2011 sampling in Lake Superior (*http://dx.doi.org/10.1016/j.fishres.2012.12.012*). The results for Lake Superior revealed non-native rainbow smelt (*Osmerus mordax*) to be the most common species at depths less than 330 feet with a lakewide estimated population of 755 million fish. Native kiyi (*Coregonus kiyi*) were the most abundant species at depths greater than 330 feet with a population of 384 million. Native cisco (*Coregonus artedi*) were widely distributed over all depths with their population estimated at 182 million.

USGS researchers collect water samples from a stream in northeastern Minnesota. The Lakewide Action and Management Plan for Lake Superior places emphasis on collecting baseline environmental data in areas with potential for mine development.

*Highlights*

# Tracking Progress and Working With Partners

*The success of the GLRI program requires accountability, education, monitoring, evaluations, communication, and partnerships to succeed. The information obtained from GLRI efforts needs to be based on the best available science and assembled and communicated consistently to decision makers to allow them to assess ecosystem conditions and to track restoration progress. Outreach and education are also crucial in the effort to restore the Great Lakes. Because the Great Lakes span many different government jurisdictions, it is critical that partnerships continue and are further strengthened to address the complex issues faced by the Great Lakes. As part of the GRLI, the USGS is tracking progress and working strategically with partners to support Lakewide Management Plans, to characterize rivermouth ecosystems, and to provide forecasting tools for stream ecosystem management.*

# Supporting Lakewide Action and Management Plans

The USGS is providing expertise, capacity, and support for the implementation of Lakewide Action and Management Plans (LAMPs; formerly Lakewide Management Plans, or LaMPs) and the associated goals, objectives, and targets for each of the Great Lakes. The LAMPs are critical binational collaborations that plan and integrate Great Lakes restoration actions. USGS work involves participation in binational Cooperative Science and Monitoring Initiative (CSMI) planning and field sampling. Each year, U.S. and Canadian organizations assess one of the Great Lakes as part of the CSMI, which is tied to the needs of LAMP committees. Information collected during CSMI assessments supports Great Lakes management programs. The USGS participates in LAMP processes, programs, workshops and projects; serves on work groups and technical committees; participates in interagency actions that implement LAMP programs and priorities; and incorporates LAMP goals and objectives into USGS planning efforts.

USGS scientists work closely with partners to coordinate activities to ensure that projects and results are applicable, useful, and supportive of LAMP goals and projects that focus on the restoration and protection of the Great Lakes. Substantial progress has been made in compiling USGS monitoring and research information into a Great Lakes Web mapper called the Science in the Great Lakes (SiGL; pronounced "seagull") Mapper. The SiGL Mapper will be able to be used in the assessment of areas where data are being collected, missing, or sparse, and also of areas where ecosystems are vulnerable. The SiGL Mapper will be a great asset for decision makers in the protection and restoration of Great Lakes ecosystems. In addition, development of a nearshore-coastal framework will be able to be used in conjunction with the SiGL Mapper to develop a strategy for coordinated research and monitoring.

## Early Successes

- Efforts for Lake Michigan included compilation of historical data and information needed to inform partners about monitoring and data available in nearshore ecosystems. For example, USGS maps of manmade fill distributions were provided to assist environmental restoration and redevelopment efforts in economically distressed areas of southern Lake Michigan watersheds in an Area of Concern.
- For Lake Erie, emphasis was placed on coordinating activities with partners.
- For Lake Huron, emphasis focused on issues affecting fisheries and nutrient inputs.
- For Lake Superior, emphasis was placed on support of data activities in areas with potential for mining development.
- Lake Ontario efforts focused around attending LAMP meetings and providing science expertise for collecting data on benthos (bottom-dwelling organisms) to provide information needed for management decisions for Areas of Concern. A journal article on the 2008 Lake Ontario CSMI was published in 2012 (*http://dx.doi.org/10.1016/j.jglr.2012.07.005*).

The waterfalls at Niagara Falls straddle the international border between Canada and the United States. Binational collaborations comprise the Lakewide Action and Management Plans that are critical to planning and integrating Great Lakes restoration actions. Photograph by Jim Nicholas, USGS.

## 2013 Successes

- Substantial progress was made in compiling monitoring information, including information collected as part of the CSMI, into the SiGL Mapper and in support of summary publications describing the status of monitoring data for each of the Great Lakes. These efforts included coordination with Tribal and State partners, the U.S. Environmental Protection Agency, and LAMPs to ensure that products and results are applicable and useful.
- A new version of the SiGL Mapper was released and can be accessed at *http://wimcloud.usgs.gov/SIGL/*.
- The nearshore-coastal framework was completed and is being used in conjunction with the SiGL Mapper to develop a strategy for coordinated research and monitoring (*http://pubs.usgs.gov/of/2013/1138/*).
- The USGS continues to participate in LAMP steering committees that represent each of the Great Lakes. Individual USGS Science Centers continue to coordinate with partners for each of the Great Lakes and to support sampling and monitoring activities.

(Photograph far left) USGS researcher deploys a passive sampler at Scanlon, Minnesota, as part of the GLRI program to monitor Great Lakes tributary streams. The Lakewide Action and Management Plan for Lake Superior places emphasis on understanding contaminant loading to the lake.

***"The USGS empowers our stakeholders by providing shared data and scientific tools that overcome jurisdictional boundaries and helps form collaborations that promote beach health and water quality improvements of Lake Michigan and its tributaries. USGS participation in Lake Michigan groups such as the Urban Waters Federal Partnership has helped to develop and strengthen relationships among communities and local, State and Federal partners. Their assistance contributes to the development of meaningful stakeholder projects that enhance ecosystems and improve public uses of Lake Michigan, and its nearshore waters and tributaries."***

*—Natalie Johnson, Coordinator,*
*Northwest Indiana Urban Waters Partnership*
*(http://urbanwaters.gov/nwi)*

# Characterizing Rivermouth Ecosystems

Rivermouths are at the heart of most large cities on the Great Lakes because they provide ideal hubs for shipping and allow easier access to the lakes themselves. Rivermouths are thus the center of where people interact with the Great Lakes. Rivermouths are highly valued as urban, industrial, and shipping centers, but historically were also places that supported extensive fish and wildlife production. As the connection between the river and lake, rivermouths are also of great importance ecologically because they are the last step connecting land use to the coastal waters. Today, interest is great in restoring these mixing zones of river and lake waters that result in unique, diverse, and productive ecosystems, which are important to both nearshore and deepwater fisheries in the Great Lakes. Despite the importance of rivermouths, little is known about how rivermouth ecosystems function or how human changes have altered those processes. This lack of understanding severely limits the ability to manage or restore these ecosystems effectively and efficiently. To improve our understanding, USGS scientists are working to identify and understand the role that Great Lakes rivermouths play in the quality of nearshore and deepwater habitats, and how the mixing dynamics of river and lake waters is related to biological production. A scientific framework has been developed to support restoration and management in these important rivermouth areas. This framework will be especially useful to managers seeking remediation and delisting of Areas of Concern, which are predominantly rivermouths.

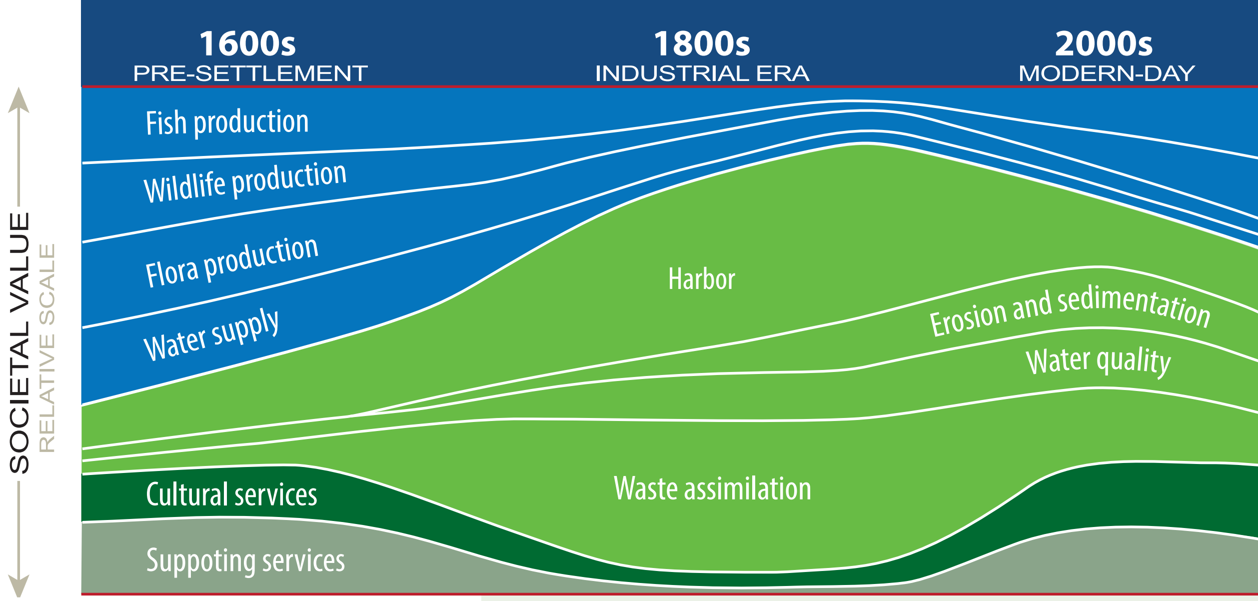
The intensive monitoring information on rivermouth characteristics is being used to develop a classification system to guide synthesis of research on rivermouths and help define "reference conditions" (historical benchmarks necessary to develop and establish ecosystems under undisturbed conditions) in support of rivermouth restoration across the Great Lakes. Decision makers can use this framework to match habitat restoration targets for Areas of Concern to previously identified stream and rivermouth impacts on the lakes. This framework serves as a guide to a variety of restoration activities including identifying critical habitat needs, ensuring alignment with fundamental ecosystem processes, and planning for effects of land use and climate change.

## Early Successes

- Intensive rivermouth sampling on the Ford, Pere Marquette, and Manitowoc Rivers (Lake Michigan) was completed in 2011 and on the Thunder Bay River (Lake Huron) was completed in 2012. Intensive sampling includes characterization of water chemistry, food web structure, mixing between riverine and lake inputs, and habitat use by aquatic organisms including fish and benthic invertebrates.
- A journal article (*http://dx.doi.org/10.1016/j.jglr.2012.09.016*) was published in 2012 that describes the importance of rivermouths in the processing and delivery of nitrogen and carbon to the nearshore zone.

**A USGS sampling team travelling between sampling locations on the Manitowoc River. As many as five laptops were used to collect data from multiple deployed instruments.**

Hypothetical example of how the values of communities around the Great Lakes and particular rivermouth ecosystem services have changed considerably over the last several hundred years.




## 2013 Successes

- A database of rivermouth characteristics was created. Information such as streamflow, water temperature, habitats, food-web structure (how plants and animals are interconnected), and watershed properties are stored in the database for more than 2,300 Great Lakes rivermouths.
- Intensive monitoring of the distribution of ecosystem processes in the Maumee River and extending into Lake Erie was initiated and will be used to assess goals and progress for restoration efforts in coastal wetlands near Toledo, Ohio. The information also can be used to assess how harmful algal species and blooms affect the growth of aquatic species in the Maumee River and Lake Erie.
- The "Great Lakes Rivermouths: A Primer for Managers" by the Great Lakes Rivermouth Collaboratory was published (*http://glc.org/files/main/RivermouthPrimer-FINAL-2013.pdf*). This primer synthesizes existing information in a new way that aims to support management of rivermouths as distinct and important ecosystems.
- A journal article (*http://dx.doi.org/10.1371/journal.pone.0070666*) was published describing how habitats and watershed land use affects fatty acid composition of algae at the base of aquatic food webs at rivermouths.
- A journal article (*http://dx.doi.org/10.1371/journal.pone.0069313*) was published describing how rivermouths alter the effect of agricultural land use on the stable nitrogen ratios in tissues of rivermouth consumers.
- A synthesis of current knowledge about ecosystem structure and function in Great Lakes rivermouths was published (*http://dx.doi.org/10.1016/j.jglr.2013.06.002*). The synthesis was based on studies of rivermouths, coastal wetlands, and marine estuarine systems and helps identify the critical gaps in understanding rivermouth ecology.

High flows are common in early spring on the Manitowoc River (above) and Ford River (below). USGS researchers completed intensive rivermouth sampling on both of these rivers in 2011.

The confluence of the Ford River with Lake Michigan near Escanaba, Michigan. The natural delta shown in the photograph is one of the few undisturbed river deltas in the Great Lakes. USGS scientists are intensively sampling Great Lakes rivermouths to provide a scientific framework for restoration and management in these important areas.

# Watershed Modeling for Stream Ecosystem Management

**This project is determining fish distributions in Great Lakes tributaries and how changes in streamflow may affect them. This information will help guide restoration efforts to achieve maximum effectiveness and success.**

The USGS is creating forecasting tools for managers to determine how water withdrawals or other hydrologic or land use changes in watersheds may affect Great Lakes ecosystems.

USGS scientists are providing forecasting tools for managers to determine how water withdrawals, landscape changes, or other changes in watersheds may affect ecological flows in the Great Lakes. Ecological flows can be defined as the flow of water in a stream, river, or lake that sustains healthy ecosystems and maintains appropriate ecosystem functions such as fish productions and access to spawning habitat. Flows vary in magnitude, especially during flood and drought events, and flows also are affected by artificial alterations such as damming, diversions, and channelization. These changes have many effects of the survival of aquatic organisms and the functioning of aquatic ecosystems. Efforts to determine appropriate ecological flows seek to preserve or restore enough of the "natural" flow magnitude and variability to protect the ecological functions essential for supporting diverse aquatic communities. Effective management decisions must recognize the natural diversity of stream ecosystems. At the same time, trying to manage every stream as a unique system would be extraordinarily challenging. To address these needs, USGS scientists and regional partners are creating a regionally consistent data framework to support modeling of landscape and hydrologic variables to relate changes in environmental conditions such as water withdrawals or climate change to ecological changes in aquatic ecosystems. The forecasting tools being developed will help assess the health of aquatic ecosystems and identify areas in need of protection, conservation, enhancement, and restoration. The information will help guide stream ecosystem efforts to achieve maximum effectiveness and success.

This project provides unified information across the Great Lakes Basin for ecosystem restoration, assessment, and management by incorporating models that relate changes in landscape and hydrologic variables and stresses to changes in ecosystem function. The information can be used by managers to assess stream ecosystem health, by natural resources professionals to identify and prioritize locations to focus stream restoration efforts and to assess stream ecosystems across jurisdictional boundaries, by managers for planning and management of game and non-game species, and by policy makers to make informed decisions on topics that relate to stream ecosystem health. The approach for classifying streams achieves a balance by incorporating natural stream diversity while minimizing challenges that management of individual streams would present. Additionally, classifying streams allows scientists, managers, and stakeholders to identify restoration and management actions that can be effective for different parts of the system. The models of ungaged streamflow, stream temperature, and fish abundance can be used to develop additional models describing how fish communities may change in response to streamflow changes and identify stream ecosystems that are most sensitive to landscape and climate changes.

## Early Successes

- Modeling techniques were developed to estimate streamflow at ungaged stream sites. These techniques are important because stream ecosystem management relies on understanding the relationship between streamflow and stream ecology.

## 2013 Successes

- Project researchers worked with the USGS Center for Integrated Data Analytics (CIDA) to develop an online mapper that will deliver the ungaged flow estimates produced by the modeling techniques to ecologists, managers, and the public.
- Preliminary information describing fish species response to altered streamflow were developed.
- A general set of stream characteristics that are critically important to fish and other aquifer organisms (such as stream size, stream temperature, and streamflow) were used to classify streams and create predictive models of stream temperature and fish abundance.

# The Future of Communicating Science for GLRI

*The USGS has developed a new tool for communicating science for the USGS GLRI to provide resource managers, scientists, and the public with the information and decision-making tools needed to help with Great Lakes restoration efforts. This new tool is called "The Great Lakes Restoration Initiative Science Explorer." The GLRI Science Explorer is a Web-based interface that allows users to search and discover the valuable research USGS scientists are conducting in the Great Lakes region.*

*This search tool can be used to find information about current and past science projects. Each project record provides descriptive information about a study (such as start date, description, principal investigator, and location) along with links to associated information products and datasets that resulted from the GLRI projects including the projects described in this document.*

*Discover USGS science by visiting http://cida.usgs.gov/glri/glri-catalog/.*

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Or visit the USGS Great Lakes Restoration Web site at:
*http://cida.usgs.gov/glri/*

(Photo, inside front cover) This astronaut photograph of the Great Lakes in sunlight was acquired on June 14, 2012, from the vantage point of the International Space Station. Lake Ontario is in the foreground, Lake Erie is on the left in the background, and Lake Huron is to the right in the background. (Photo, inside back cover) Threads of light at night surrounding the Great Lakes as viewed from the International Space Station. Photographs courtesy of National Aeronautics and Space Administration.

Great Lakes
RESTORATION

*We thank the Great Lakes Restoration Initiative for the funding support that enabled us to conduct science in support of Great Lakes restoration, and thank our many Federal, Tribal, State, Provincial, local, nongovernmental organizations, university, industry and other partners and the public who have worked with USGS on these science accomplishments. Our collective commitment to and support of Great Lakes restoration is truly making a difference now and for future generations!*

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