

SCIENCE IN ACTION:

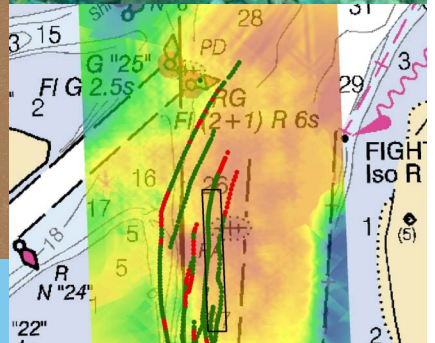
Lessons Learned from Fish Spawning Habitat Restoration in the St. Clair and Detroit Rivers



St. Clair -
Detroit River
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Initiative

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February 2016

THE RESTORATION TEAM

This publication summarizes lessons learned from a series of fish spawning habitat restoration projects completed between 2004 and 2015 in the St. Clair and Detroit rivers. This work resulted from a long-term collaboration among federal, state and private groups interested in studying and restoring the St. Clair-Detroit River System.

Restoration partners include: Michigan Sea Grant, University of Michigan Water Center, U.S. Geological Survey, U.S. Fish and Wildlife Service, SmithGroup JJR, Michigan Department of Natural Resources, Essex Region Conservation Authority, Ontario Ministry of Natural Resources and Forestry, Michigan Wildlife Conservancy, and St. Clair-Detroit River Sturgeon for Tomorrow.

FUNDING

The development of spawning reef projects has been supported through numerous grants, gifts and matching contributions. In addition to in-kind support from partner agencies, funding for reef restoration projects was provided by: the Great Lakes Restoration Initiative, National Oceanic and Atmospheric Administration, Sustain Our Great Lakes, U.S. Fish and Wildlife Service Coastal Program, Great Lakes Fishery Trust, Michigan Coastal Zone Management, Environment Canada, Canada-Ontario Agreement, Ontario Ministry of Natural Resources, BASE, DTE Energy, and the Michigan Wildlife Conservancy.

ABOUT THIS PUBLICATION

This publication was developed to capture and share the ideas and experiences of the habitat restoration partners. Content was adapted from a number of journal articles and reports. Lynn Vaccaro, a research specialist with the University of Michigan Water Center, was responsible for much of the synthesis and writing. Lynn has worked closely with the restoration team since 2011 and has helped coordinate four recent fish spawning reef projects established in U.S. waters. Stephanie Ariganello edited the publication; Todd Marsee was responsible for the graphic design.

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Table of Contents

Executive Summary	4
I. The Case for Fish Habitat Restoration.....	8
II. An Adaptive Management Framework.....	13
III. An Adaptive Management Team	16
IV. Planning a Spawning Reef Project.....	21
V. Avoiding Issues with Navigation and Sedimentation.....	24
VI. Project Permitting, Construction and Monitoring.....	28
VII. Selected Results and Outcomes.....	32
VIII. Spawning Reef Project Case Studies.....	34
Conclusion	43
References.....	43



Science in Action: Lessons Learned from Fish Spawning Habitat Restoration in the St. Clair and Detroit Rivers

THE CASE FOR FISH SPAWNING HABITAT RESTORATION

In the Great Lakes region, the St. Clair and Detroit rivers historically served as some of the most important spawning grounds for fish such as lake sturgeon, walleye, lake whitefish and cisco. However, many of the natural spawning grounds — limestone reefs and rocky areas — were destroyed when shipping channels were constructed. Similar spawning areas in tributary rivers were made inaccessible by dams or were damaged by shoreline development and sedimentation.

The waterways connecting Lake Huron and Lake Erie continue to support the largest remaining population of lake sturgeon in the Great Lakes, despite massive population declines overall. Restoration efforts in these rivers could help rebuild native fish communities throughout the Great Lakes. Many scientists believe that the recovery of lake sturgeon is hindered by a lack of accessible, high-quality habitat, including the rocky habitat needed to successfully incubate fish eggs.

In 2001, a diverse team came together to restore rocky habitat in the river system by creating fish spawning reefs. By applying an adaptive management process when developing each project, the team has advanced scientific understanding and improved conditions for native fish. This process has led to new strategies for siting, designing and constructing spawning habitat and for facilitating productive adaptive management.



Map of completed fish spawning reef projects in the St. Clair and Detroit Rivers.

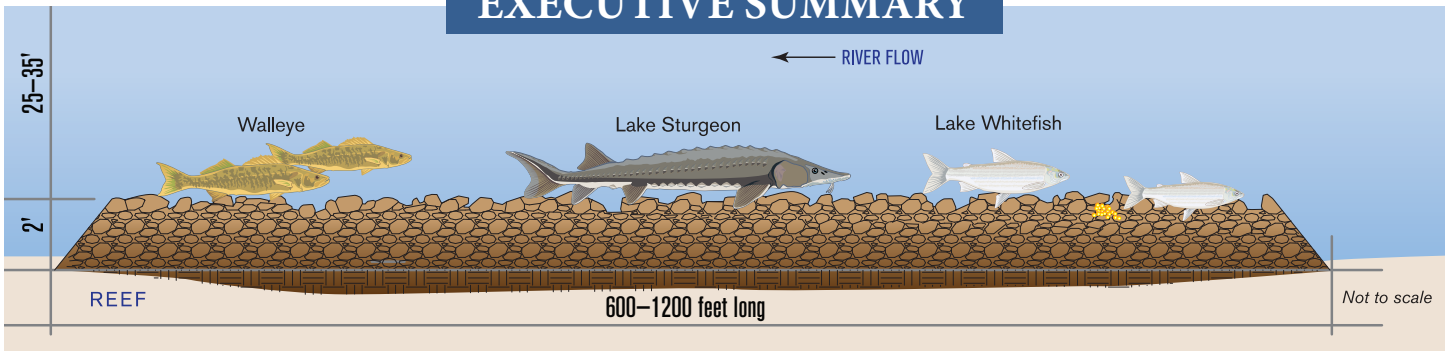
The team has distilled the lessons learned through six reef restoration projects completed between 2004 and 2015 in the St. Clair and Detroit rivers in a new report, which is summarized here.

AN ADAPTIVE MANAGEMENT FRAMEWORK

Adaptive management can be difficult to fully implement, and clear, applicable examples can be hard to find. The framework the restoration team adopted provided a structured process for experimentation, monitoring and decision making that identified and addressed the inherent uncertainty in ecological restoration. The team learned important lessons at each stage of the following adaptive management cycle.

- **ASSESS THE PROBLEM.** A range of evidence, as well as input from a diverse group of experts, helped develop working hypotheses to guide the team's strategy.
- **BUILD CONSENSUS.** Ongoing engagement with scientists, agency personnel, funders, stakeholder groups and residents ensured that the restoration projects were well supported and became part of a larger initiative to remediate the rivers.
- **DEVELOP A RESTORATION PLAN.** Each spawning reef project served as a large-scale experiment, with a carefully chosen location, design and monitoring plan. Each reef built on lessons learned during earlier projects, with the purpose of tackling remaining questions.
- **IMPLEMENT RESTORATION ACTIONS.** The team learned to expect setbacks during each project's permitting and construction processes. Unanticipated challenges often led to an improved design or new relationship with a stakeholder group.
- **MONITOR AND EVALUATE OUTCOMES.** By leveraging the resources of several state, federal and university research groups, the team was able to consistently conduct pre- and post-restoration assessments, capitalize on ongoing agency monitoring programs, and support discrete research projects to tackle emerging issues.

EXECUTIVE SUMMARY



Cross section of a typical constructed fish spawning reef.

• MAKE ADJUSTMENTS BASED ON LESSONS LEARNED.

Time, resources and communication were essential for fully analyzing and reviewing results. The team made a range of adjustments to the restoration process, including modifying hypotheses about which species would benefit from constructed reefs, changing the way restoration locations were chosen, expanding their team and improving the stakeholder consultation process.

AN ADAPTIVE MANAGEMENT TEAM

The reef team worked best when it included participants fulfilling distinct roles, including scientists, grant managers, team facilitators and coordinators, fishery managers, professional engineers, outreach specialists, local champions and a range of advisors. Key lessons learned include:

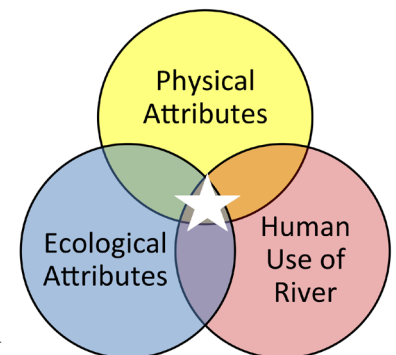
- Personal relationships and regional collaborations, such as the St. Clair–Detroit River System Initiative, helped the team coalesce and remain together for more than 10 years without a formal agreement.
- Team coordination and grant management required dedicated time and skills, which the team was able to build into budgets. Quarterly team meetings and regular email updates helped team members participate in ongoing decisions.
- Outreach and consultation were incorporated into all stages of project planning, using the connections of everyone on the team. The team regularly engaged stakeholders and members of the public, who often offered unanticipated assistance or objections.
- Shared decision making helped ensure that issues were anticipated and solved collectively, and everyone felt responsible and comfortable with plans. The contributions of team members were consistently acknowledged and good press was shared by all project participants.

PLANNING A SPAWNING REEF PROJECT

In the St. Clair and Detroit rivers, spawning reefs could not be created in the places where that habitat had once naturally existed — areas that had been altered by the construction of shipping channels. Therefore, the team was faced with the challenging task of finding the next-best location to create a reef, ideally in a location fish could find and where the rock would remain relatively free of algae and sediment.

The team reviewed studies about target fish species and combined this with knowledge of local fish populations and existing and historical spawning locations in the river system. Candidate restoration sites were identified using a GIS model that integrated siting criteria and helped the team to think systematically about the whole corridor. An iterative process that included modeling, field work and consultations allowed the team to locate projects based on ecological and physical attributes of an area, as well as human uses of the river. Ideal locations included the following key attributes:

- Deep waters, 25-50 feet, to limit algae growth
- Fast flows, at least 0.5 meters/second, depth averaged
- Outside of dredged navigation channels
- Connected to potential downstream nursery areas through water flow
- No known sediment contamination or point sources of pollution
- On the U.S. side of the border (for projects funded through U.S. grants)
- Areas where sturgeon travel and/or spawn based on telemetry studies
- Smooth, relatively flat, solid bottom with no existing habitat
- Shoreline property owners willing to provide permission
- No potential interference to marine navigation



Venn diagram illustrating the criteria used to select candidate restoration sites.

EXECUTIVE SUMMARY

PROJECT PERMITTING, CONSTRUCTION AND MONITORING

Implementing a restoration effort involved a series of steps that did not always proceed in a linear fashion. Key lessons learned:

- **FUNDING:** By showing success through initial pilot projects, the development of spawning reefs became part of the remediation plans associated with the St. Clair River and Detroit River Area of Concern programs. As a result, the team was able to attract funding through the Great Lakes Restoration Initiative for four of the six spawning reef case study projects. The team benefited from open communication with funders about successes, challenges and necessary project adjustments and delays.
- **REEF DESIGN:** The most recent projects consist of a single reef bed, 2 feet thick, covering 1.5 to 4 acres of river bottom. A long, narrow rectangle, oriented parallel to water flow, allows water and sediment to move smoothly over and around the reef.
- **ROCK TYPE:** The team experimented with a number of rock types during early reef projects and found that 4-8 inch angular, quarried limestone worked well for lake sturgeon and did not support sea lamprey spawning.
- **PERMITTING:** Each reef project has undergone a long and explicit review process, including state and federal permits. The team now consults with stakeholder groups early in the design process, including river remediation advisory councils, the commercial shipping industry, fishing groups and local residents.
- **CONSTRUCTION:** Water depth and shipping traffic influenced the selection of rock placement methods. Multiple project partners provided oversight through independent surveys and site visits.
- **MONITORING:** Before and after restoration, research teams evaluated the following criteria associated with each reef project: adult fish use of the area, egg deposition, larval fish production and physical conditions. Assessment techniques often needed to be modified for use in a large, busy river.

AVOIDING ISSUES WITH NAVIGATION AND SEDIMENTATION

Extra attention has been devoted to making sure constructed reefs do not interfere with commercial shipping and other uses of the river. Therefore, direct consultations with ship operators and others were conducted to understand how a particular location is used. In one location, the team decided a test reef was the only way to fully assess feasibility and potential impacts from commercial freighters.

Excessive sediment infilling and algae growth are known to deter fish from spawning in rocky areas. After realizing that sections of two reef projects were trapping more sand and silt than expected, the restoration team consulted with additional experts and significantly enhanced the site selection and project design process. Key lessons learned include:

- **IDENTIFY POTENTIAL SEDIMENT SOURCES.** A number of clues — such as dredging records and the current and historical shape of the river — can help identify areas within a river that typically experience erosion and deposition and identify potential sediment sources such as muddy tributaries or eroding shoals.
- **LOOK FOR INDICATORS OF SEDIMENT PROBLEMS.** The team used sidescan sonar, scuba divers and underwater cameras suspended from a boat to characterize the river bottom at a proposed restoration area. The team found that areas with significant loose sediment with visible waves or ripples should be avoided, while zebra and quagga mussel beds indicate a more stable river bottom that could be suitable for reef development.
- **MEASURE WATER VELOCITY CAREFULLY.** The team used Acoustic Doppler Current Profilers to measure and map water velocity and selected a specific reef locations with steady, high velocities.
- **MAKE USE OF MODELS.** Measuring sediment transport in the field is very challenging, so the team made use of river flow models and more recently, lab and computer simulations to evaluate locations and improve reef siting and design.

REEF PROJECT SPECIFICATIONS AND LAKE STURGEON SPAWNING OBSERVATIONS

REEF PROJECT NAME	BELLE ISLE	FIGHTING ISLAND	MIDDLE CHANNEL	POINTE AUX CHENES	HARTS LIGHT	GRASSY ISLAND
Project Specifications						
River	Detroit	Detroit	St. Clair	St. Clair	St. Clair	Detroit
Community	Detroit, MI	La Salle, ON	Clay, MI	Algonac, MI	East China, MI	Wyandotte, MI
Year Built	2004	2008, 2013 (expanded)	2012	2014	2014	2015
Size (acres)	0.3	2.0	1.0	1.5	3.8	4.0
Lake Sturgeon Spawning Observations						
Before Restoration	Absent	Absent	Absent	Absent	Few eggs	Absent
After Restoration	Adult fish, but no spawning detected	Spawning confirmed	Spawning confirmed	Spawning confirmed	Spawning confirmed	No data yet

EXECUTIVE SUMMARY

FISH SPECIES OBSERVED ON REEF PROJECTS

	Belle Isle	Fighting Island	Middle Channel	Pointe Aux Chenes	Harts Light
Fish that show signs of spawning activity on reefs					
Black redhorse*		■			
Emerald shiner	●		▲		
Golden redhorse*			■	▲	
Lake sturgeon	■	●	● ▲	●	●
Lake whitefish	●	●			
Northern hog sucker*	● ■			▲	
Quillback*	●	■			
Rock bass	■	▲	▲	▲	▲
Round goby (non-native)	▲	● ▲	▲	▲	▲
Shorthead redhorse*	● ■	▲	■	▲	▲
Silver redhorse*	● ■	■	■	■	
Smallmouth bass	▲	■			
Stonecat		▲	■		▲
Trout-perch	●	●			
Walleye	● ■	● ■	● ■	● ■	● ■
White bass ^	■	■	■		
White perch (non-native)^	■	■			
White sucker*	● ■	■	■	■	■
Fish that seem to be using the reefs in other ways					
Burbot		▲		▲	▲
Channel catfish		▲			
Common carp					▲
Creek chub			▲		
Darter			▲		
Gizzard shad	▲			▲	
Logperch	▲				
Mudpuppy		▲	▲		
Northern madtom	▲	▲	▲		▲
Northern pike	▲				
Slimy sculpin			▲		
Spottail shiner		▲	▲		
Tubenose goby	▲		▲		
Yellow perch	▲	▲			

- Eggs deposited on mats placed on reef
- Spawning ready adults caught on reef
- ▲ Other adults or juveniles observed on reef

Table illustrates species caught on spawning reef sites between 2005 and 2015, after construction. Observations are influenced by sampling methodology and effort, which varies from site to site.

* A variety of sucker eggs were found at all reef sites, but were not usually identified to species, and therefore were not included in this table.

^ White bass and white perch eggs were found at sites with spawning ready adults, but eggs were not identified to species and were not included in this table.

SPAWNING REEF PROJECT CASE STUDIES

In 2004, the restoration team established its first pilot spawning reef project near Belle Isle in the Detroit River. The team has now developed three spawning reef sites in the St. Clair River and three sites in the Detroit River, with two additional locations possible as part of the Detroit River remediation plan to restore fish and wildlife habitat and populations. The full report includes detailed case studies of each reef project.

Pre- and post-restoration monitoring illustrates the fish species associated with constructed reefs (see table). Monitoring egg deposition on reef sites prior to restoration found no, or very limited, signs of sturgeon spawning. After the reefs were built, sturgeon spawning was confirmed on four of the five constructed spawning reefs.

Many other fish species have been observed using the reef projects; 18 native fish species have shown signs of spawning activity, including lake whitefish, walleye and a range of sucker species. Another 15 species have used the reefs in other ways, including northern madtom, a fish listed as endangered in Michigan. Initial results are promising; however, it will take many years and a multi-faceted monitoring effort to determine if the spawning reefs are increasing fish populations in the river system.

While most people will never see a constructed spawning reef on the river bottom, the projects are contributing to river-wide restoration efforts with benefits for local communities. For example, the St. Clair River has a popular catch and release and limited-take fishery for lake sturgeon, which attracts anglers from around the region. The gradual recovery of lake sturgeon and other native fish serves as an important symbol of how urban rivers can be restored and people can connect with their unique natural resources.

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Restoration partners for the spawning reef case study projects include: Michigan Sea Grant, University of Michigan Water Center, U.S. Geological Survey, U.S. Fish and Wildlife Service, SmithGroup JJR, Michigan Department of Natural Resources, Essex Region Conservation Authority, Ontario Ministry of Natural Resources, Michigan Wildlife Conservancy, and St. Clair-Detroit River Sturgeon for Tomorrow. In addition to in-kind support from partner agencies, funding for reef restoration projects was provided by: Great Lakes Restoration Initiative, National Oceanic and Atmospheric Administration's Restoration Center, Sustain Our Great Lakes, U.S. Fish and Wildlife Service Coastal Program, Great Lakes Fishery Trust, Michigan Coastal Zone Management, Environment Canada, Ontario Ministry of Natural Resources, BASF, DTE Energy, and Michigan Wildlife Conservancy.

I. The Case for Fish Habitat Restoration

INTRODUCTION

In the Great Lakes region, the St. Clair and Detroit rivers historically served as some of the most important spawning grounds for fish such as lake sturgeon, walleye, lake whitefish and cisco. However, these rivers have been extensively modified and fish populations have suffered. The river bottoms were dredged to create deep channels for large, commercial ships. The dredging and the discarded dredged materials changed the flow of the river and damaged the natural limestone reefs where millions of fish spawned. Development within the watershed and along the shoreline degraded wetlands and polluted the waters. While water quality has improved, many fisheries experts believe that access to suitable habitat continues to limit the recovery of native fish communities in the St. Clair–Detroit River System.

In 2001, a small team came together to restore habitat for native fish in the System. Initially the premise was simple: re-create some of the rocky substrate that had been lost or degraded. However, these rivers are complex, dynamic and highly altered, presenting a multitude of uncertainties that continually challenge both the team’s understanding of the river system and their efforts to restore fish spawning habitat.

By applying an adaptive management process to habitat restoration efforts, the team has advanced scientific understanding and improved conditions for native fish species in these rivers. Along the way, the team learned new strategies for siting, designing and constructing spawning habitat and for facilitating a productive adaptive management process (Manny et al. 2015).

This guide summarizes lessons learned through a series of restoration projects completed between 2004 and 2015 in the St. Clair and Detroit rivers (Figure 1).

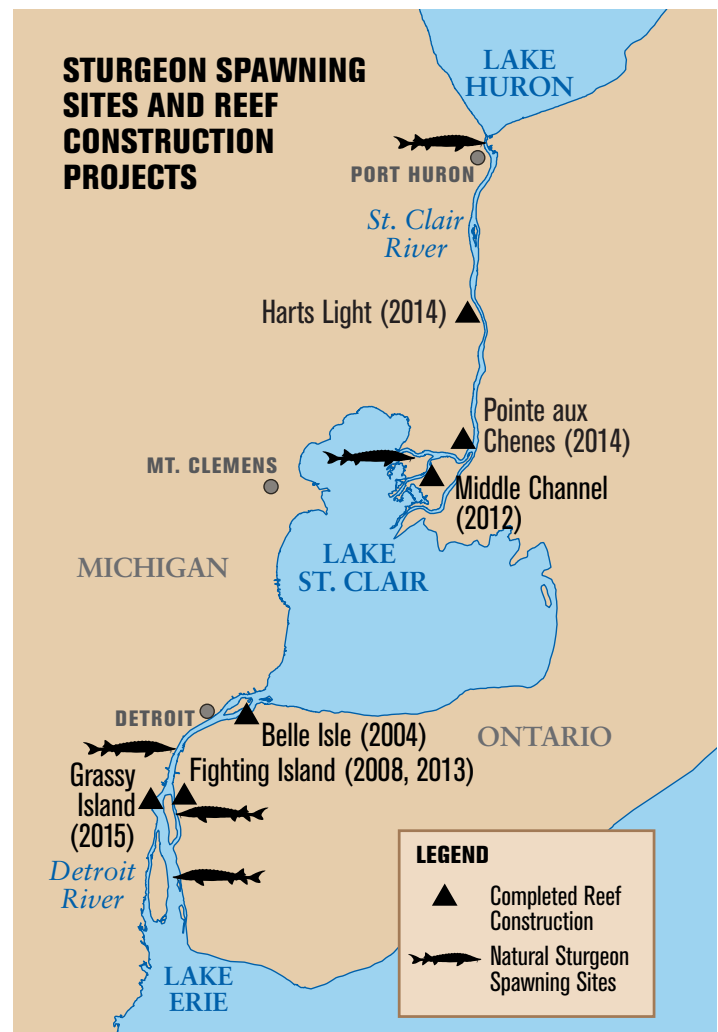


Figure 1. Map of completed and planned fish spawning reef projects in the St. Clair and Detroit rivers.

This information was compiled to help others — including local leaders, project coordinators, restoration funders professional engineers and biologists — learn from and apply the knowledge we’ve acquired through our adaptive management approach.

Lake Sturgeon

Lake sturgeon are unlike any other fish in the Great Lakes. They can grow up to 7 feet long and can weigh up to 250 pounds. They are often called living fossils because they have existed on the planet since the time of the dinosaurs. The shape and function of their bodies has remained virtually unchanged for millions of years (Figure 2).

Some of the sturgeon's primitive traits include a skeleton composed almost entirely of cartilage, bony plates or scutes instead of scales, and a shark-like tail. Although lake sturgeon look somewhat like sharks, they don't have teeth, and instead, have a downward-facing sucker mouth they use to suck up small animals from the bottom



Figure 2. Illustration of lake sturgeon. Credit: Emily Damstra.

of the river or lake, including snails, crustaceans, aquatic insects, mussels and fish.

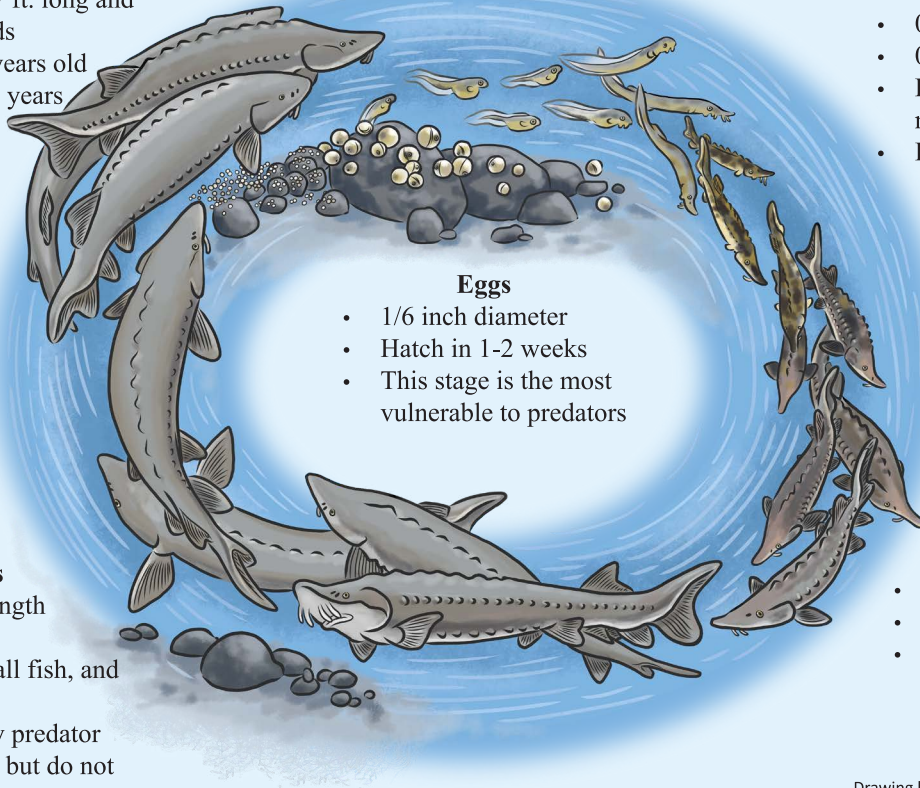
Lake sturgeon are one of the longest-lived and slowest to mature freshwater fish species. Male lake sturgeon live an average of 55 years and don't begin reproducing until age 15. Females take 20-25 years to reach reproductive age, and live 80-150 years. Females spawn only once every four years on average, and males typically spawn every other year.

Despite restrictions on fishing and improvements in water quality, lake sturgeon recovery has been slow. Because sturgeon take decades to reach reproductive age, it will take an equally long time to see whether restoration efforts lead to larger fish populations.

Lake Sturgeon Life Cycle

Adults

- Can grow up to 7 ft. long and weigh 250 pounds
- Can live to 150 years old
- Spawn every 2-7 years



Eggs

- 1/6 inch diameter
- Hatch in 1-2 weeks
- This stage is the most vulnerable to predators

Larvae

- 0.25-5 inches in length
- 0-5 months old
- Drift downstream to nursery habitat at night
- Eat aquatic insects

Juveniles

- 1.5-3.5 feet in length
- 2-26 years old
- Eat mussels, small fish, and aquatic insects
- Humans are only predator
- Similar to adults but do not spawn

Young Of Year

- 5-16 inches long
- 0.5-1 year old
- Eat aquatic insects



Drawing by Taaja Tucker trtucker@usgs.gov

Figure 3. Illustration of the lake sturgeon life cycle. Credit: Taaja Tucker, USGS.

TARGET FISH SPECIES

Restoration efforts initially focused on lake sturgeon (*Acipenser fulvescens*), a species that is listed as threatened or endangered in all but one of the Great Lakes states and provinces (Pollock et al. 2015). Lake sturgeon's size, conservation story and charisma helped motivate and guide restoration efforts; however a variety of other fish also use the constructed reefs. For example, a number of fish have similar spawning habits to lake sturgeon, including: lake whitefish (*Coregonus clupeaformis*), a commercially important fish; walleye (*Sander vitreus*), a popular sport fish; and northern madtom (*Noturus stigmosus*) a small, state-endangered catfish. These fish are considered "lithophilic broadcast spawners," meaning they release their eggs and sperm in the water immediately above rocky areas.

A variety of habitat types, such as wetlands, rivers and lakes, are needed to support a diverse community of fish and to provide for individual fish species throughout their life cycles. The team carefully considered lake sturgeon habits and needs (e.g., Auer 1996, Thomas and Haas 2002, Kerr et al. 2010, Boase et al. 2014). During the spring spawning season, lake sturgeon migrate to rivers and seek out gravel and rocky areas in fast flowing waters to deposit and fertilize their eggs. The eggs nestle into the crevices between rocks where they remain protected from predators and oxygenated by the flowing water. Several weeks later, larvae emerge from the eggs and drift downstream to calmer waters with abundant plankton. Young fish grow rapidly, reaching 7 inches within a year. Juvenile and adult lake sturgeon forage on bottom-dwelling fish and invertebrates in shallow waters of the Great Lakes and overwinter in deeper lake waters. All of these habitat types must be available, connected and healthy in order to sustain sturgeon populations (Figure 3).



Figure 4. In 1880, more than 4 million pounds of sturgeon were taken from Lake Huron and Lake St. Clair.

HISTORICAL PERSPECTIVE

Lake sturgeon were historically abundant in all of the Great Lakes. They served as an important food source for many Native American tribes. When European settlers arrived in the region, sturgeon were so numerous during the spring spawning run that they were reportedly capable of capsizing fishing boats (Manny and Mohr 2013).

In the late 1800s, people began catching large numbers of lake sturgeon for their meat and eggs (Figure 4). In 1880, more than 4 million pounds of sturgeon were taken from Lake Huron and Lake St. Clair and processed in Michigan. By 1928, the total sturgeon harvest from all the Great Lakes fell to less than 2,000 pounds. The remaining sturgeon faced a growing number of threats. Newly constructed dams blocked access to river spawning habitat. Other spawning locations were damaged by sedimentation from farming and logging and increasing industrial pollution. These changes, combined with the sturgeon's slow growth, led to its dramatic decline. Recovery, by all accounts, has been slow, and the current lake sturgeon population is estimated to be 1 percent of its historic abundance in Michigan (Tody 1974, Manny and Mohr 2013, Chiotti et al. 2013).



Figure 5. Historical photographs of the construction of the Livingstone Channel showing the limestone reef, dewatered, before and after blasting to deepen the channel.



Figure 6. Islands created to force water through the shipping channels.

Bi-national fishing regulations enacted in the 1970s have largely curtailed overfishing and allowed certain fish species, such as walleye, to rebound. Today, the State of Michigan prohibits commercial fishing for lake sturgeon and closely regulates sturgeon sport fishing.

The federal Clean Water Act of 1972 enabled regulators to eliminate or manage the discharge of industrial chemicals to the rivers. Scientists have noticed fish populations slowly rebounding in the St. Clair and Detroit rivers — lake whitefish spawning runs were observed in 2005 for the first time in 80 years (Roseman et al. 2007).

The remaining population of lake sturgeon in the St. Clair-Detroit River System — one of the largest in the Great Lakes — spawn in only a few locations. Project scientists have inspected these sites and found that sturgeon do not have enough clean rock to adequately protect and incubate their eggs (McClain and Manny 2000). Sturgeon have been found depositing eggs on some unusual materials. For example, coal cinders that were dumped in the river when ships unloaded near Algonac, Michigan have been used by spawning sturgeon (Manny and Kennedy 2002, Nichols et al. 2003).

THE ST. CLAIR AND DETROIT RIVERS

The St. Clair and Detroit rivers form an international boundary between Michigan and the Canadian province of Ontario. Water from the three upper Great Lakes (Superior, Michigan and Huron) courses through these rivers and into Lake Erie at a rate of about 100 billion gallons per day.

Before Europeans settled the Great Lakes region, vast wetlands lined the St. Clair and Detroit rivers. The river channels were more complex, with a mosaic of deep and shallow areas, fast-flowing rapids and beds of submerged vegetation. Over time, European settlers developed the

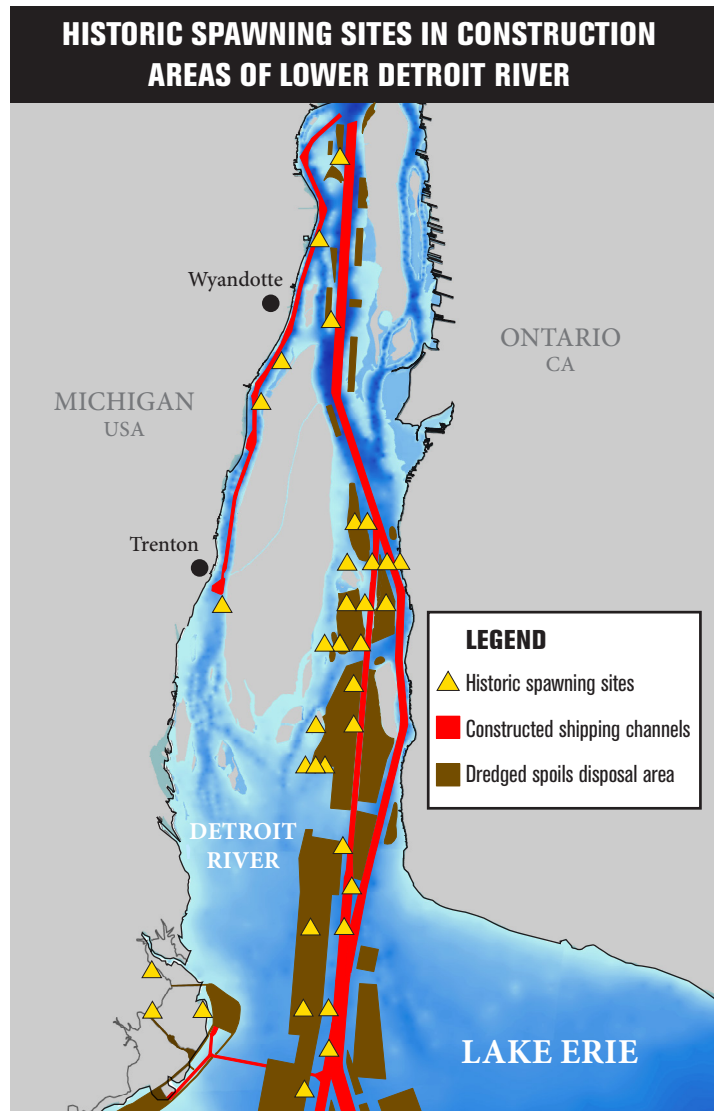


Figure 7. Map indicating areas dredged and covered by dredge spoils. Triangles indicate the location of historical spawning sites. Map developed by Dave Bennion (USGS).

shoreline, harvested fish in large numbers and began heavily using the rivers for transportation.

Beginning in 1874, the U.S. government began systematically deepening and straightening the river channels to accommodate large commercial vessels. Bennion and Manny (2011) studied historical accounts of shipping channel construction in the Detroit River and found that more than 60 million cubic yards of material was removed from the river bottom. The construction created 60 miles of dredged channels and subsequently covered 15.5 square miles of river bottom during the disposal of dredged materials. These numbers are particularly striking for a river that is only 28 miles long.

Blasting and dredging removed rock rubble and bedrock where millions of fish deposited their eggs (Figure 5).

Dredged material was disposed of in and along the river, creating islands designed to force water flow through the designated shipping channels (Figure 6). As a result, many historically productive fish spawning grounds were removed, covered or deprived of adequate water flow. Analysis of maps of historic fish spawning sites indicate that 35 spawning areas were damaged by the construction of shipping channels, potentially affecting 28 species of fish that used these spawning grounds (Goodyear et al. 1982) (Figure 7). Reports indicate that lake whitefish spawning runs in the Detroit River disappeared rapidly following the Livingstone shipping channel construction project, which removed a limestone bedrock formation ideal for whitefish spawning (Roseman et al. 2012).

A deep understanding of the system's unique history and current fish communities informed the team's assessment of the problem and decision to re-create some of the fish spawning habitat that had been lost or degraded historically (Hondorp et al. 2014).

LEARNING FROM OTHER RIVER SYSTEMS

There are many examples of large river restoration efforts that aim to improve ecosystem conditions and benefit fish, such as those that involve removing or modifying dams or re-creating more natural floodplains. These projects highlight the challenges of river restoration, the importance of linking hydrodynamics and ecological dynamics, and the need for comprehensive and accessible monitoring data.

Similar Projects

Lack of suitable and accessible fish spawning and nursery habitat is often thought to limit fish production, and many groups are working to re-connect and remediate spawning habitat in rivers in the Great Lakes basin and beyond (McClellan et al. 2015). The team looked to similar habitat projects in river systems, for example:

- Beginning in 1985, rock was added to the St. Lawrence River and its tributaries to enhance sturgeon spawning in areas where dams blocked access to historical spawning grounds (e.g., La Haye 1992, Johnson 2006, Dumont et al. 2011).
- In the 1990s, scientists observed that lake sturgeon were spawning on rock that had been added to stabilize the shoreline of the Fox River and Wolf River in Wisconsin. This provided additional impetus for the team to consider adding rock in the Detroit River to promote lake sturgeon spawning.

- In 2010, 32 artificial reefs were created in Thunder Bay, Michigan to compensate for a natural reef that was covered during the disposal of cement kiln dust.
- More recently, artificial spawning reefs have been developed in the Milwaukee River as part of an initiative to re-introduce lake sturgeon.

Unique Considerations

While there is much to learn from other river systems and their habitat restoration projects, the St. Clair and Detroit rivers differ from other large rivers in several important ways. These rivers are connecting channels that are fed primarily from water flowing out of Lake Huron — rather than a network of tributaries in a large watershed. As a result, flow through the St. Clair and Detroit rivers is remarkably consistent from month to month and the water is relatively clear.

During spawning season, lake sturgeon typically migrate to areas with fast flowing waters and seek out rock that is clear of sand and sediment. However, fish behaviors differ depending on the size, depth, and flow patterns of the river, and this was carefully considered when designing fish habitat restoration projects. For example, in small rivers, sturgeon find their preferred spawning habitat in shallow rapids, but in the St. Clair and Detroit rivers, they typically spawn in deeper areas with high flows and clean rock (Figure 8).



Figure 8. Lake sturgeon in spawning area at the head of the St. Clair River, where waters are 50 feet deep. Credit: Adam Lintz

II. An Adaptive Management Framework

Adaptive management is a term that is frequently used within natural resource management, but clear and applicable examples can be hard to find. Adaptive management requires that management actions, in our case developing a fish spawning reef, are implemented in a way that deliberately improves scientific understanding and future restoration efforts. In an ideal situation, a large-scale experimental design is used and specific results are predicted and evaluated. For example, the restoration projects referenced here were designed and monitored to address specific knowledge gaps, such as what type of material would best support successful spawning. By incorporating research and monitoring, each project improves those that follow by both enhancing our understanding of natural systems and reducing management costs.

Although the iterative learning process within adaptive management seems intuitive, it can be difficult to fully implement when restoring habitats or large ecosystems (e.g., LoSchiavo 2013, Williams 2014). For instance, restoration practitioners may not have the time or resources to weigh all options before selecting a restoration approach, and they may be hesitant to acknowledge uncertainties and knowledge gaps. Restoration funders may not want to support restoration projects that are designed as experiments and may not want to invest in a comprehensive evaluation and monitoring plan. In addition, design and monitoring details from related projects may not be shared widely and, thus, may not be available to inform specific habitat restoration efforts.

This section summarizes the adaptive management framework used to implement and learn from fish habitat restoration projects in the St. Clair–Detroit River System (Figure 9). Specific restoration strategies and techniques are further explored in subsequent sections, as well as tips for building and facilitating a team that can implement this approach to habitat restoration. Our hope is that others can learn from and improve upon our process for making decisions, as well as the technical aspects of remediating fish spawning habitat in large rivers.

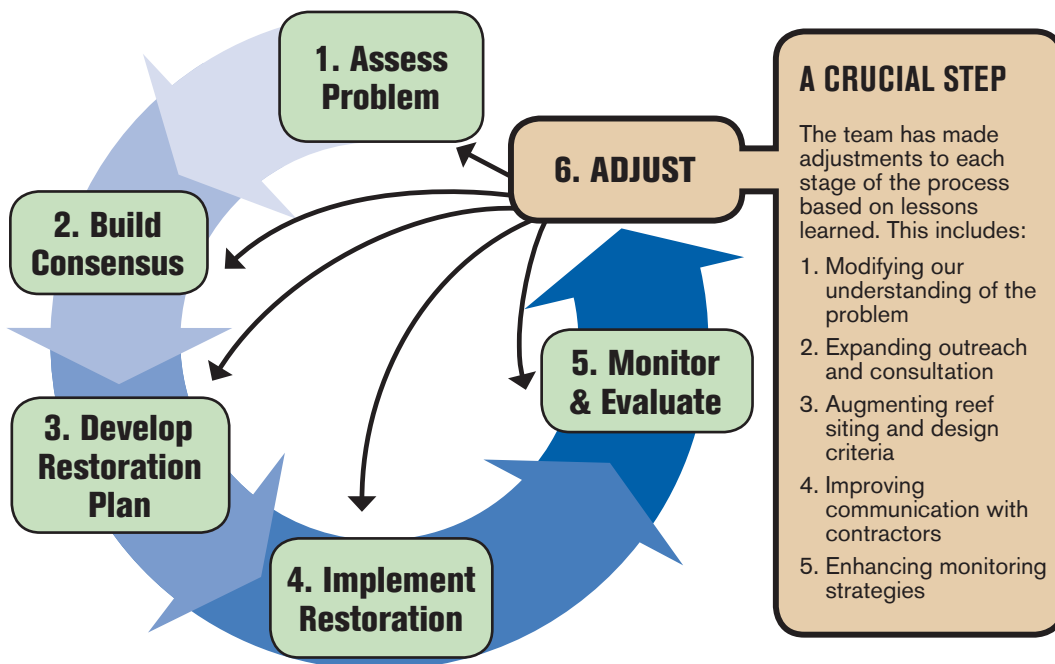


Figure 9: The adaptive management process used by the reef restoration team. Adaptive management is a rigorous method for “learning by doing.” The framework provides a structured, iterative process for planning, experimentation and monitoring so future projects can build on lessons learned.

THE TEAM'S ADAPTIVE MANAGEMENT PROCESS

1. Assess the Problem

A successful adaptive management process must be grounded in a thoughtful, comprehensive assessment of the main problem. This involves both compiling available scientific information and integrating the professional judgment of appropriate experts and stakeholders. It is important that future work be based on a scientifically defensible and mutually agreed upon definition of the problem and understanding of the ecological system. This foundation facilitates the development of working hypotheses that can guide restoration actions.

In order to develop an approach for fish restoration in the St. Clair-Detroit River System, the team had to make a best scientific guess about what was currently limiting fish populations, given the many ways the rivers have been degraded. Members of the reef project team conducted many years of research, assessing the status of fish populations, evaluating the condition of historic lake sturgeon spawning sites, finding the few remaining spawning sites in the system, and carefully documenting the changes to the river bottom habitat (e.g., Caswell et al. 2004, Manny and Kennedy 2002). As with other rare species, data about lake sturgeon was limited and therefore they used professional judgment, pooled knowledge and a range of evidence (Pollack et al. 2015). After much research and discussion, the reef team developed the hypothesis that a lack of suitable spawning habitat limited the production of lake sturgeon in this river system. Additional background information is provided in Section I, *The Case for Spawning Habitat Restoration*.

2. Build Consensus – Establish a Strong Coalition

Over time, ongoing research and collaborative efforts accumulated scientific evidence in support of fish spawning habitat restoration. Many workshops, symposiums and conferences specifically focused on the status and management needs of lake sturgeon and other similar fish species. Access to suitable spawning and nursery habitat was frequently cited as an important factor for the recovery of lake sturgeon and similar fish (e.g., Holey et al 2000, Hayes and Caroffino 2012, Pollack et al. 2015). These meetings also helped recruit members and strengthen relationships among members of the restoration team.

The team wove outreach and engagement into all stages of restoration planning, which helped them learn from and gain the support of residents, the commercial shipping



Figure 10. Team members consulting with commercial ship operators prior to developing restoration plans.

community, recreational anglers, environmental groups, funders and permitting agencies (Figure 10). Project team members participated in and benefited from a number of regional initiatives, local groups and outreach events. For example, the St. Clair-Detroit River System Initiative provided an essential forum for exchanging ideas and building consensus among the 30 U.S. and Canadian partner organizations about the need for spawning habitat restoration. Additional lessons learned about building a team and facilitating an effective adaptive management process are discussed in Section III, *An Adaptive Management Team*.

3. Develop a Restoration Plan

Based on the working hypothesis that access to suitable spawning habitat was limiting the recovery of fish populations, the team developed a series artificial spawning reefs to compensate for historic habitat losses. Each reef project served as a management scale experiment, with a carefully chosen location, design and monitoring plan that built on lessons learned during earlier projects, with the purpose of tackling remaining questions.

From the outset, the team recognized there were big gaps in knowledge. For example, what type of reef materials would work best? How should reefs be sited to maximize long-term benefits? How should projects be monitored and evaluated? The experimental design of the team's first three projects — each with multiple reef beds made of different rock types, placed in different locations within the river channel — addressed this first set of questions. Through careful monitoring, the team was able to identify a single rock type that worked well for target fish species.

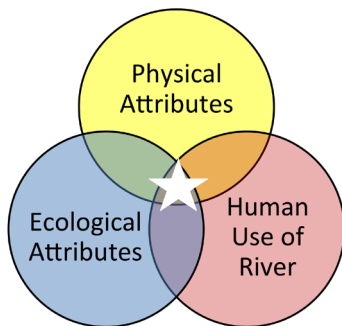


Figure 11. Venn diagram illustrating the criteria used to select candidate restoration sites.

Numerous meetings and an iterative process allowed the team to locate projects based on ecological and physical attributes of an area, as well as human uses of the river (Figure 11). Initial reef projects were sited based on the science team’s experience on the river, professional judgment and observations about the few remaining sturgeon spawning sites. Candidate sites for more recent projects were identified using a GIS-based model that integrated siting criteria and allowed the team to think systematically about the whole corridor when prioritizing candidate sites (Bennion and Manny 2014). Section IV, *Planning a Spawning Reef Project*, provides more details on site selection and project design.

4. Implement Restoration Actions

Implementing a restoration effort involves a series of steps that do not always proceed in a linear fashion, including: securing funding, assessing a proposed site, selecting coordinates and dimensions for a reef, developing engineering drawings, securing permits, selecting and overseeing a construction firm, and conducting pre- and post-restoration monitoring. Regular team meetings and on-going communication allowed the team to review new data and make project design and implementation decisions in an iterative process.

New information often emerged during subsequent stages that caused the team to revisit and revise the original plan. For example, information received during the public comment period for permit applications caused the team to re-locate projects or adjust the reef coordinates and dimensions. The team learned to expect new challenges with every project and to prepare emotionally, build setbacks into the timeline, and maintain a diverse network of advisors and stakeholders who could help when needed. For more details on project implementation, see Section VI, *Project Permitting, Construction and Monitoring*.



Figure 12. Monitoring of eggs deposited on constructed spawning reefs. Credit: USGS.

5. Monitor and Evaluate Outcomes

Scientific assessment of the constructed reefs helped determine if restoration goals were being met and provided information integral to the adaptive management process. A number of partners contributed to reef monitoring and research, including scientists from the U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (FWS), Michigan Department of Natural Resources (MDNR) and the University of Michigan (Figure 12).

The reef team typically collected at least one year of baseline data and two years of post-construction data at each spawning habitat restoration site. This included an evaluation of both the spawning activity and the physical condition of the reefs. For each of the restoration projects, team members tracked a suite a performance measures including adult fish use of the reef, fish egg deposition and fish larval production. The reef site and a control area were monitored both before and after construction, and statistics were used to separate the impacts of the reefs from natural year-to-year variation in fish populations. Biological monitoring methods are described in more detail in Section VI.

6. Make Adjustments Based on Lessons Learned

A careful evaluation of a restoration project, including monitoring results and reflections on the process, has enabled the team to make adjustments at all stages of the process — including changing how the problem is conceptualized, engaging additional experts and stakeholders, and improving the way the projects are designed, built and monitored. As a result, the team has improved both restoration techniques and the adaptive management process that they used to guide decision making over the past ten years. Examples of these lessons learned are described in the following sections.

III. An Adaptive Management Team

In addition to improving techniques for fish spawning habitat restoration, the reef projects have also provided lessons on project planning, team coordination and stakeholder engagement. This section outlines the different roles taken on by members of the extended reef team and provides tips on keeping a group engaged, coordinated and moving forward.

THE COALITION SUPPORTING SPAWNING REEF PROJECTS

Remediation of natural ecosystems is a complex process. It requires people with different skills and motivations based in organizations with different capacities. A diverse team is well positioned to identify unique opportunities, implement all stages of a restoration project, and anticipate and address the inevitable hurdles. The reef team worked best when it included the following.

Scientists

Although researchers may not be in a position to lead restoration projects, their involvement is essential. Scientists from different disciplines can help with many stages of the adaptive management process, including:

- Identifying the causes of a problem
- Evaluating current conditions in the system and potential restoration sites
- Prioritizing and assessing project sites
- Designing projects to advance scientific understanding
- Evaluating project outcomes

The idea for developing spawning reefs originated with fish biologists from two federal agencies — the U.S. Geological Survey (USGS) and Fish and Wildlife Service (FWS) — who had many years of experience studying the river system and collaborating on work in other river systems. Researchers



Figure 13. Restoration team members monitoring lake sturgeon populations in the St. Clair River. Credit: FWS

The Restoration Team

The reef team worked best when it included people able to fulfill the following roles:

- Scientists
- Grant Managers
- Team Facilitators and Coordinators
- Fishery Managers
- Design Engineers
- Outreach Specialists
- Local Champions
- Advisors

from the Michigan Department of Natural Resources (MDNR) and the University of Michigan soon joined the core team and began looking for funding to advance sturgeon spawning habitat restoration.

Each organization was able to bring unique research capacities, equipment and techniques to the complex process. For example, MDNR has an ideally situated field station on Lake St. Clair that others were able to use to store equipment and launch boats. In addition, MDNR partners were adept at monitoring sport fish at the focus of state management

efforts. FWS scientists had resources to study threatened and endangered species, and USGS partners were skilled at tracking the early stages of a fish's life cycle (Figure 13). In addition to their own expertise, university scientists brought in graduate students who were often co-advised by agency scientists and able to test out new research ideas and techniques.

Grant Managers

Restoration projects, especially expensive ones like the spawning reef projects, require people skilled at grant management and contract oversight. It is important that a team's fiscal agent is trusted and fully integrated into the team to avoid concerns about their motivations and integrity in managing a project's resources. Specific responsibilities include:

- Identifying funding opportunities
- Developing funding proposals and budgets
- Knowing when and how to combine different types of funding
- Developing and overseeing sub-contracts.

Michigan Sea Grant and the Essex Region Conservation Authority managed restoration grants for reef projects on the U.S. and Canadian sides of the rivers, respectively. Project partners at federal agencies faced limitations related to the types of grants for which they could apply and they lacked expertise to efficiently manage these types of grants and contracts.

The University of Michigan, the home institution for Michigan Sea Grant, was well suited to be the reef team's fiscal agent because it had support and procedures in place for tasks that can be administratively challenging, such as submitting federal grant applications, running a competitive bidding process, drafting sub-contracts and managing invoices. The team benefited from the university's purchasing and grants oversight, as well as legal and contracting specialists.

Team Facilitators and Coordinators

A skilled facilitator empowered to coordinate meetings helped the team work through difficult decisions. Skilled facilitation helped harness and integrate the knowledge of diverse team members and helped ensure everyone shared responsibility for outcomes from team decisions. The designated project coordinator took the lead on tasks that could otherwise be neglected, including scheduling

meetings, developing meeting agendas and notes, following up on action items in-between meetings, drafting reports and project summaries, and serving as a single point of contact for the public.

Project partners from Michigan Sea Grant and the University of Michigan Water Center acted as facilitators for the reef projects, which complemented their grant management responsibilities. Input from the team ensured that decisions were based on sound science and used the team's collective best judgment.

Fishery Managers

The involvement of state and federal fishery management agencies brought numerous benefits to the collaboration, including:

- Improved decision making
- Additional scientific expertise
- Linkages to long-term monitoring programs and management objectives
- Added credibility with stakeholders
- Faster permitting processes

The reef team was able to use agencies' long-term monitoring programs to establish goals and track progress toward fish population targets. In addition, these monitoring programs were often able to expand in order to complement reef restoration efforts. For example, extra questions about the reef projects were added to a questionnaire for anglers (creel survey), and telemetry studies included receivers that could track fish movements near constructed reefs. Neither of these activities were supported directly from reef restoration funds but added considerably to the resolution of outstanding questions.



Figure 14. Team members visiting the area where rock was loaded onto barges for reef construction.

Design Engineers

Most restoration projects require support from landscape designers and environmentally minded engineers. Ongoing conversations between biologists and engineers helped ensure the project designs were ecologically appropriate, logistically feasible and cost effective. Project engineers are usually responsible for:

- Developing project drawings and construction specifications
- Developing permit applications
- Overseeing project construction

Engineering and design firm SmithGroup JJR designed the St. Clair-Detroit River reef projects. The reef team worked with the same firm for all U.S. projects, so project engineers were able to learn and improve their approach over time. The engineering team helped develop proposals, anticipated potential hurdles at different restoration locations and developed analyses to address specific concerns about potential impacts to river water levels or commercial navigation (Figure 14).

Outreach Specialists

Outreach and engagement are ideally integrated into all stages of restoration planning and implementation. Public opinion can influence funding, permitting and the long-term stewardship of restoration projects. Outreach, education and communication specialists can help:

- Identify related projects and potential partners
- Spread the word to garner public and funder support
- Develop strategies for dealing with potential controversies
- Build connections between community members and natural resources

Michigan Sea Grant helped the reef team develop consistent communication tools, including presentations, fact sheets, videos and web content — and strategies for engaging specific audiences such as landowners, municipal officials and stakeholder groups (Figure 15).

Additionally, all members of the reef team engaged in different outreach activities, depending on their connections, geographies and interests. This included presentations at Rotary clubs, fishery workshops, schools and state park visioning sessions. Having a connection to different restoration groups, lake management committees, angler associations and industry stakeholders proved to be



Figure 15. Members of the restoration team at an outreach event.

tremendously valuable. For example, outreach efforts with the Public Advisory Councils for the remediation efforts of the St. Clair and Detroit rivers led to the inclusion of the spawning reef projects in their planning documents, which turned out to be essential for getting certain types of funding.

Local Champions

Recent research has found that local support for restoration projects is key for a project's long-term success. Although spawning reef projects are under water and do not require ongoing maintenance, these projects benefited from local support. Most reef team meetings were held in Ann Arbor, Michigan, where several partner organizations were based, 40 miles from the Detroit River and 90 miles from the St. Clair River. However, the team worked hard to develop relationships with local champions. Two groups in particular were instrumental — St. Clair–Detroit River Sturgeon for Tomorrow and the Detroit River Area of Concern Public Advisory Council.

Members of Sturgeon for Tomorrow helped the team reach out to landowners adjacent to proposed reef projects and met with residents who had concerns. They also helped the team and permitting agencies understand and address specific concerns related to fishing activities, ferry operations and recreational boat traffic at proposed reef locations. A local voice can provide a compelling explanation of the potential benefits of a project, such as how a thriving sturgeon population can support local businesses and build the area's reputation as a Sturgeon Angling Capital of Michigan.

Advisors

A varied network of project advisors helped round out the restoration team, contributing unique expertise and assisting when relevant issues emerged. The reef team cultivated a diverse group of advisors who were not necessarily involved in all planning decisions, but who were available to review plans and help anticipate issues. Advisors included people with expertise in fluvial geomorphology and hydraulics, and people who understood specific stakeholder groups or potential funders.

It was helpful to engage people with extensive experience with the St. Clair-Detroit River System, as well as people with experience working on other large rivers and other types of river manipulations (e.g., dredging, dam removals, flow diversions). These advisors were particularly helpful when unexpected issues emerged, such as observations of sediment accumulation on the Middle Channel reef.

TIPS FOR MANAGING A NIMBLE TEAM

The spawning reef team typically meets about four times a year, with calls and other meetings scheduled as issues arise. Over time, the team has become larger and communication has become more formal. All team members need to feel engaged in the process, responsible for project outcomes and comfortable offering contradictory opinions.

The team has found the following strategies to be particularly helpful in facilitating an adaptive management process with a collaborative team:

- Build a diverse team with strong relationships and a deep pool of potential advisors.
- Articulate a compelling mission that energizes participants and helps them justify continued involvement and support from their organizations.
- Maintain regular communication, solicit input through different methods and accommodate different levels of participation.
- Provide resources for a skilled facilitator and a dedicated project coordinator.
- Regularly reach out and engage stakeholders and the public who may offer unanticipated assistance or objections.
- Incorporate outreach and consultation into all stages of project planning, using the connections of everyone on the team.
- Be candid about concerns. Anticipate and solve issues collectively.
- Visit and revisit decisions objectively. Acknowledge that best judgment is often required.
- Ensure that everyone feels both comfortable with and responsible for decisions and outcomes and that they have ample opportunity to voice concerns.
- Allow time to observe and learn from completed projects.
- Consistently acknowledge different contributions and share good press generously.
- Develop a specific, appropriate and rewarding role for scientists in projects. This includes developing testable hypotheses and research objectives that meet management needs and advance scientific understanding.
- Allocate adequate resources for ongoing monitoring as well as research to address emerging issues.



Figure 16. Participants in the 2015 annual meeting of the St. Clair – Detroit River System Initiative.

THE GREAT LAKES: FERTILE GROUND FOR COLLABORATION

A number of political and institutional factors influenced the way the reef restoration team came together and what it has been able to accomplish. Members of the reef team participate in a variety of regional, cross-agency committees, working groups and collaborative projects, which over time, have strengthened ties among organizations. These regional activities provided prospective partners with a good sense of other agency and organization missions, their culture, and whether individuals from those organizations would be a good fit with the overall team.

At a more local level, members of the core restoration team all participated in the St. Clair–Detroit River System Initiative, a partnership that began in 2004, involving state and federal agencies, universities, consultants and non-profits from both U.S. and Canada (Figure 16). The partners all shared an interest in restoring fish populations and their habitats throughout the river system for various reasons. The initiative allowed members of the reef team to get to know each other and develop trust and a common vision for the river's recovery. In addition, the initiative helped build consensus around restoration strategies and provided a neutral banner under which restoration projects could be performed. Annual meetings, separate from reef restoration team meetings, provide a platform to discuss progress and emerging issues with a larger group.

Funding for early reef projects was pieced together from different small grants and contributions. This required the team to be creative and cooperative and seek out

organizations with overlapping missions and institutional capacity to support restoration planning without dedicated grant funding. Many state, federal and regional organizations with a Great Lakes focus have offices in southeast Michigan, which facilitated strong personal and working relationships. Grant proposals provided a type of agreement between team members and organizations, but often significant in-kind and matching contributions from partners were not formally identified. Longstanding relationships enabled the project team to come together without a more formal agreement such as a Memorandum of Understanding.

The technical experience, demonstrated successes and diverse partnerships built during early projects enabled the team to take advantage of funding opportunities that became available in 2010. The Great Lakes Restoration Initiative completely changed the funding game for restoration work and enabled the team to establish four spawning reef projects between 2012 and 2015. However, connections, both personal and institutional, remained critical to the team's success. For example, spawning reef projects were prioritized for funding because they had been incorporated into the locally developed remediation plans for the St. Clair and Detroit rivers. In addition, the federal restoration initiative provided different funding avenues for different types of organizations, which the team integrated to expand their collective impact. Federal agencies received funding for monitoring in support of restoration efforts, which could be combined with funds for specific restoration projects to more fully implement science-based adaptive management.

To learn more, visit: www.scdrs.org

IV. Planning a Spawning Reef Project

The next three sections provide more in-depth perspectives of the restoration strategies employed in the most recent reef projects with the hope that both the process and specific design decisions will be of value to other practitioners. In the spirit of adaptive management, however, the team will continue to improve upon current methods as new information emerges — as those using this guide are also encouraged to do.

FUNDING

Funding is, of course, fundamental to nearly any restoration effort, and the finances of a project can influence how well a team is able to apply a scientifically rigorous adaptive management process. In many cases, financial support is needed up front to adequately evaluate a location and design a good project. However, it can be challenging to make a compelling case for a restoration effort that is not yet fully developed or “shovel ready.” Some restoration funding programs provide separate grants for planning (including design, engineering and permitting) and implementation, which can be very useful in these situations. The case studies in Section VIII describe the unique combination of funding for each reef project.

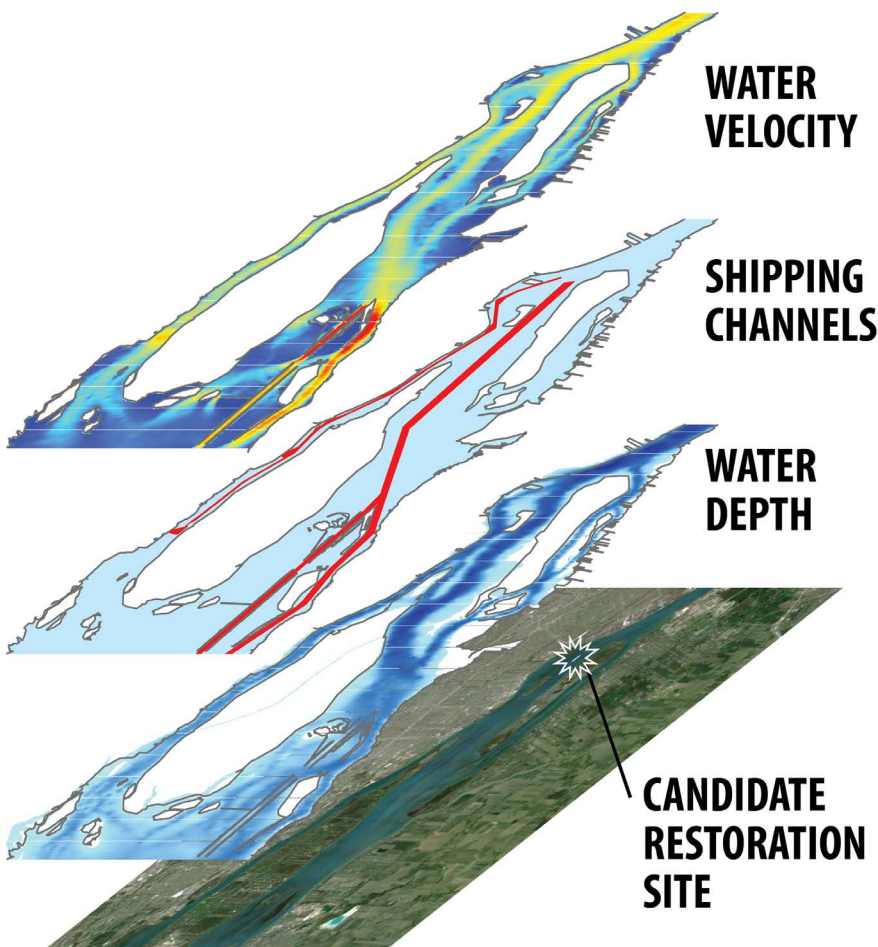
The reef team found it essential to stay in frequent contact with funders and to be transparent if the site assessment uncovered issues that could require a major change in plans. At different turns, funders were able to extend grant periods, so the team could make changes to proposed plans. It can be difficult to openly talk about challenges and delays with funders, but the team found that most would prefer to accommodate delays rather than see money wasted on a poorly planned project. Being open and responsive to new information as it emerges is part of an effective adaptive management process.

SITE PRIORITIZATION

Most ecological restoration is guided by studies of historical habitat — where it existed, how it functioned and what factors helped sustain it. Ideally, restoration efforts address the root cause of degradation and allow the habitat to gradually recover in the place it once existed. However, in the St. Clair and Detroit rivers, spawning reefs could not be created in the places where that habitat had once naturally existed — in areas altered by the construction of shipping channels. Therefore, the reef team was faced with the challenge of finding the next best location to create a reef, ideally in a location fish could find and where the rock would remain relatively free of algae and sediment.

Optimal conditions for fish spawning habitat were identified based on studies of both existing and historical spawning locations for lake sturgeon, walleye and whitefish, which seek out similar habitats (e.g., Goodyear 1982, Manny et al. 2010, Boase et al. 2011). The team also reviewed published studies from other river systems and integrated this information with knowledge of local fish populations (e.g., Auer 1999, Bruch and Binkowski 2002, Kerr et al. 2010).

Many fish have been shown to respond to four variables when selecting where to spawn in river systems: water temperature, depth, velocity, and bottom substrate type (cobble, gravel, sand, etc.). Members of the team developed a GIS model that integrates water depth and velocity and identifies locations that could be suitable candidates for spawning habitat remediation (Figure 17).



Criteria used to Locate Spawning Reefs

- Deep waters, 25-50 feet
- Fast flows, at least 0.5 meters/second, depth averaged
- Outside of dredged navigation channels
- Connected to potential downstream nursery areas
- No known sediment contamination or point sources of pollution
- On the U.S. side of the border for projects funded through U.S. grants.
- In area where sturgeon spawn and/or travel based on telemetry studies
- Smooth, relatively flat, solid bottom with no existing habitat
- Shoreline property owners that are willing to provide permission
- No potential interference to marine navigation

Figure 17. Figure illustrating the geographic information that was combined to prioritize candidate restoration locations.

- **DEPTH.** Depths less than about 14 feet were considered to be of low quality for lake sturgeon spawning habitat because plants are likely to grow on rock in shallower waters, which is known to deter sturgeon seeking spawning grounds. Sturgeon telemetry studies in the St. Clair and Detroit rivers have not found any sturgeon in waters shallower than 9 feet. Interestingly, sturgeon regularly spawn in shallow waters in smaller Great Lakes tributaries, but this is likely because water velocity is higher in the shallow rapids and not because the fish prefer shallow waters. Sturgeon are known to spawn at the head of the St. Clair River where waters depths are over 50 feet and there is heavy freighter traffic. The model gives a higher score to areas where water depths exceed 31 feet because these areas are somewhat protected from the propeller wash of freighters.
 - **VELOCITY.** Studies consistently show that sturgeon seek out fast-flowing water or the highest flow velocities that are available in a given area, presumably because strong currents keep rock clear of fine sediments and help oxygenate eggs. In other systems, sturgeon spawn in waters with velocity between 0.3 to 8 feet/second. The team used predicted water velocities from three different hydrologic models to assign different areas scores based on how suitable each would be for spawning habitat restoration. Flow velocities less than 1.6 ft/s were assigned a value of 1; velocities between 1.6 and 2.4 ft/s were assigned a value of 2; and velocities over 2.4 ft/s were assigned a value of 3.
- The model then assigned a suitability score to areas throughout the corridor, excluding dredged shipping channels. This first level of site prioritization allowed the team to think systematically about the whole corridor between Lake Huron and Lake Erie, and to use an objective, scientifically defensible and efficient process for prioritizing candidate sites and focusing subsequent field investigations.

SITE ASSESSMENT AND SELECTION

Once candidate restoration sites were identified, the team reviewed what was known about each site and began conducting fieldwork at the most likely locations (Figure 18). In some cases, known sources of pollution, such as combined sewer overflow releases or legacy sediment contamination, excluded an area from further consideration. Members of the team were involved in many related fish studies and would use other observations about target fish species to help elevate a potential habitat restoration area. On-site fieldwork was used to: (1) identify any unexpected issues with the site; (2) guide the placement and design of reefs; and (3) provide baseline data for an evaluation of the project's impact.

The field assessment of a proposed restoration area included the following elements:

- **RIVERBED BATHYMETRY:** Existing river-wide surveys were supplemented with single- and multi-beam surveys of the proposed reef area to develop a detailed map of water depth and river bottom topography. Reefs have been sited in relatively flat areas in deep water, where it is too dark for algae to grow. Thick algae growth deters fish that spawn on rocky areas.
- **WATER VELOCITY:** Acoustic Doppler Current Profiler (ADCP) measured flow patterns across the candidate area of river bottom to select a site with steady, high-velocity water flows.
- **RIVER BOTTOM SEDIMENTS:** Sidescan sonar, underwater video, and when possible, scuba dive observations were used to characterize the sediment along the river bottom and to ensure there was no evidence of sediment moving through or accumulating on the river bottom at the site, such as sand ripples. Survey tools were also used to document any existing habitat or structures that should be avoided, such as productive gravel beds, boulders or sunken ships. Reefs are located in areas where currents naturally scour away soft sediments, leaving behind a stable, hard-pan clay bottom with some gravel or zebra and quagga mussels embedded.
- **FISH USE OF THE AREA:** Egg mats were used to assess fish spawning in a proposed restoration area. Some spawning activity by target fish species indicated that the site has the right conditions to attract desired fish and could be suitable for restoration. However, the team was careful to avoid areas with high egg deposition and good rocky or gravel substrate, which might indicate that the site already had productive habitat that could be compromised by establishing a reef.



Figure 18. Assessing of physical conditions at a candidate restoration location. Credit: USGS.

Field assessment data was integrated using GIS to identify specific coordinates for reef placement. In addition, the team consulted with a number of experts, including physical science advisors, permitting agencies and local stakeholders to expose any other potential problems at a site. In more recent projects, the team has done intensive flow modeling, which can indicate how fish larvae might move between a reef site and downstream nursery grounds. Shoreline ownership issues, concerns from the commercial shipping industry and other human uses of the river often led the team to make small adjustments to the reef placement. Additional project planning strategies are explained in detail in Section V, *Avoiding Issues with Navigation and Sedimentation*.

V. Avoiding Issues with Navigation and Sedimentation

ADDRESSING POTENTIAL NAVIGATION CONCERNS

The St. Clair and Detroit rivers form a busy transportation corridor that connects the upper and lower Great Lakes. Deep-draft commercial freighters carrying iron ore, coal, rock, salt and grain regularly pass through, load and unload in the corridor. The Army Corps of Engineers maintains a federal navigation channel that is 27 feet deep throughout the corridor. Some sections of the navigation channel require regular dredging to maintain adequate depth, while other sections are naturally deep enough to accommodate freighters.

The restoration team's goals have been to restore fish spawning habitat within the river system, where thousands of acres of rocky river bottom habitat have been lost. Unfortunately, there are relatively few areas outside of current shipping channels in U.S. waters that meet all requirements for locating a spawning reef. Some of the best conditions for target fish species occur in close proximity to shipping channels, so the potential interaction between freighters and constructed reefs have been carefully considered.

The reef team has sited several projects close to shipping lanes when all other conditions were favorable for spawning.

For example, three pilot spawning reefs built in 2004 at Belle Isle are 21, 42 and 93 feet from the navigation channel. These reefs have not impacted shipping in any way, and the rock has not shifted noticeably in the decade since it was built. A more recent project, the Harts Light reef, is in a naturally deep, narrow section of the St. Clair River that is technically within the federal navigation channel.

To help anticipate and address concerns, the team developed a good relationship with the Lake Carriers' Association, the trade association for Great Lakes-licensed vessels that transport cargo. The team now consults with the Association before finalizing reef location and design.

ANTICIPATING AND AVOIDING SEDIMENT IN-FILLING OF REEFS

Over the past 10 years, the restoration team has learned to create spawning reefs that attract desired fish species and support successful spawning. However, some sections of completed reef projects have become covered in sediment, which limits their value as fish habitat over time. For example, project scientists noticed a significant amount of sand accumulating on the Middle Channel reef just one year after reef construction.

RECOMMENDATIONS RELATED TO FLUVIAL GEOMORPHOLOGY AND SITE SELECTION:	RECOMMENDATIONS RELATED TO HYDRODYNAMICS, SITE ASSESSMENT AND PROJECT DESIGN:
<ul style="list-style-type: none"> • Identify upstream sediment sources • Avoid sediment depositional zones • Consider temporal variability and storm events • Estimate bed load • Look for mobile bed form such as sand ripples • Make use of other available data (e.g., dredging records) 	<ul style="list-style-type: none"> • Map water velocities and bottom substrates • Know the limitations of technology such as ADCP and side-scan sonar • Evaluate alternative reef designs • Consider habitat heterogeneity • Develop computer and physical models

Table 1. List of key recommendations developed at the 2014 reef hydrodynamics workshop.

As a result of this experience, the team now uses a number of specific strategies to evaluate the potential risk of sedimentation before selecting a site and finalizing a project design. Many of these strategies (Table 1) originated from a workshop held in 2014 to solicit advice from scientists with expertise in fluvial geomorphology, hydrodynamics and sediment transport.

The Basics of Sediment Transport

Rivers carry silt and sand through two primary mechanisms — as suspended sediment and bed load sediment. Smaller particles of sediment can be held in suspension by river currents, making a river look muddy at certain times. Sediment, including silt, sand, gravel and boulders, can also

slide, roll or bounce along the river bottom, which is referred to as bed load. Bed load sediment often moves in fits and starts. What looks like a stable bed of sand or gravel on the river bottom could be gradually or sporadically moving downstream.

Features on the river bottom, such as a constructed reef, can create an obstruction that traps sediment. Although bed load sediment is typically a small percentage of all the sediment carried by a river, bed load movement determines the shape and stability of a river channel and likely contributed to the infilling that occurred at the Middle Channel reef. Meaningful field measurements of sediment movement are notoriously difficult; however, the team has learned to look for indicators of sediment problems and to make use of computer models.

FREQUENTLY ASKED QUESTIONS

How will freighters affect a reef?

A passing freighter can create an incredible amount of turbulence in the water. In the Great Lakes, commercial vessels can be 1,000 feet long and weigh nearly 100,000 tons fully loaded (Figure 19). In the corridor, they can reach speeds up to 12 miles per hour, using propellers up to 17.5 feet in diameter. In addition to their physical influence in the river system, commercial shipping is important to the region's economy. Hence, the potential impacts of commercial navigation on reef projects, and the other way around, were carefully considered by the reef team and permitting agencies.

The team reviewed engineering data about propeller wash and scour resistance and determined that 4-8 inch limestone can easily resist water velocities of 3 feet/second, and that speeds up to 6 feet/second should cause minimal, if any, displacement. Reefs are placed in deep water, far enough away from a freighter route that it is very unlikely that propeller wash would be strong enough to dislodge the reef material.

In some places, such as the head of the St. Clair River, lake sturgeon and walleye spawn and fish larvae emerge successfully, despite heavy ship traffic directly overhead. Project scientists find healthy larval fish drifting through even very busy sections of the river system. Lake sturgeon larvae are remarkably resilient and are able to swim against the current and burrow back into gravel, if disturbed, before they are ready to begin drifting.



Figure 19. Measuring water velocity as a 1,000 foot freighter travels the Detroit River. View from freighter and research boat. Credit: UM Water Center and USGS.

Will reef construction and monitoring impact navigation?

Construction and monitoring has occurred without any noticeable impact to navigation. Reef construction has typically taken 6-12 weeks. If rock is placed with a dump barge, the vessel is only on site for a few minutes at a time; if using the crane and clamshell method, a barge is anchored on site during the workday and moved at night. The contractor has followed all standard Coast Guard protocols to avoid conflicts with other vessels, and yielded to commercial freighters as requested.

Reef projects are monitored by experienced fisheries biologists using small research vessels. The research team quickly learned to navigate any potential obstacles at restoration sites when placing or retrieving sampling equipment for monitoring. They have modified some sampling equipment for use in high traffic areas so surface buoys are not needed.

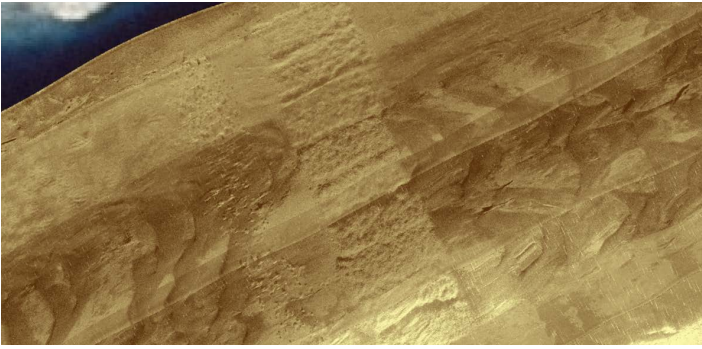


Figure 20. Sidescan sonar images of sand ripples near Middle Channel. Credit: MDNR.

Know Your River System

Rivers can be seen as a complex system with predictable patterns of water flow, water velocity, erosion and deposition. An understanding of how candidate restoration sites sit within the larger geomorphology of the river system has helped the restoration team identify upstream sediment sources, anticipate where sediment is likely to be deposited and evaluate whether modifications to the river bottom are likely to cause sediment to settle and accumulate.

In contrast with other large rivers that are fed by a watershed with many smaller rivers (e.g., the Mississippi or Missouri River), water in the St. Clair and Detroit rivers comes primarily from Lake Huron. As a result, their water is generally clear with less suspended sediment, and water flows are fairly steady from season to season. Although below capacity, the St. Clair and Detroit rivers do transport significant amounts of sediment, as evidenced by the ongoing need for dredging throughout the corridor and the presence of deltas at both river outlets. This means that small variations in water velocity can determine where and when sediment settles out, and reef projects will not necessarily be scoured during seasonally high flows.

Identify Sediment Sources

When considering a site, the reef team looked upstream several miles of the proposed restoration area to identify potential sediment sources, including tributary rivers (especially if there is a sediment plume or shoal at the mouth) or certain land uses (e.g., row crop farming) or surficial geology (e.g., glacial outwash deposits) in the watershed that are likely to generate sediment-laden run-off. Historical patterns can also provide clues. Comparisons of the present river channel with historical maps or images can identify areas that have reformed as a result of significant erosion or deposition, such as islands, banks or shoals that change in size or orientation. Structures intended to control erosion, such as seawalls, can be an indicator as well.

Avoid Depositional Areas

The reef team now uses a variety of tools to inspect the river bottom of a proposed restoration area and to look for indicators of potential sediment problems. Areas with active deposition can usually be identified by the accumulation of sand, clay and organic matter on the river bottom. Waves or ripples in bottom sediments indicate that material is actively moving along the river bottom and could fill in a reef structure.

Survey methods include underwater cameras suspended from a boat, scuba divers, side scan sonar and, when possible, high-resolution multi-beam sonar. Sand ripples — signs of active deposition — can be seen near two of the completed reef projects that experienced sediment buildup; however, these features were too large to be easily detected by underwater video camera and scuba divers (Figure 20). The team has found that a variety of visualization tools are necessary to get both a close look at specific locations and a more expansive scan of the area to identify large features on the river bottom.

Measure Water Velocity Carefully

In general, faster-flowing water has more energy and can carry more and larger particles of sediment. Therefore, erosion typically happens in high-water-velocity areas and sediment will settle out and be deposited in slower moving water. There are many ways to measure and model water velocity and the limitations of each method should be considered.

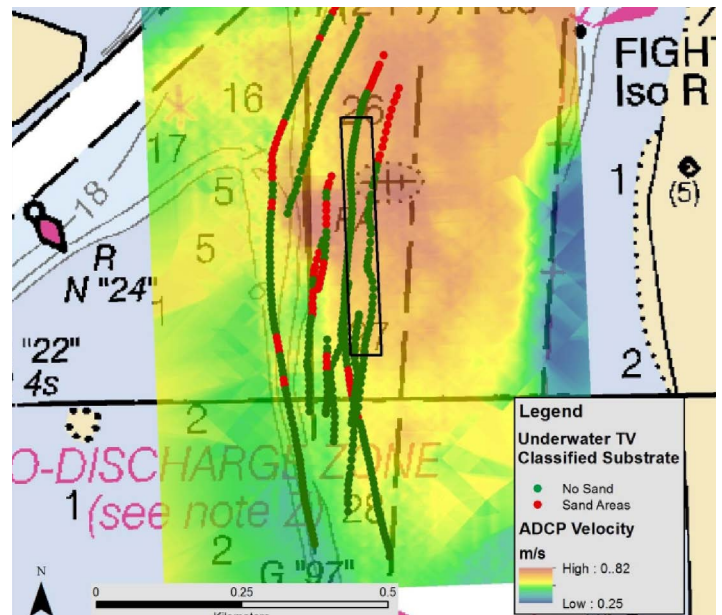


Figure 21. Map illustrating water velocity, substrate classification and proposed reef site. Credit: USGS.

Water Current Meters can be used from a boat to take point measurements at different depths in the water. However, movement of the research boat, the wake of passing boats, and waves that bounce off seawalls can all complicate measurement of water velocity. Heavy meters that are mounted on a winch can minimize these issues and improve the reliability of measurements.

A good picture of water velocity and flow structure at the river bottom is especially valuable for reef siting, but challenging to measure. Near-bed measurements are variable and sensitive to bottom roughness, distance from bottom and measurement techniques. Divers can use handheld meters, but the divers themselves will also change water flow patterns.

The reef team has used an Acoustic Doppler Current Profiler (ADCP), which is a hydroacoustic current meter that measures water velocities throughout the water column similar to sonar (Figure 21). This equipment generates data that require significant expertise and time to process and interpret. Although ADCP measures water velocity at multiple depth intervals simultaneously, near-bed velocities cannot be measured with this method and must be estimated based on water velocities measured higher in the water column.

Look for Changes in Water Velocity

The team has seen that sediment accumulation can vary widely within a single project that consists of multiple reef beds spread across a channel, and have determined that small differences in conditions within a channel can influence a reef's performance over time. This has led the team to make very fine-scale measurements of water velocity and changes in water flow across a proposed site. Small features in the river bed can create turbulence and eddies that drive localized erosion and deposition and cause sediment build-up in a reef.

To guide recent reef projects, partners from USGS ran a series of ADCP transects across a proposed restoration site to create a detailed map of water velocities. They found that tight spacing of ADCP transects, roughly 1/40th of the river width, or 30 to 120 feet apart, is important. This provided a screening tool that can identify indicators of potential sediment problems, such as a localized drop in water velocity or unusual eddies (Figure 22).



Figure 22. Developing physical and computer models to study water flow over constructed reefs. Credit: Aline Cotel (UM).

Use Computer Models

The reef team does not typically measure sediment movement at a restoration site, because it is very difficult to get accurate numbers that account for changes over time. Instead the team is developing sediment transport models for the St. Clair and Detroit rivers in collaboration with the USGS Geomorphology and Sediment Transport Laboratory. The models can be used to predict sediment deposition at different locations and simulate the potential impact of storm events. So far, these models have been able to explain observed sedimentation patterns at the Fighting Island reef and evaluated sedimentation at the Harts Light reef location where a scuba diving survey was not possible.

In addition, reef project partners from the University of Michigan College of Engineering are developing physical and computer models to examine how water flows over simulated reefs. The computer model will test different designs for a proposed restoration area, taking into account the area's unique bathymetry, river morphology and flow patterns. A flume and water tunnel will be used to visualize water flow patterns and measure shear stress over an experimental reef. The team is evaluating how sediment dynamics might be affected by different reef shapes, such as ramp or airfoil reefs, longer or shorter reef beds, or different degrees of reef surface roughness.

Apply Lessons Learned

Re-creating natural habitats in a dynamic and highly altered river system is inherently complex. River hydrology and sediment dynamics are particularly hard to measure and predict accurately and often lead to unexpected outcomes when restoring river habitats. Through ongoing monitoring and collaboration with physical scientists, the reef restoration team has significantly improved their reef siting and design process and improved the long-term performance of constructed reefs. The tips and models the team has developed could be applied to a range of river restoration efforts.

VI. Project Permitting, Construction and Monitoring



Figure 23. Crane and clamshell used to place reef material.



Figure 24. Dump barge used to drop reef material.

REEF DESIGN

Project design engineers worked with the biologists and field scientists to apply lessons from earlier projects, and to optimize reef dimensions for each particular location and budget. It was often an iterative process. For example, earlier projects consisted of multiple reef beds spread across a channel to maximize the chances of fish finding them. However, the cross-channel design placed some reef beds in areas with sub-optimal water velocities. Projects involving complex reef shapes and multiple rock types are also more expensive. The team found that some economy could be achieved through larger or bundled projects that minimize costs of transporting equipment and materials to the site.

The most recently constructed projects consist of a single reef bed, covering 1.5 to 4 acres of river bottom. The reefs were designed as a long, narrow rectangle, oriented parallel to water flow, with relatively low vertical relief (about 2 feet thick). This design minimizes disruption to water flow so water moves smoothly over and around the reef. Sustained high velocities help wash away fine sediment and maintain clean interstitial spaces. Reefs are 2 feet thick in order to create adequate interstitial spaces for eggs to settle into and

remain both aerated by flowing water and protected from predation and dislodgement. In other rivers, scientists have found that fish eggs survive and hatch at a higher rate when deposited on rock rubble at least 12 inches thick and free of sediment, algae and mussels (Kerr et al. 2010).

REEF CONSTRUCTION

For each reef project, the reef team selected a marine construction contractor through a competitive bidding process, and as part of the request, bidders proposed the most suitable rock placement methods and rock sources. Even at this stage, project plans can (and did) change. Contractors can often identify small modifications to the project design that allow more cost-effective rock sourcing or placement.

Rock for the case study projects (highlighted later in this publication) was placed using one of two methods: some projects were built using a GPS-guided clam shell bucket and crane mounted on a barge that is anchored on site during the work day; rock for other projects was dumped on site by a side or bottom dump barge and then smoothed using a steel beam (Figures 23 and 24). A variety of survey methods ensured that rock placement is uniform and precise.

The clam shell placement has been more precise and is capable of producing a more complex reef shape. The contractor can easily monitor rock placement and create a map showing exactly where rock has been placed. However, this method is much slower and was not suitable at the Harts Light Reef site where the water depth and freighter wakes made anchoring on site very difficult. The dump barges produced a lumpier reef that needed to be smoothed and carefully surveyed.

The team has made a number of changes to the reef design, construction specifications and bidding process over the years. For example, during the bidding process, contractors are now told the desired rock and reef dimensions, and then must calculate the needed tons of rock, select a quarry, and propose a rock transport and placement method. Reef project plans specify how much the reef alignment and shape can deviate from drawings to accommodate cost-effective construction methods, while still benefitting fish.

ROCK SIZE AND TYPE

The team experimented with a number of rock types during early reef projects, including round fieldstone; quarried, angular limestone; coal cinders; and mixtures of different rock types. Monitoring has found that target fish species do not have a consistent preference for the different rock types tested. However, the potential for constructed reefs to support undesirable invasive species has emerged as an important consideration. Sea lamprey build nests in gravel that is less than 1-2 inches in diameter (Applegate 1950, Wigley 1959), and round goby seek out the crevices within piles of large rock. To avoid creating desirable habitat for such invasive species, 4-8 inch angular limestone has been used for recent projects, which is typically produced by local quarries specifically for the reef projects (Figure 25). Using larger quantities of a single rock type has brought down costs.

PERMITTING AND LANDOWNER CONCERNS

Reef projects in the St. Clair and Detroit rivers have each undergone a long and explicit review process, including state and federal permits to place structures in the river. In addition, because these waters are governed by the 1909 Boundary Waters Treaty, a formal consultation with U.S. Department of State and Canadian Department of Foreign Affairs was required to ensure no potential impacts to water levels and flows. Depending on the origin of the construction funds, a formal compliance process under the National Environmental Protection Act may also be required. When possible, the team anticipated concerns and consulted with

stakeholders prior to permitting. Some common concerns and the team's response are described in more detail in the following section.

The Michigan Department of Environmental Quality and U.S. Army Corps of Engineers require permits to establish spawning reefs on river bottomland. Permits are necessary to fill or place structures within the rivers, under the provisions of the Natural Resources and Environmental Protection Act 451,P.A. 1994, Part 301 Inland Lakes & Stream, Part 325 Submerged Lands, and Section 404 of the Federal Clean Water Act, and Section 10 of the Federal River and Harbors Act of 1899. Permit applications must include a description of the project purpose, site selection criteria, alternatives considered and spawning reef plans.

As part of the state permitting process, the project team had to demonstrate support from all adjacent shoreline property owners. Unlike Great Lakes bottomlands, which are owned by the state, the bottomlands of inland lakes, rivers and Great Lakes connecting channels are technically owned by adjacent shoreline property owners. Although these riparian rights are limited, shoreline property owners must provide permission for projects like the development of a fish spawning reef. For projects adjacent to municipal parkland, only a single letter of permission was needed from the township or city.

Two reef projects have been sited adjacent to private homes and coastal businesses (Harts Light reef and Grassy Island reef). In both cases, the team sent letters and a permission form to all adjacent homes, knocked on doors of homes that did not respond, and made phone calls whenever a number could be located. The support of a local partner was invaluable when visiting homes and explaining the relevance of a project to indifferent or skeptical homeowners.



Figure 25. Quarried limestone, 4 – 8 inches in diameter, used for recent spawning reef projects.



Figure 26. Graduate student from the University of Michigan studying juvenile fish in areas downstream of a constructed spawning reef.

Before construction, the team sent a note to all landowners, letting them know when construction would begin and what to expect. Outreach specialists also posted fliers and project FAQs at marina bait shops and municipal offices as construction was beginning. Ongoing engagement with local residents was key to several of the projects and kept the surrounding community connected and invested in the projects. For example, two residents alerted the team and helped deter a proposed pipeline project that would have passed directly under a completed reef project.

As part of the federal permitting process, the Army Corps issues a public notice for every permit application, allowing interested parties to submit comments and concerns. Knowing that certain groups, such as the Lake Carriers' Association, are likely to comment on spawning reef permit applications, the project team began consulting with them in advance of submitting a permit application. For more details, see Section V *Avoiding Issues with Navigation and Sedimentation*.

BIOLOGICAL MONITORING

Rigorous pre- and post-restoration monitoring has allowed the team to learn from past experiences and improve scientific understanding of fish ecology and spawning habitat remediation over time. A number of partners contribute to reef monitoring, including scientists from the U.S Geological Survey (USGS), U.S. Fish and Wildlife Service (FWS), the Michigan Department of Natural Resources (MDNR) and the University of Michigan. In some cases, additional assessment of juvenile fish communities, spawning and nursery habitat linkages, fish population genetics, and fish movements using telemetry, were included when funding allowed (Figure 26).

The reef team typically collected at least one year of baseline data and two years of post-construction data at each habitat restoration site, including an evaluation of biological activity and physical factors. The reef site and a control area were monitored both before and after construction, following a Before After Control Impact study design. Statistical techniques were used to separate the impacts of the reefs from natural year-to-year variation in fish populations.

The following provides a brief summary of the core monitoring and assessment program for each reef project.

PHYSICAL ASSESSMENT: As described in Section V, the team has used a variety of equipment, including sonar, underwater video, and an Acoustic Doppler Current Profiler, to evaluate water flow and characterize the river bottom before and after reef development. Video and direct observations through scuba diving helped evaluate movements of river bottom substrates, the accuracy of the reef rock placement, and the condition of the reefs over time.

ADULT FISH USE OF REEF AREA: Partners from the FWS led the assessment of adult fish use of the project area using set-lines, gill nets and trap nets before and after reef development (Figure 27). Fish communities were assessed for multiple weeks during the spring and fall spawning season. This information allowed the team to evaluate which fish were using the reef, which fish were “spawning ready” when visiting the reef, and how the reef changed fish use of the area.



Figure 27. Team from the FWS assessing adult fish use of the spawning reefs using setlines. Credit: FWS.

FISH EGG DEPOSITION: USGS scientists developed a unique method for measuring fish egg deposition in large, busy rivers like those of the St. Clair-Detroit River System (Roseman et al 2011b). Egg mats were made by wrapping furnace filter material around a metal frame and were placed on the river bottom without using a buoy that could get tangled in boat propellers (Figure 28). Before and after reef establishment, egg mats were placed at three locations within a 1 mile stretch of river: above, on and below the reef site. The team measured the egg mats on a weekly basis through the spring and fall spawning seasons.

Mats were brought to the water surface and fish eggs were picked off, counted and brought back to the laboratory for incubation and identification when fish larvae emerge. Measures of egg deposition by species, per area, throughout the season provided an excellent indicator of spawning activity on the reef and in the surrounding area.

LARVAL FISH PRODUCTION: USGS scientists used bongo nets and D-frame drift nets to evaluate the numbers and types of fish larvae emerging and drifting off the reef (Figure 29). Nets were deployed in the evening when larvae typically begin drifting, and samples are collected every two hours. Fish larvae estimates are essential for evaluating whether a reef environment adequately incubates eggs and allows eggs and larvae to survive — a challenging aspect of fish habitat remediation and evaluation that is sometimes overlooked. Partners are continually seeking additional ways to track the survival of larvae and juveniles after they leave the spawning reef environment and show the impact of restoration beyond the larval stage.

LINKS TO AGENCY MONITORING PROGRAMS: State, federal and provincial partner agencies have long-term, system-wide, monitoring programs that can help inform restoration planning and evaluate population-level impacts. Long-term monitoring is especially important for looking at long-lived, slow-to-mature species such as lake sturgeon. For example, the Michigan Department of Natural Resources has been monitoring lake sturgeon populations in the St. Clair River and Lake St. Clair since 1996 (Thomas and Haas 2002).

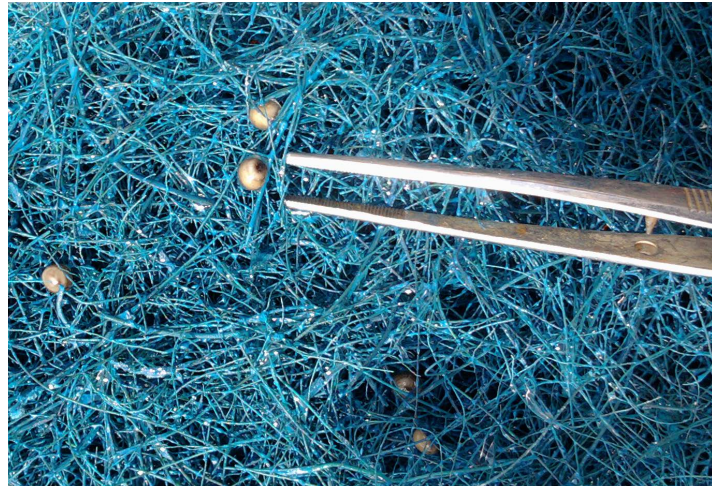


Figure 28. Using tweezers to pick fish eggs from an egg mat that is used to assess spawning activity. Credit: USGS.



Figure 29. Team from the USGS collecting larval fish as they drifted downstream from a spawning reef.

VII. Selected Results and Outcomes

PROJECT RESULTS

In 2004, the restoration team established its first pilot spawning reef project near Belle Isle in the Detroit River. The team has now developed three spawning reef sites in the St. Clair River and three sites in the Detroit River, with two additional locations possible as part of the Detroit River remediation plan to restore fish and wildlife habitat and populations. Each project generated important lessons about fish spawning, habitat restoration, and adaptive management. The final section of this report includes detailed case studies of each reef project and the team has produced a number of related scientific papers.

Pre- and post-restoration monitoring is revealing how different fish use the constructed reefs. Monitoring egg deposition on reef sites *prior* to restoration found no or very limited signs of sturgeon spawning. After the reefs were built, sturgeon spawning was confirmed on four of the five constructed reefs — a sign the projects are successfully attracting spawning ready adults (Table 2). Larval fish sampling has found viable young sturgeon drifting downstream from all the reef projects where sturgeon eggs

were documented (Bouckaert et al 2014). However, sturgeon larvae are often observed upstream as well as downstream, making it hard to pinpoint where the larvae originated.

Many other fish species have been observed using the reef projects — 18 native fish species have shown signs of spawning activity, and another 15 species have been found using the reefs in other ways (Table 3). Project monitoring documented the return of lake whitefish spawning runs to the Detroit River, which had not been observed in 80 years (Roseman et al. 2007). Walleye, a popular sport fish, also uses the spawning reefs, though the benefits of artificial reefs for walleye and lake whitefish are not conclusive (Manny et al. 2010). In addition, northern madtom, a small fish that is listed as endangered in Michigan, has been found on the reefs, prompting the team to do more targeted studies (Manny et al. 2014). Initial results are promising; however, it will take many years and a multi-faceted monitoring effort to determine if the spawning reefs are increasing fish populations in the river system.

REEF PROJECT NAME	BELLE ISLE	FIGHTING ISLAND	MIDDLE CHANNEL	POINTE AUX CHENES	HARTS LIGHT	GRASSY ISLAND
Project Specifications						
River	Detroit	Detroit	St. Clair	St. Clair	St. Clair	Detroit
Community	Detroit, MI	La Salle, ON	Clay, MI	Algonac, MI	East China, MI	Wyandotte, MI
Year Built	2004	2008, 2013 (expanded)	2012	2014	2014	2015
Size (acres)	0.3	2.0	1.0	1.5	3.8	4.0
Lake Sturgeon Spawning Observations						
Before Restoration	Absent	Absent	Absent	Absent	Few eggs	Absent
After Restoration	Adult fish, but no spawning detected	Spawning confirmed	Spawning confirmed	Spawning confirmed	Spawning confirmed	No data yet

Table 2. Reef project specifications and lake sturgeon spawning observations.

Recommendations for Monitoring

Comprehensive monitoring of restoration is an essential but often under-funded and poorly implemented aspect of adaptive management. As a result, it can be hard to determine the effectiveness and performance of a restoration action and improve management over time. Based on the team's experiences and reviews of other reef projects, a few recommendations have emerged for monitoring reef restoration projects (McLean et al. 2015).

Recommendations:

- Develop reef monitoring programs that match the spatial and temporal extent of the biological responses and physical stressors. For example, monitor fish larvae at multiple points downstream of a spawning reef to determine larval survival.
- Monitor the physical, as well as biological changes in reefs. This includes rock movement, sediment accumulation and growth of algae on the reef over time.
- Standardize biological and physical monitoring and methodology to allow for comparisons among reefs and through time. This means coordinating with other restoration teams in the region and striving to secure agency support for consistent, long-term monitoring.
- Measure quantitative response variables, not just qualitative variables of the constructed reefs. For example, in addition to visually inspecting a reef, also measure the depth of sediment within the reef rock.

Broader Impacts

While most people will never see a constructed spawning reef on the river bottom, the projects are contributing to river-wide restoration efforts with real benefits for communities. Based on these and other remediation projects, the St. Clair River is ready to be removed from the list of Great Lakes Areas of Concern. The St. Clair River has a popular catch and release and limited-take fishery for lake sturgeon, which attracts anglers from around the region. This unique fish has become an important part of the region's identity and Clay Township has submitted a formal request to become known as the "Sturgeon Angling Capital of Michigan." The gradual recovery of lake sturgeon and other native fish serves as an important symbol of how urban rivers can be restored and people can connect with their unique natural resources.

	Belle Isle	Fighting Island	Middle Channel	Pointe Aux Chenes	Harts Light
Fish that show signs of spawning activity on reefs					
Black redhorse*		■			
Emerald shiner	●		▲		
Golden redhorse*			■	▲	
Lake sturgeon	■	●	● ▲	●	●
Lake whitefish	●	●			
Northern hog sucker*	● ■			▲	
Quillback*	●	■			
Rock bass	■	▲	▲	▲	▲
Round goby (non-native)	▲	● ▲	▲	▲	▲
Shorthead redhorse*	● ■	▲	■	▲	▲
Silver redhorse*	● ■	■	■	■	
Smallmouth bass	▲	■			
Stonecat		▲	■		▲
Trout-perch	●	●			
Walleye	● ■	● ■	● ■	● ■	● ■
White bass ^	■	■	■		
White perch (non-native) ^	■	■			
White sucker*	● ■	■	■	■	■
Fish that seem to be using the reefs in other ways					
Burbot		▲		▲	▲
Channel catfish		▲			
Common carp					▲
Creek chub			▲		
Darter			▲		
Gizzard shad	▲			▲	
Logperch	▲				
Mudpuppy		▲	▲		
Northern madtom	▲	▲	▲		▲
Northern pike	▲				
Slimy sculpin			▲		
Spottail shiner		▲	▲		
Tube-nose goby	▲		▲		
Yellow perch	▲	▲			

- Eggs deposited on mats placed on reef
- Spawning ready adults caught on reef
- ▲ Other adults or juveniles observed on reef

Table illustrates species caught on spawning reef sites between 2005 and 2015, after construction. Observations are influenced by sampling methodology and effort, which varies from site to site.

* A variety of sucker eggs were found at all reef sites, but were not usually identified to species, and therefore were not included in this table.

^ White bass and white perch eggs were found at sites with spawning ready adults, but eggs were not identified to species and were not included in this table.

Table 3. Fish species and different life stages observed on reef projects.

VIII. Spawning Reef Project Case Studies

Each fish spawning habitat remediation project has generated important lessons that have been applied in subsequent projects through the adaptive management approach. Beginning with the team's first spawning reef project constructed in 2004, the restoration team only pursued projects that allowed for adequate pre- and post-construction monitoring of environmental variables and fish populations, knowing there would be many lessons to learn. As a result, the team has advanced understanding of the needs and preferences of target fish species in the river system and improved techniques for monitoring restoration projects.



Figure 30. Belle Isle reef project layout.

BELLE ISLE REEF, DETROIT RIVER

YEAR COMPLETED: 2004

Overview

In 2001, Michigan Sea Grant began working with a small team of scientists interested in restoring habitat for lake sturgeon and other native fish with similar spawning habits in the Detroit River. Project partners had just completed an assessment of 12 reputed spawning sites in the river and found they were not suitable to sustain river fish populations due to siltation, lack of suitable rock rubble or inadequate flows (McClain and Manny 2000). The team decided to

re-create some of the rocky substrate that had been lost or degraded over time by building and studying a pilot fish spawning reef. The project also included outreach activities designed to increase public understanding of native fish species and the impacts of habitat loss in the Detroit River.

FUNDING: The team received a NOAA Great Lakes Restoration Grant through the Michigan Coastal Management Program and a supporting grant from the Great Lakes Fishery Trust, which altogether provided \$422,000. The team additionally leveraged significant in-kind support from DTE Energy (a utility company) and project partners for construction, assessment and outreach.

PLACEMENT: Three fish spawning reefs were constructed along the southeastern shore of Belle Isle, adjacent to a dredged navigation channel (Figure 30). The closest reef bed is just 21 feet from the navigation channel. This site was selected for a number of reasons, including:

- It had clean, fast-flowing waters from Lake St. Clair.
- The river bottom was hard, flat and devoid of existing habitat structures.
- It was deep enough that light penetration was limited and no algae growth was expected.
- It was close to Peche Island, where former known sturgeon spawning grounds had been degraded by human activities.
- It was adjacent to public lands, which could have facilitated land-based construction methods had they been necessary.

DESIGN: This pilot project included three rocky reef beds, each 160 x 259 feet, and about 2 feet thick. Each bed was made of different rock types known to support lake sturgeon spawning in other locations: 1-3 inch coal cinders, 16-24 inch broken limestone, and 6-10 inch rounded cobble stone (Figure 31). Boulders were placed at the head of each reef bed to protect it from ice scour.

BIOLOGICAL OBSERVATIONS: Prior to reef development, the study area was little used by fish and few spawning-ready adults or fish eggs were collected. After reef establishment, 14 species of native fish were found to spawn on the reef, based on collections of adult spawning-ready fish or eggs deposited on egg mats (and subsequently hatched and identified in the lab).

Native fish using the reef included; lake whitefish, northern pike, emerald shiner, quillback, white sucker, northern hog sucker, silver redhorse, shorthead redhorse, trout-perch, white bass, rock bass, yellow perch and walleye. Two invasive species also used the reefs: white perch and round gobies. One spawning-ready lake sturgeon was caught on one of the reefs, but, to date, the team has not been able to document sturgeon spawning. Egg mats have been placed on the reefs nearly every year since the project was established and spawning by whitefish, walleye and several sucker species have been documented on the reefs most years.

PHYSICAL OBSERVATIONS: After more than 10 years, these reefs remain relatively clear of algae, silt and mussels, and continue to attract spawning fish. However, boulders placed at the head of each reef bed cause water currents to slow and sediment to settle into the reef immediately behind the boulders. All reef rock remains in place, despite proximity to passing freighters.



Figure 31. Jennifer Read and Bruce Many on Belle Isle construction barge.

Lessons Learned

PROCESS LESSONS LEARNED: The location originally proposed in grant applications was deemed unsuitable and the team had to select a new site, revise the anticipated construction methods and reduce the project scope to fit within the budget. The team became skilled at working with construction contractors, permitting agencies, industry partners such as DTE Energy, and funders to come up with creative solutions and re-work the project design. The team learned to be candid with funders about challenges and potential project changes, realizing that project success was ultimately more important than completing a project within a specific timeline.

TECHNICAL LESSONS LEARNED: The pilot project demonstrated that artificial substrate could support spawning for a range of fish species, but lake sturgeon might be harder to attract than anticipated. The team hypothesized that a larger reef project located closer to a known spawning site would be easier for sturgeon to find and use, and both of these attributes were incorporated into plans for the Fighting Island reef. Instead of focusing on a singular species, future projects were also promoted as native fish restoration efforts, based on the diversity of fish using the Belle Isle reef.

Reef material remained in place despite ice movements, river currents and ship traffic, so future projects were designed without the protection of boulders or armor stones at the upstream end of reefs. Coal cinders donated by DTE Energy were found to be attractive to native fish, but this material is no longer available.

OUTREACH LESSONS LEARNED: Although the reef was designed for lake sturgeon, the discovery of lake whitefish eggs, the first documented in nearly 80 years, led to a large-scale press event including legislators, agency leaders, school groups and project partners. What could have been considered a negative (lack of sturgeon spawning) was turned into a positive, allowing us to further our outreach goal of increasing awareness of native fish species and their habitat needs.

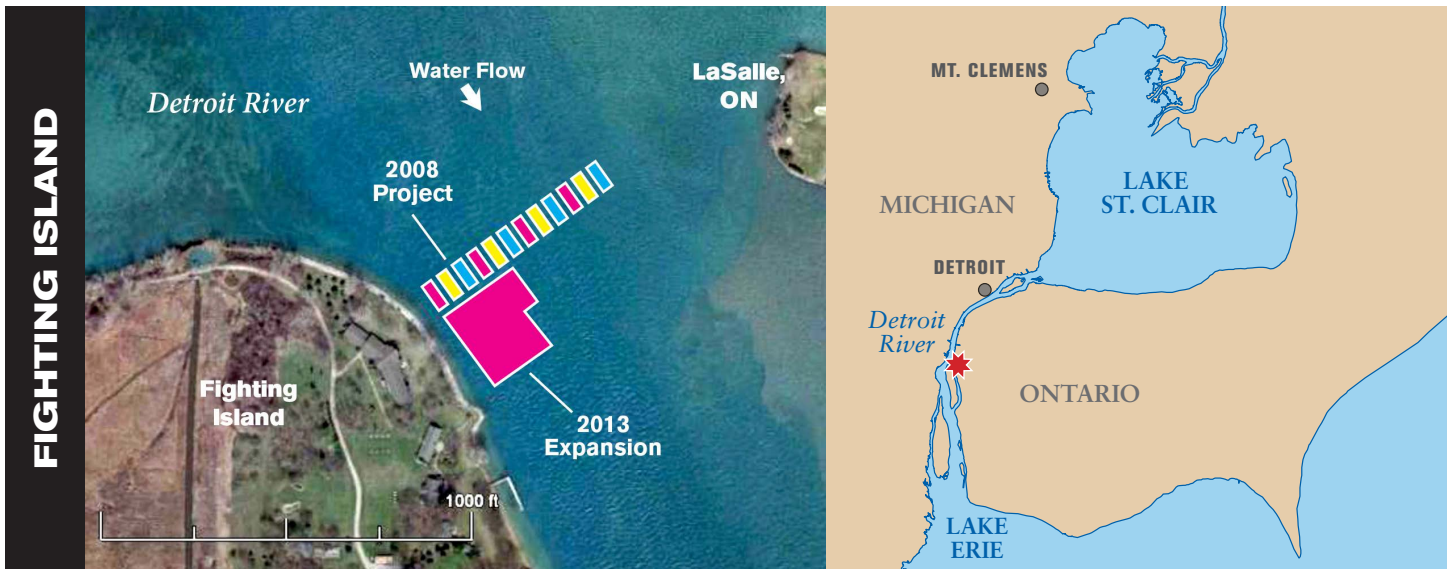


Figure 32. Fighting Island reef project layout.

FIGHTING ISLAND REEF, DETROIT RIVER

YEAR COMPLETED: 2008, EXPANDED IN 2013

Overview

This project was completed in Canadian waters of the Detroit River, and the project was managed by different partners than the U.S. reef projects. The Essex Region Conservation Authority (ERCA) and Ontario Ministry of Natural Resources (OMNR) led the project. Scientists at the United States Geological Survey (USGS) and the U.S Fish and Wildlife Service (FWS) and an outreach specialist from Michigan Sea Grant were also partners. The team developed a reef restoration plan that incorporated lessons learned through the Belle Isle project, creating a larger project closer to a known sturgeon home area. Outreach plans included interpretive signage on both sides of the Detroit River and public events.

FUNDERS: The team pieced together funding from a number of sources, including Environment Canada, OMNR, DTE Energy, BASF (a chemical company) and Michigan Wildlife Conservancy for a construction budget of approximately \$200,000. Engineering and field assessments were completed by partners without dedicated funding.

PLACEMENT: Twelve experimental reef beds were constructed across the river channel between La Salle, Ontario and Fighting Island (Figure 32). This area was selected because lake sturgeon were known to inhabit the area and to spawn nearby.

DESIGN: The initial project included 12 reef beds that were spread across the channel to maximize the chances that fish would pass over and find the reefs. The reef beds were each 36 x 82 feet and were made of one of four rock types: 4-20 inch limestone; 2-4 inch limestone; natural rounded stone; and a mixture of these three materials. Boulders were scattered in the area downstream of the reefs to provide shelter for fish to aggregate and find refuge from the currents.

In 2013, the five beds closest to Fighting Island were expanded using 6-12 inch stone. The updated reefs measured 187 x 233 feet and did not include a downstream boulder field.

PHYSICAL OBSERVATIONS: The reef beds constructed in 2008 that are closest to the Canadian mainland became covered in sediment within a couple years. Sediment is thought to originate from the Thames River and be carried along the eastern shore of the Detroit River. However, the beds closest to Fighting Island remain relatively free of silt, algae and mussels. The head of Fighting Island diverts and accelerates water flow, helping clean reef beds in the area immediately downstream and adjacent to the head of the island. This information guided the 2013 project expansion that extended the five reef beds closest to Fighting Island.



Figure 33. A graduate student from Michigan Technological University caught and studied sturgeon larvae drifting off of the Fighting Island reef. Credit: USGS

BIOLOGICAL OBSERVATIONS: Pre-construction assessments found that only walleye and lake whitefish spawned in the area. After the reefs were developed, 11 species of adult fish were collected during the first spawning season. The fish collected and observed included an increased abundance of northern madtom (an endangered catfish species) and the first documented spawning by lake sturgeon on a man-made reef in the Detroit River.

During most years after reef development, the project team has collected spawning-ready adult lake sturgeon, viable lake sturgeon eggs and lake sturgeon larvae on the reef (Figure 33). The team also found adults and eggs of walleye, lake whitefish, trout-perch and various sucker species on the constructed reefs. Lake whitefish preferentially spawn on the natural gravel areas near the reef, rather than on the rock rubble of the spawning reef (Roseman et al. 2011a, Bouckaert et al. 2014).

Lessons Learned

PROCESS LESSONS LEARNED: The Fighting Island reef project was created by a unique binational collaboration that incorporated private funders and many government entities. The project demonstrated that an ambitious restoration effort could be accomplished with limited funding when many agencies and organizations are able to dedicate some staff and equipment to advance a shared mission. However, without dedicated funding resources, physical and biological assessment did not occur consistently every year after construction.

As a result, the team did not yet know how sediment was affecting the reef when design work began on the Middle Channel reef project. This project emphasized the importance of timely physical assessment to inform the adaptive management process.

TECHNICAL LESSONS LEARNED: Proximity to known sturgeon spawning sites emerged as an important siting consideration. The team adopted a more rigorous assessment program and reduced the use of buoys to improve monitoring in high traffic areas. The team began carefully evaluating the habitat value of existing substrate after realizing that lake whitefish would spawn on constructed reefs when the native river bottom was primarily clay, but they would preferentially spawn on natural gravel areas, if available. Monitoring of project sites gradually grew into system-wide, long-term monitoring of the rivers.

OUTREACH LESSONS LEARNED: Plans for the installation of interpretive panels were eliminated due to limited funding. However, Michigan Sea Grant and ERCA were able to provide in-kind staff time to begin development of content, photos and other information for signs. This became useful a few years later when both agencies were able to secure money for construction and installation of the signage.

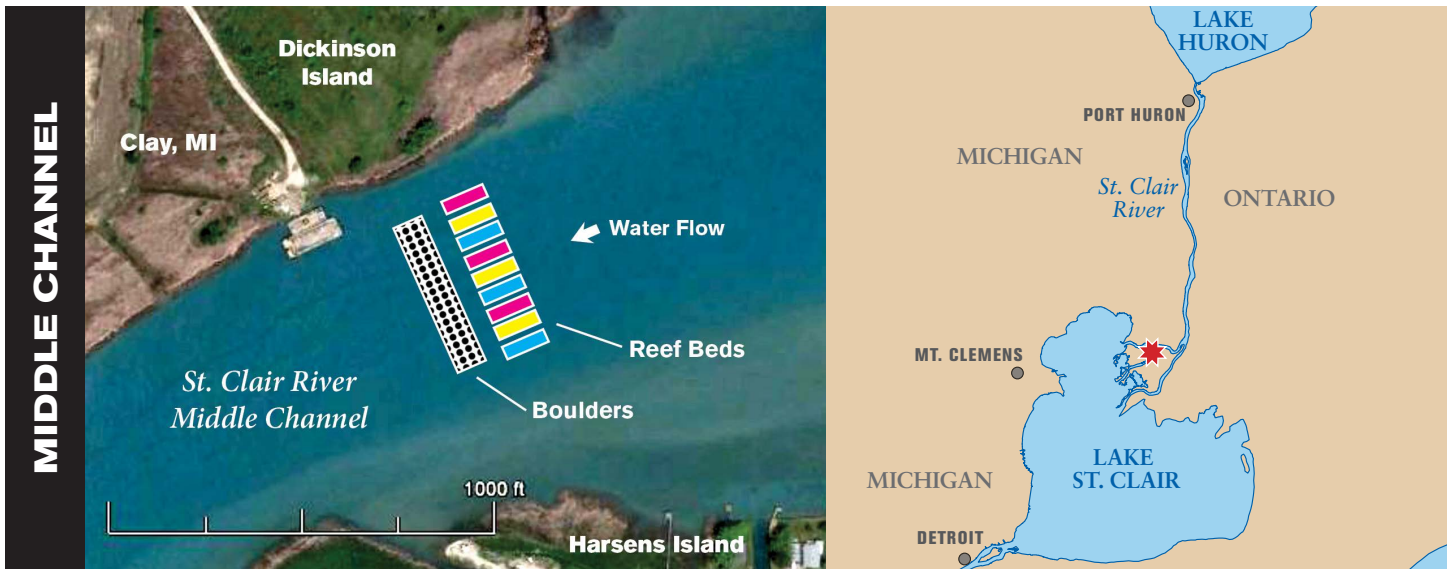


Figure 34. Middle Channel reef project layout.

MIDDLE CHANNEL REEF, ST. CLAIR RIVER

YEAR COMPLETED: 2012

Overview

In 2009, the team began planning their first reef restoration project in the St. Clair River. Lake sturgeon numbers were higher in the St. Clair River than the Detroit River, but both rivers experienced similar types of habitat loss and degradation. Lake sturgeon were known to spawn on a small pile of coal cinders near Algonac, Michigan. The team hoped to improve fish reproduction by expanding the available high-quality habitat near Algonac, with the objective of boosting sturgeon populations throughout the St. Clair-Detroit River System. To be competitive for restoration grants, the team secured permits in 2009, using a reef design similar to that of the 2008 Fighting Island reef project.

FUNDING: The team received grants of \$1.1 million from the NOAA Restoration Center and the U.S. FWS Coastal Program and leveraged additional support for pre- and post-

assessment, all of which was connected to the federal Great Lakes Restoration Initiative.

PLACEMENT: The project was located in the Middle Channel of the St. Clair River, in the upper reaches of the delta. This location met the siting criteria identified in earlier projects (deep, clean, fast-flowing waters, stable river bottom with no existing fish spawning habitat, etc.). It also had a few additional advantages:

- No commercial shipping traffic.
- Sturgeon were known to spawn nearby in the North Channel.
- It was immediately upstream of a large wetland complex that could provide nursery habitat for young fish produced on the reef.

DESIGN: The project included nine reef beds spread across the channel (Figure 34). This layout was believed to increase the chances a sturgeon would find the new habitat. Each

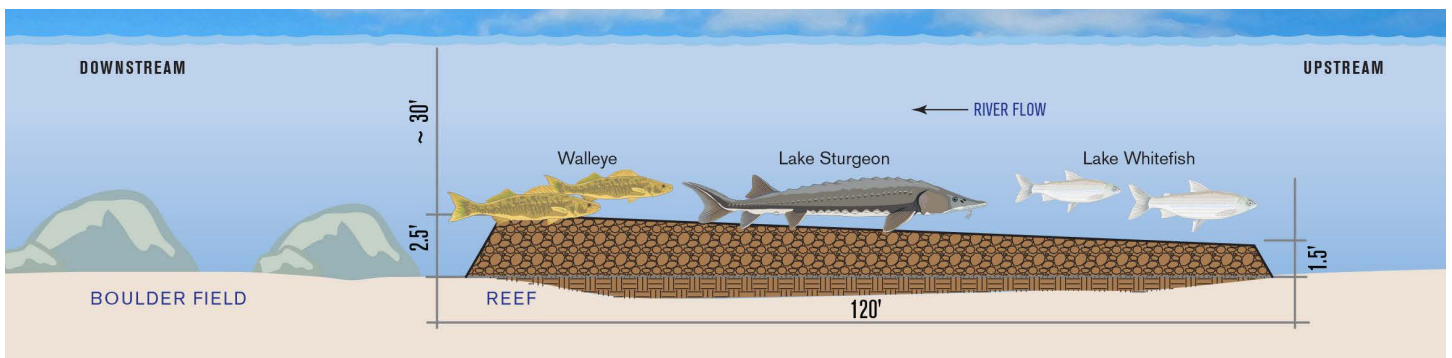


Figure 35. A cross section diagram illustrating the sloping shape of each reef bed in the Middle Channel project (not too scale).

reef bed was 120 x 40 feet and sloped gently from 1.5 feet thick at the upstream end to 2.5 feet at the downstream end (Figure 35). The sloping, wedge shape was expected to force water to speed up slightly as it moved over the reef and scour away sediment. Each reef bed was built from one of three rock types: 4-8 angular limestone, 4-6 inch rounded field stone, and mixture of the two — which allowed the team to experimentally test the advantages of different rock types and placements within the channel. About 200 boulders were placed immediately downstream of the reef beds to provide fish a refuge from the currents.

BIOLOGICAL OBSERVATIONS: Prior to reef construction, 20 fish species were observed at the site, but few eggs were collected, indicating little if any spawning activity. Lake sturgeon were observed spawning on the reef as the project was being constructed, an exciting observation for the team! In both 2012 and 2013, sturgeon, walleye and white sucker eggs were collected on the reef, and viable sturgeon larvae were documented downstream of the reef. Time and additional research will be needed to track these young fish and show the project's impact on juvenile and adult fish communities.

PHYSICAL OBSERVATIONS: Project scientists have used scuba divers, side scan sonar and underwater cameras to monitor the condition of the reef beds over time. Sand began filling in the spaces between the rocks in the year following construction, and roughly half of the reef area appears to be covered in sand. This has led the team to wonder if they missed indicators of sediment movement during the preliminary site assessment. Subsequent reexamination of the river bottom within one mile of the reefs revealed sand ripples or dunes that are indicative of active sediment movement and were missed during initial pre-assessment video surveys. Super Storm Sandy hit the region in fall of 2012, which created massive waves in Lake Huron, noticeably eroded shorelines, created unusually turbid waters in the St. Clair River and likely increased the amount of sediment movement in the area.

Lessons Learned

PROCESS LESSONS LEARNED: To make the project appear “shovel-ready” to funders, the team secured permits several years before receiving grant funding. Although the team made small design adjustments before construction, they did not re-visit the choice of location or the cross-channel layout of the proposed reef in order to keep the project on schedule. In retrospect, closer review of the site assessment data and more information from similar reef projects could

have helped the team better anticipate sediment in-filling problems. For example, the Fighting Island reef project employed a similar design and also experienced sediment accumulation, but results from this project were slow to emerge and were not ready in a format that could have influenced the Middle Channel project.

After realizing that more sediment was accumulating in the Middle Channel reef than expected, the team convened a workshop to solicit the advice of experts in sediment transport and hydraulic engineering. As a result of these experiences, the team has grown to include more physical scientists and the group now formally reviews available data and evaluates design decisions at several points in the project development process.

TECHNICAL LESSONS LEARNED: The project's success at attracting its target fish species and supporting successful spawning validated many of site selection and project design decisions. However, the condition of the reef rock material has degraded over time, which has likely reduced the quality of the habitat for spawning by some fish species. The project demonstrated that small differences in reef placement within a channel can dramatically affect the performance of the habitat, and analysis of fine-scale physical conditions at a proposed reef site, as well as the area several miles upstream, is essential.

The team has significantly enhanced the site selection and assessment processes to ensure that they understand potential sources of sediment, where sediment is regularly deposited and whether modifications to the river bottom are likely to cause sediment to settle. The team has learned to conduct more rigorous hydrodynamic modeling in advance of reef construction. For more details on sedimentation issues, see Section V. *Avoiding Issues with Navigation and Sedimentation*.

OUTREACH LESSONS LEARNED: Concern over excess sedimentation brought some negative comments and media coverage. The team worked hard to provide honest information about the extent of the problem, potential causes and steps being taken through the adaptive management process to inform future projects. The team also explained that although there was more sedimentation than expected, some sedimentation was factored into the project design and while less than desired, the amount of available spawning habitat was in fact increased in the area.



Figure 36. Harts Light reef layout.

HARTS LIGHT REEF AND POINTE AUX CHENES REEF, ST. CLAIR RIVER

YEAR COMPLETED: 2014

Overview

Video footage of sturgeon spawning on the previous project, the Middle Channel reef, was circulated widely and caught the interest of potential funders and the council that guides the St. Clair River Area of Concern program. In 2013, the team began evaluating locations for future projects along the St. Clair River and settled on two optimal locations. Planning and implementation of both projects happened in tandem, which reduced costs at all stages. The team was able to analyze results from earlier projects, select a single rock type, simplify reef design and dramatically increase the amount of area remediated.

FUNDING: The Great Lakes Restoration Initiative provided the team with \$3.5 million to create two spawning reefs in the St. Clair River and to advance the remediation plan for the river. Partner agencies contributed additional time and effort for assessment, planning and outreach, including an additional \$70,000 for reef building from the FWS Coastal Program.

PLACEMENT: The Harts Light reef was placed between St. Clair and Marine City, Michigan, in a narrow, deep and fast-flowing section of the St. Clair River. After consultation with the shipping industry, the Harts Light reef was placed partially within the navigation channel, in an area that is never dredged and waters are 38 to 50 feet deep. The Pointe Aux Chenes reef was established

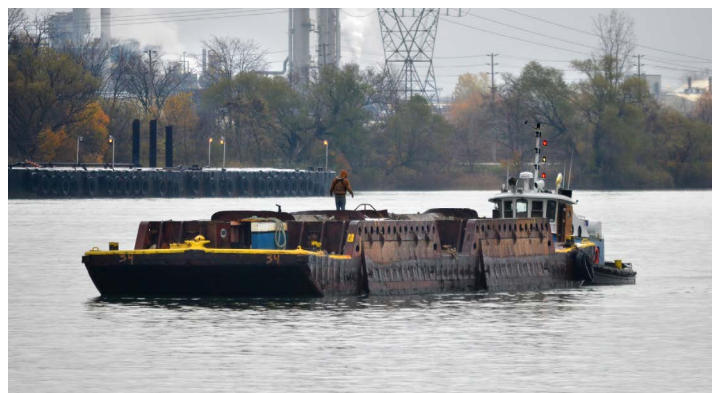


Figure 37. Dump barge used to build Harts Light reef.

between Algonac and the head of Russell Island. Water velocities and bottom sediments were examined throughout the area, allowing the team to place the reef in the spot with the highest water velocity and no sand. Zebra and quagga mussels could be found in both locations, indicating that the river bottom was relatively stable with minimal sand deposition. Hydrologic modeling confirmed that sites had suitable water flow that should scour away sand and finer-grained sediments.

DESIGN: Both reefs were built as long, narrow rectangles, oriented parallel to the current (Figures 36 and 38). The shape and orientation keeps water flowing quickly around and over the reef in order to help scour way sediments. Both projects were built with 4-8 inch angular limestone rock.

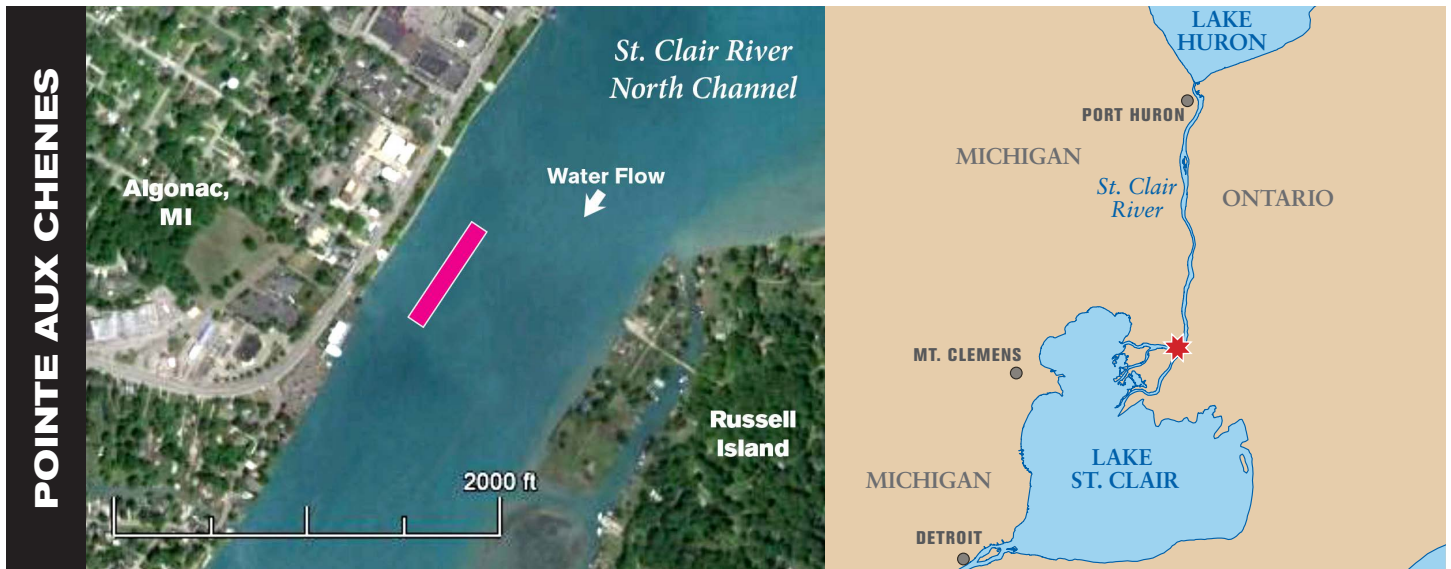


Figure 38. Pointe Aux Chenes reef layout.

- Harts Light Reef: Includes 2 adjacent reef units, totaling 3.8 acres (1007 x 165 ft.), 300 feet from shore.
- Pointe Aux Chenes: Single reef bed totaling 1.5 acres (605 x 108 ft.), 250 feet from shore.

OBSERVATIONS: Both projects were completed in the fall of 2014 and post-restoration assessment is ongoing. Large numbers of sturgeon eggs were collected on each constructed reef and viable sturgeon larvae were caught drifting downstream of each reef project in 2015, providing validation of the team’s restoration process.

Lessons Learned

PROCESS LESSONS LEARNED: Realizing that more sediment was building up on the Middle Channel Reef than expected, the team delayed construction of these two projects by a year. This gave the team time to distill and apply lessons from earlier projects, which required additional data collection and modeling. Time, flexibility and candid communication within and beyond the team were essential to implementing an effective adaptive management approach.

TECHNICAL LESSONS LEARNED: For these projects, the team adopted a more rigorous site assessment in advance of building a reef. Methods varied depending on the location. For example, a scuba dive assessment was only possible at Pointe Aux Chenes, where conditions were more amenable, and a sediment transport model was only possible at Harts Light, where water flow was simpler to model. The team instituted a more formal review of all the data for each site

before moving ahead with construction, which resulted in a change in the size and location of each reef late in the planning process.

Although these projects were much simpler designs than earlier projects, conditions at Harts Light were challenging — deep waters and regular freighter traffic made anchoring difficult. The contractor revised construction methods mid-project, using a dump barge to drop rock rather than a clamshell and crane placement, which produced a lumpier reef (Figure 37). The team carefully reviewed all survey information and required the contractor to return to the site and smooth the reef surface with a steel beam in spring of 2015.

OUTREACH LESSONS LEARNED: Proactive outreach was essential for addressing issues that arose during permitting. Shoreline property owners, which included private homes adjacent to the Harts Light reef, needed to provide permission for projects on adjacent river bottom lands. A local champion helped the project coordinator visit homes and meet with local residents that raised concerns about the constructed reefs. In addition, freighter captains expressed concern that construction vessels, research vessels or the reef itself could impede navigation, and that turbulence caused by freighters would disrupt the Harts Light reef. Direct communication with the Lake Carriers’ Association allowed the team to successfully modify the project layout and address their concerns.



Figure 39. Grassy Island reef project layout.

GRASSY ISLAND REEF, DETROIT RIVER

YEAR COMPLETED: 2015, IN PROGRESS

Overview

The creation of additional spawning reefs is a formal part of the remediation plan for the Detroit River Area of Concern. The team began planning a Detroit River project when developing a grant application in 2012. Originally, the project was to be located offshore from historic Fort Wayne, but the team decided to move the project based on issues that emerged during permitting.

FUNDING: The team received a grant from the Sustain Our Great Lakes program, which was supplemented by additional Great Lakes Restoration Initiative funds, totaling approximately \$2.1 million. Project partners, including USGS and FWS, leveraged additional funding to expand pre- and post-assessment.

PLACEMENT: The Grassy Island reef is located approximately 3,800 feet offshore from the cities of Ecorse and Wyandotte, and upstream of Grassy Island in the Detroit River. The site has the necessary physical attributes and is close to the Fighting Island reef and a known home area for lake sturgeon. Historically, the site supported a vibrant commercial lake whitefish fishery. Today, recreational anglers catch an abundance of walleye there. Although walleye and whitefish may not benefit measurably from a constructed reef, these fish demonstrate that the site has the right physical conditions for lake sturgeon.

DESIGN: Similar to the Harts Light and Pointe Aux Chenes reefs, the Grassy Island reef is a long, narrow rectangle



Figure 40. Members of the restoration team riding on a freighter through the St. Clair and Detroit rivers.

covering 4 acres of river bottom (143 x 1219 feet) (Figure 39). Angular limestone rock 4-8 inches in diameter will be placed on the river bottom, forming a reef 2-feet thick.

OBSERVATIONS: The reef was constructed during fall of 2015, so there are no observations to date.

Lessons Learned

Coordination with the commercial shipping industry was important for the evolution of this project (Figure 40). The Lake Carriers' Association, expressed concerns during the public comment period associated with the permitting process in 2013. This initiated a direct conversation with the Association and ultimately led the team to move the project from Fort Wayne to the Grassy Island site, where freighter activity was less likely to interfere with the reef. Good communication with the Association has continued and enabled the team to consult with lake carrier leadership, expanding the team's understanding of the river system and facilitating a smoother permitting process.

Conclusion

Conservation and restoration of natural resource assets can help revitalize communities, support unique recreational opportunities and attract the people and businesses that drive local economies (Figure 41). However, ecological restoration work is not easy, and it requires a combination of skill, persistence and luck. We hope this publication provides a valuable summary of lessons learned about fish habitat restoration in the St. Clair-Detroit River System.

The spawning reef restoration work benefited from an unusual alignment of priorities, funding and relationships and a solid base of research and monitoring. However, the St. Clair and Detroit rivers are not obvious candidates for ecosystem restoration, given the many factors that have degraded aquatic habitats over time (Figure 42). Yet, a thoughtful adaptive management process, open communications strategy and a strong, diverse collaboration were instrumental in overcoming many hurdles and capitalizing on unique funding opportunities. We encourage other potential project coordinators, scientists, and champions and restoration practitioners to reach out to the reef team and to continue improving on the process and techniques outlined in this summary.



Figure 41. There is a popular catch and release and limited-take fishery for lake sturgeon in the St. Clair River. Credit: St. Clair-Detroit River Sturgeon for Tomorrow.



Figure 42. Despite heavy development, the Detroit River continues to support a diverse fish community.

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