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Enhancing Lake Sturgeon Passage at Hydroelectric Facilities in the Great Lakes:

Results of a Workshop Sponsored by the Great Lakes Fishery Trust

February 1–2, 2011

Reported by

Mark A. Coscarelli
Great Lakes Fishery Trust

Robert F. Elliott
U.S. Fish and Wildlife Service
Green Bay Fish and Wildlife Conservation Office

Patrick S. Forsythe
U.S. Fish and Wildlife Service
Green Bay Fish and Wildlife Conservation Office

Mark E. Holey
U.S. Fish and Wildlife Service
Green Bay Fish and Wildlife Conservation Office

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Executive Summary

The Great Lakes Fishery Trust (GLFT) sponsored a workshop on February 1–2, 2011, in Detroit, Michigan, to identify the knowledge gaps and resulting research needs to successfully provide passage for Great Lakes lake sturgeon at hydroelectric facilities. Workshop results will assist the GLFT Board of Trustees and the Scientific Advisory Team in the development of a directed research grant program to help facilitate passage of lake sturgeon within tributaries of the Great Lakes.

Forty workshop participants identified many knowledge gaps that limit our ability to successfully pass lake sturgeon at hydroelectric facilities. Gaps receiving the most attention during breakout discussion groups included but were not limited to:

- search patterns and guidance mechanisms used by adult and juvenile lake sturgeon during upstream/downstream migration;
- characteristics of entrances/exits (i.e., size, morphology) of volitional or technical fish ways that promote movement;
- the role of attraction flows, substrate size, dissolved oxygen, ambient light, time of day, and temperature in passage success;
- abiotic (i.e., river flow) and biotic (i.e., presence/absence of other individuals) motivational cues as a function of sex, age or size, reproductive stage, and physiological condition of individuals;
- the ultimate fate of adult lake sturgeon that are successfully passed upstream/downstream versus those that fail; and
- methods that best time upstream migration with opportunities that allow individuals to achieve reproductive success.

There was general consensus among participants that a lack of focused research on strategies to pass lake sturgeon over dams limits the ability of managers to achieve passage goals. A synthesis of the gap in knowledge led to a research framework targeted to reduce uncertainties of successful sturgeon passage (i.e., upstream migration of adults, downstream migration of adults, downstream migration of larvae and juveniles). This framework includes the following categories:

Lake sturgeon behavior during migration and passage: Specific research activities in this category may include telemetry studies that seek to determine if upstream/downstream migratory routes are random or based on stream flow or the behavior of adults and juveniles after entering impoundments.

Physiological consequences of passage: Recent work suggests that passage compromises the physiological condition of sturgeon in general, but individual sturgeon do recover well from a single passage attempt. Research in this category would benefit from studies seeking to determine the physiological impacts of multiple passage attempts including trap and transfer techniques, and differences related to size, sex, and reproductive condition.

Passage design, technology, implementation, and development of operational windows: There are many inventive engineering solutions that can be applied to lake sturgeon passage efforts. However, the implementation of these solutions would be greatly enhanced with studies seeking to tie specific technologies with survival rates of adults, juveniles, and larvae.

Advancement of technologies that improve assessment and monitoring: Perhaps one of the largest gaps to lake sturgeon passage involves how to measure success. Thus, research attempting to deploy novel techniques to quantify movement and theoretical or empirical research attempting to tie passage efforts to population level parameters (i.e., recruitment) would be desirable.

Participants also learned about the role of the GLFT in lake sturgeon rehabilitation, the current global status of sturgeon species, technical and behavioral considerations learned from passage efforts implemented for other species, and the current status of lake sturgeon population and hydroelectric facilities that block migration in Great Lakes tributaries. A post-workshop evaluation provided to participants generally indicated that the planning and steering committee acquired an excellent cross-section of individuals from industry, research, and management. The largest proportion of participants also felt that the goals of the workshop were adequately met.

Great Lakes Fishery Trust Background

The Great Lakes Fishery Trust (Trust) was created in 1996 as a result of a settlement agreement to mitigate for the unavoidable fish losses from the operation of the Ludington Pumped Storage Hydroelectric facility located on Lake Michigan near Ludington, Michigan, co-owned by Consumers Power and Detroit Edison utilities. Grant funds awarded under the agreement give preference to Lake Michigan projects with a focus on the following activities:

- Research directed at increasing the benefits associated with Great Lakes fishery resources
- Rehabilitation of lake trout, lake sturgeon, and other fish populations
- Protection and enhancement of fisheries habitat, including Great Lakes wetlands
- Public education concerning the Great Lakes fisheries
- Acquisition of property for the above purposes, or to provide access to the Great Lakes fisheries

As provided in the settlement agreement, the GLFT was established as a private, nonprofit corporation that answers to a Board of Trustees comprised of representatives from the Michigan Department of Natural Resources, the office of the Michigan Attorney General, the Michigan National Wildlife Federation, Grand Traverse Band of Ottawa and Chippewa Indians, the Michigan United Conservation Clubs, and the U.S. Fish and Wildlife Service. Using funds derived from the settlement, the GLFT contracts administrative and management support services through Public Sector Consultants Inc., a firm based in Lansing, Michigan.

Mission and Vision Statement

The mission of the GLFT is to provide funding to enhance, protect, and rehabilitate the Great Lakes Fishery. The GLFT will manage its resources to compensate for the lost use and enjoyment of the Lake Michigan fishery resulting from the operation of the Ludington Pumped Storage Plant. The GLFT envisions the Great Lakes as supporting a sustainable and diverse fishery that meets the needs of the Great Lakes community in terms of a healthy environment, wholesome food, recreation, employment, commerce, and preservation of its cultural heritage. The GLFT will dedicate its assets to fostering realization of this vision, particularly for Lake Michigan. The guiding principle of the GLFT is to consider the total environment, recognizing the connections in the chemical, physical, and biological processes of the Great Lakes ecosystem as well as the human uses and values associated with this magnificent resource. The GLFT recognizes that public understanding of, and involvement in, Great Lakes fishery management is essential to successfully attaining its objectives.

Accomplishments to Date

Grants to mitigate fish losses totaled more than $50 million dollars from 1998–2010; approximately 61 percent of the grant money was awarded to projects with connection to restoring healthy ecosystems and sustainable fish populations, including sturgeon; 22 percent was awarded to projects that provide access to the fishery; and 15 percent went to projects that support Great Lakes stewardship. The GLFT has worked cooperatively with research institutions; state, tribal, and national management agencies; regional authorities; and private foundations to maximize the effectiveness of its grant programs and encourage collaboration. Since 2000, the GLFT has also funded semiannual sturgeon coordination meetings designed to convene lake sturgeon researchers and fisheries managers to better understand the most pressing research questions for rehabilitation. GLFT has invested over $4 million in the rehabilitation of lake sturgeon populations to date. By 2020, the GLFT will have invested nearly $100 million to protect and restore the Great Lakes fishery.

Workshop Proceedings

Introduction

Lake sturgeon were historically widespread across the Great Lakes basin with individuals using most of the major tributaries for reproduction in the spring. Populations declined dramatically beginning in the 1800s due to anthropogenic activities such as overfishing pollution and the construction of dams that changed natural river flows and associated aquatic environments. Numbers of lake sturgeon are now estimated to be at < 1 percent of historic levels with many populations showing little or only limited signs of natural recovery.

At a workshop held in mid-2000 sponsored by the Great Lakes Fishery Trust, 45 individuals from state, federal, provincial, and tribal natural resource agencies identified four major impediments to rehabilitation of lake sturgeon populations including: (1) a lack of adequate knowledge of the status (i.e., numerical abundance and levels of annual reproduction) and distribution of remnant populations; (2) a lack of sufficient understanding of habitat constraints throughout the life cycle, the role of habitat structure in population regulation, and other barriers to reproductive success; (3) a lack of sustainable and cost-effective artificial propagation techniques and associated strategies to accelerate recovery; and (4) a lack of adequate fish passage technologies for lake sturgeon in areas where dams form barriers to upstream migrants and downstream movement of adults and offspring. The GLFT used the proceedings from this meeting to guide its funding strategies for lake sturgeon rehabilitation. Subsequent GLFT-sponsored biannual meetings have provided a forum to foster communication and exchange of information relating to the study, management, and restoration of lake sturgeon in the Great Lakes Basin, and also to address priority research and assessment needs and selected emerging issues.

Photo courtesy of Patrick Forsythe.

Over the past ten years, GLFT-funded projects have made substantial progress toward reducing the uncertainty with regard to these impediments (see Literature Cited; Appendix A). For example, remnant lake sturgeon populations have been surveyed and recent estimates of adult spawning stock and levels of recruitment are available. Movement patterns and behaviors of adults (i.e., natal homing for spawning), and the cues individuals use to time reproduction have been quantitatively evaluated. Habitat requirements for all life stages, estimates of mortality, and the sources limiting survival early in life are better understood. Propagation strategies are now guided by specific life history requirements and behavior of the species (i.e., natal stream-side rearing to promote homing). Further, collection methods that maximize genetic diversity and maintain the genetic integrity of remnant populations, and release strategies that promote high survival rates have been implemented basin-wide.

Practices that seek to maintain stable river flows during spawning have also been improved in the past decade. However, many hydroelectric facilities remain in place, blocking migrating adults from reaching historic spawning areas and reducing miles of in-stream larval and juvenile nursery habitat; these facilities are likely the greatest impediment to lake sturgeon populations reaching the density and age structure characteristic of healthy/restored levels (see the 2000 Workshop Proceedings). Additionally, the design, development, and implementation of structures that pass lake sturgeon around hydroelectric facilities are comparatively lacking. More specifically, very few solutions for accomplishing successful upstream and downstream sturgeon passage have been tested through a systematic examination of variation in physical stream conditions and technical modifications that best interact with the complex behavior of migrating adults, juveniles, and larvae.

The GLFT's goal in sponsoring this workshop was to advance lake sturgeon restoration by focusing its resources on, and encouraging others to carry out a research agenda that can reduce the impact of hydroelectric facilities on the overall goal of lake sturgeon restoration in the Great Lakes. While we recognize that other passage issues exist (e.g., natural barriers or low-head dams), the development of this agenda was intended to foster collaboration among resource managers, planners, scientists, and industry representatives with the background, experience, and tools necessary to identify the major gaps in knowledge related to barriers caused by power generation.

Workshop Organization, Goal, and Objectives

Workshop Organization

The workshop was organized by a steering committee convened with input from the GLFT Scientific Advisory Team. Members of the steering committee were: Mark Holey, U.S. Fish and Wildlife Service project leader and Scientific Advisory Team (SAT) member; Mark Coscarelli, Great Lakes Fishery Trust manager; Gary Dawson and Scott DeBoe from Michigan Consumers Energy and SAT members; Paul Jacobson, Electric Power Research Institute; Rob Elliott and Patrick Forsythe, fisheries biologists from the U.S. Fish and Wildlife Service in Green Bay; and Joe Koonce from Case Western Reserve University. Amy Rittenhouse of Public Sector Consultants assisted the steering committee with technical support and execution of the workshop.

Workshop Goal

Identify the knowledge gaps that limit our ability to provide effective upstream and downstream passage of all life history stages of lake sturgeon at hydroelectric facilities in the Great Lakes.

Workshop Objectives

- Identify impediments and knowledge gaps to effectively provide upstream and downstream passage of lake sturgeon at hydroelectric facilities
- Identify and prioritize a list of research and management questions that need to be answered to provide effective passage of lake sturgeon
- Define the characteristics of effective upstream and downstream passage of lake sturgeon over dams
- Synthesize the existing knowledge of successful sturgeon passage efforts in the Great Lakes and elsewhere
- Foster communications among lake sturgeon researchers and managers and hydroelectric companies by providing an opportunity for formal and informal interactions
- Develop a research strategy to overcome impediments to effective sturgeon passage jointly among government and hydroelectric companies
- Provide a report on the workshop proceedings to the GLFT that can be used to guide future funding decisions

Facilitated discussion groups were used as the primary tool to accomplish the objectives and achieve the goal of the Lake Sturgeon Passage Workshop. A social event was held on the evening of Day 1 (February 1), during which time participants shared informal discussion and informational materials on their sturgeon activities that included copies of published and unpublished reports, posters, and looped video presentations (see Appendix B). Forty attendees participated in the group discussions (see Appendix C). The demographics of the participants included representatives from federal (USFWS; USACE; USDOE; USGS), state (Wisconsin DNR; Michigan DNR; Minnesota DNR) and provincial (OMNR; DFO - Canada) natural resources agencies, U.S. national and federal research laboratories (Oak Ridge; Conte; EPRI), universities (Michigan Tech; University of California; Carleton University; University of Guelph) and private industry organizations, including North American Hydro, Stantec Inc., Michigan Consumers Energy, We Energies, Ontario Power Generation Inc., Manitoba Hydro, Kleinschmidt Associates, and Inter-Fluve, Inc. A summary of the issues and identification of emerging issues is provided in Appendix D.

Photo courtesy of Patrick Forsythe.

Summary of Prepared Presentations

Global Perspective of Sturgeon Population Status

Dr. Paul Jacobson, head of marine and hydrokinetic energy research at the Electric Power Research Institute, presented data on the global status of sturgeon populations. Following Bemis and Kynard (1997), Dr. Jacobson reported on the current IUCN (i.e., International Union for Conservation of Nature; *http://iucn.org/*) status of *Acipenserform* species from nine biogeographic regions worldwide including: the Northeastern Pacific (2 species), Mississippi River, and Gulf of Mexico (5 species); Great Lakes, Hudson Bay, and St. Lawrence River (2 species); Northwestern Atlantic (2 species); Northeastern Atlantic (2 species); Ponto-Caspian Region (11 species); Siberia and Arctic Ocean (2 species); Amur River, Sea of Okhotsk, and Sea of Japan (3 species); and China (3 species). For all species reported (see Exhibit 1), in-stream barriers including hydroelectric facilities are thought to be the primary source of decline because most either restrict migration of spawning adults or reduce the amount of downstream nursery habitat. Although passage efforts have been implemented worldwide, global efforts to research different passage techniques and collect data using long-term monitoring after passage implementation lag behind comparable projects for jumping migratory fish (e.g., trout and salmon), according to Dr. Jacobson.

EXHIBIT 1. List of Sturgeon and Paddlefish Species

Species	International Union for Conservation of Nature Status	Trend*
Adriatic sturgeon, *Acipenser naccarii*	Endangered	Decreasing
Alabama sturgeon, *Scaphirynchus suttkusi*	Endangered	Decreasing
American paddlefish, *Polyodon spathula*	Vulnerable	Unknown
Amur sturgeon, *Acipenser schrenckii*	Endangered	Decreasing
Atlantic (Baltic) sturgeon, *Acipenser sturio*	Endangered	Decreasing
Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*	Vulnerable	Increasing
Beluga, *Huso huso*	Endangered	Decreasing
Chinese paddlefish, *Psephurus gladius*	Endangered	Unknown
Chinese sturgeon, *Acipenser sinensis*	Endangered	Decreasing
Dwarf sturgeon, *Pseudoscaphirynchus hermanni*	Endangered	Decreasing
False shovelnose sturgeon, *Pseudoscaphirhynchus kaufmanni*	Endangered	Decreasing
Green sturgeon, *Acipenser medirostris*	Near threatened	Stable
Gulf sturgeon, *Acipenser oxyrinchus desotoi*	Near threatened	Increasing
Kaluga, *Huso dauricus*	Endangered	Decreasing
Lake sturgeon, *Acipenser fulvescens*	Least concern	Increasing
Pallid sturgeon, *Scaphirhynchus albus*	Endangered	Decreasing
Persian sturgeon, *Acipenser persicus*	Endangered	Decreasing
Russian sturgeon, *Acipenser gueldenstaedtii*	Endangered	Decreasing
Sakhalin sturgeon, *Acipenser mikadoi*	Endangered	Decreasing
Ship sturgeon, *Acipenser nudiventris*	Endangered	Decreasing
Shortnose sturgeon, *Acipenser brevirostrum*	Vulnerable	Decreasing
Shovelnose sturgeon, *Scaphirhynchus platorynchus*	Vulnerable	Decreasing
Siberian sturgeon, *Acipenser baerii*	Endangered	Decreasing
Stellate sturgeon, Acipenser stellatus	Endangered	Decreasing
Sterlet, *Acipenser ruthnus*	Vulnerable	Decreasing
Syr-darya shovelnose, *Pseudoscaphirhynchus fedtschenkoi*	Endangered	Decreasing
White sturgeon, *Acipenser transmontanus*	Least concerned	Stable
Yangtze sturgeon, *Acipenser dabryanus*	Endangered	Decreasing

*Trends in growth are based on currently available monitoring data.

Biological Factors Related to Sturgeon Passage

Dr. Henriette (Yetta) Jager, Oak Ridge National Laboratory, and Dr. Joe Cech, Professor Emeritus, University of California at Davis, presented information on theoretical (i.e., modeling) and empirically tested biological factors related to sturgeon passage efforts.

Dr. Jager discussed how habitat fragmentation by dams influences population persistence using white sturgeon in the Snake River as a case study. Dr. Jager's work stressed the importance of passage by showing that fragmented stream habitats, created by loosely spaced dams, can turn a healthy source population into a metapopulation of sinks with significantly lower long-term viability. Reasons for this may include insufficient free-flowing habitat for spawning or refuge, Allee effects (decline in individual fitness at low population size), lower probabilities of successful recruitment, and increased vulnerability to catastrophes. Dams also imposed a heavy penalty in terms of population persistence as the probability of turbine strike and entrainment mortality increased (i.e., due to an increase in trash-rack spacing). Ultimately, Dr. Jager's modeling showed that symmetric upstream and downstream passage provides the greatest net benefit to sturgeon population persistence; however, the level of benefit may depend of the attributes of the segments to be reconnected (i.e., long vs. short).

The objectives of Dr. Cech's portion of this co-authored presentation were to illustrate the success and stress response of adult white sturgeon to a "sturgeon compatible" fish ladder. Results from Dr. Cech's laboratory work showed that adult white sturgeon generally exhibit burst swimming during passage and can negotiate a structure with peak water velocities up to 2.0 meters/second (> 0.45 m/s attraction flows) over 24.4 meters at 4 percent bed-slope in < 131 seconds. However, the highest percentage of successful passage (63 percent) occurred with aligned passage slots, deeper tail pool depths, and with individuals in greater health (Cocherell et al. 2011). Sturgeon also showed significant physiological responses to passage in terms of decreased plasma pH, and increased plasma cortisol, and lactate concentrations. Yet, these stress responses generally were not detectable in the test fish 24 hours after its passage experiment was concluded.

Technical Challenges Related to Sturgeon Passage

Mike Parsley, a fishery research biologist and project lead at the USGS's Western Fisheries Research Center, Columbia River Research Laboratory, and Dr. Rob McLaughlin, Assistant Professor at the University of Guelph in the Department of Integrative Biology, synthesized information on the various technical challenges related to sturgeon passage as well as the unintended consequences, tradeoffs, and assessment and monitoring needs.

Mike Parsley began his presentation of technical challenges by highlighting that the site-specific biological requirements for successful reproduction in lake sturgeon (e.g., upstream passage of adults to spawning sites and downstream passage of adults, larvae and juveniles) will largely dictate the operational windows for passage efforts. Operational windows and tributary-specific needs are important because of the different challenges associated with effectively guiding and attracting individuals to volitional upstream and downstream passage routes or trap and haul facilities. Ladders, nature-like bypasses, or elevators for upstream passage must also have conditions suitable for exit/release above barriers and grades necessary to prevent impingement, delays in migration, and unintended fallback after passage: design parameters that are largely unknown for upstream passage of sturgeon. Likewise, operational windows, routes of movement, guidance, and attraction flows must also be considered for downstream passage. For example, many hydroelectric facilities require adult sturgeon to ascend the water column to enter open spillways for downstream passage. Yet knowledge of the timing and whether lake sturgeon, a benthic orientated species, is behaviorally capable of completing passage in this way are unknown. Dispersing larvae, juveniles, and some adult lake sturgeon can pass through trash racks and thus pass downstream

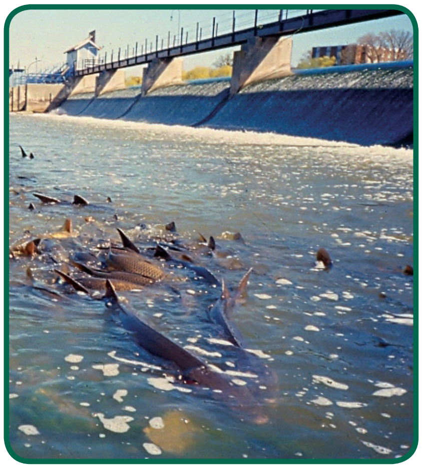


Photo courtesy of Rob Elliott.

through operating turbines. However, mortality rates of passage in this manner have not been evaluated. The use of bypass channels for downstream passage have also not been evaluated in natural settings, leaving little design criteria for construction activities.

There are also unintended consequences of upstream and downstream passage including expansion of this range of invasive species and diseases, increased predation, and elevated mortality due to fishing or poaching, according to Dr. McLaughlin. The technical challenges associated with these consequences range from designs that can effectively exclude exotics and diseased fish from using fishways, and include methods to deter predation and mortality from fishing and poaching of migrating sturgeon.

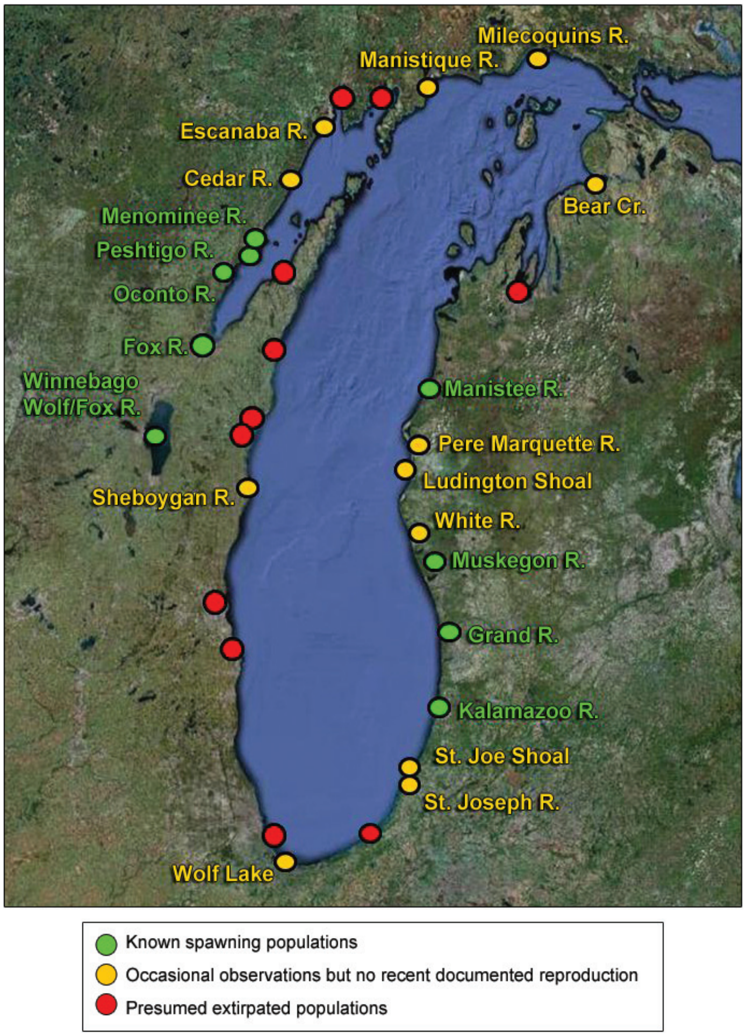
In this presentation, McLaughlin and Parsley also discussed the need for design and construction activities to provide for infrastructure that enables quantitative monitoring of fish movements and passage effectiveness such as passive integrated tag antenna arrays, and forebay and tailrace collection of juvenile and adult lake sturgeon. Construction, monitoring, and assessment protocols would also be best served placed in a framework that promotes adaptive management, as the first option selected for passage may not be the best one.

Remnant Lake Sturgeon Populations and Hydroelectric Facilities in the Great Lakes

Rob Elliott, lake sturgeon biologist with the U.S. Fish and Wildlife Service in Green Bay, summarized the distribution and status of lake sturgeon populations and characteristics of hydroelectric facilities on tributaries across the Great Lakes with emphasis on Lake Michigan. According to Mr. Elliott, there are currently four large concentrations of lake sturgeon in the Great Lakes basin where adult numbers exceed 5,000 individuals (e.g., Lake Winnebago, Lake St. Clair, and portions of the Ottawa River and the St. Lawrence River are either separated from the Great Lakes proper or are using large interconnecting Great Lakes waterways).

Of populations associated with tributaries with open and direct connection to the Great Lakes, approximately ten have moderate and stable numbers (i.e., ≥ 200–500 individuals in the annual spawning run) including the Menominee and Peshtigo Rivers, and many including the Manistee, Muskegon, Kalamazoo, Fox, and Oconto, Rivers are classified as small (i.e., ≤ 100) and of concern in terms of their long-term viability (Exhibit 2). Many tributaries where sturgeon were thought to spawn historically currently have only occasional or incidental observations of sturgeon with no known reproduction, or individuals are considered extirpated entirely (see *2000 Workshop Proceedings*

EXHIBIT 2. Lake Michigan Tributaries with Known Spawning Populations, No Known Reproduction, and Presumed Extirpated Populations



SOURCE: Map created by Rob Elliott (U.S. Fish and Wildlife Service) using satellite image from Google Maps.

for further details; Figure 1; Exhibit 2). However, efforts to rehabilitate extirpated or depleted populations are ongoing at several locations via streamside rearing and stocking.

Lake Michigan tributaries that support annual spawning runs, have evidence of successful natural recruitment, and thus may be candidates for future passage efforts, are provided in Exhibit 3. Hydroelectric facilities sited on these Lake Michigan tributaries have similar features including a relatively low head (< 30 feet), a spillway that can seasonally pass more water than is routed through the power house, a free-flowing section at the base of the dam, and an impoundment on the upstream side. However, the number and proximity of dams on a single tributary, the presence and size of power canals, the amount of unrestricted river miles to the first barrier and historic spawning areas, differences in river flow volume and channel width, impoundment size, degree of separation between the power house and power canal, and proximity of other dams (Exhibit 2) are notable variations in terms of implementing future passage efforts, according to Mr. Elliott.

EXHIBIT 3. Estimated Population Size of Lake Sturgeon for Nine Lake Michigan Tributaries with Facilities that Block Access to Historic Spawning or Nursery Habitat

Lake Michigan tributary	Estimated annual spawning population size	Sample hydroelectric dams that block access to historic sturgeon habitat*
Fox River	50–75	De Pere
Kalamazoo River	20–42	Allegan
Manistee River	21–66	Tippy, Hodenpyl
Menominee River	500	Menominee, Park Mill
	250	Grand Rapids, White Rapids, Chalk Hill
Muskegon River	60–100	Croton, Hardy
Oconto River	50	Stiles, Lower Oconto Falls, Upper Oconto Falls
Peshtigo River	200	Peshtigo, Potato Rapids
St. Joseph River	Unknown (few)	Barrien Springs
Wolf River	20,000	Shawano, Balsam Row

*Hydroelectric dams are listed in sequential order (downstream to upstream) and provide examples of structural configurations typical of the lower-most dams that occur within the historic lake sturgeon migration corridor within these rivers.

Building a Framework for Lake Sturgeon Passage

Using the foundation of information provided by the focal presentation, four workshop discussion groups were asked to identify and expand upon the range of knowledge gaps that limit our ability to successfully pass lake sturgeon at hydroelectric facilities. There was little attempt by the discussion group leaders (Mark Coscarelli, Rob Elliott, Patrick Forsythe, and Mark Holey) to filter suggestions identified by the participants. However, participants on Day 1 were encouraged to think generally about knowledge gaps across the diversity of barrier types and plausible scenarios, such as dams with and without power canals, impoundment size, dam height, sequential order of the focal structure (i.e., first vs. upstream barrier to migration), and proximity of other facilities. Participants were further asked to think about how variation in dam structure and river placement dictates operational windows and interacts with sturgeon life stages including upstream and downstream movement of adults and outmigration of larvae and juveniles.

On Day 2 of the workshop, breakout discussion groups were given concrete examples to discuss in the form of the Chalk, Grand Rapids, Menominee, Park Mill, and

White Rapids Dams, five hydroelectric facilities on the Menominee River, Wisconsin (see Exhibit 2). This system was provided as a model system by the planning and steering committee to illustrate the diversity of hydroelectric facility types in the Great Lakes, and the complexity of passage issues relative to other Lake Michigan priority areas discussed. Today, these five hydroelectric facilities also prevent an estimated 2,000 genetically identifiable (i.e., unique) lake sturgeon from reaching upstream natal spawning habitats on the Menominee River (DeHaan et al. 2006; Welsh et al. 2008; Bott et al. 2009), a factor contributing to drastic population decline. The Menominee River historically contained river flows and ample sediment-free substrate in its headwater reaches; ideal habitat to support lake sturgeon spawning behavior and protection of embryos and larvae. The summary that follows represents a synthesis by the steering committee of the many knowledge gaps, provided here in the form of questions suggested during both days and provided via a post-workshop evaluation survey (see Exhibit 4 and Appendix D).

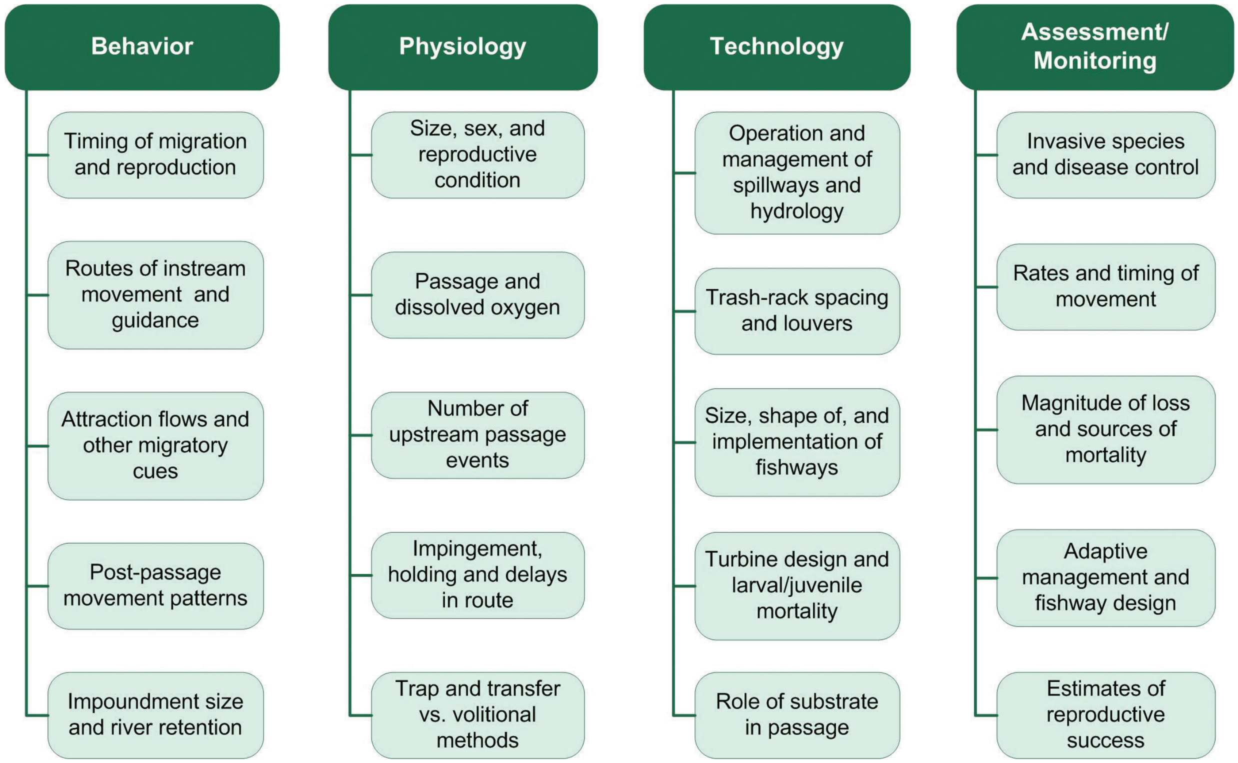
EXHIBIT 4. Knowledge Gaps to Lake Sturgeon Passage Efforts at Hydroelectric Facilities in Great Lakes Rank Ordered by Number of Groups that Listed the Gap

Knowledge gaps	Number of groups
How can lake sturgeon passage efforts be monitored, how should effectiveness be defined, and can passage structures be built in a modular/adaptable way based on applied experience?	4
Are search patterns of adult and juvenile lake sturgeon during upstream/downstream migratory routes random or based on stream flow, and do guidance mechanisms vary as a function of river size?	4
What methods are most effective in guiding individuals into a fishway, are there characteristics (i.e., size, morphology) of openings/exits that promote movement, and what is the role of attraction flows, substrate size, dissolved oxygen, ambient light, time of day, and temperature in passage success?	4
Can sturgeon passage efforts be co-implemented to accommodate other native migratory fish species, what mechanisms should be deployed to exclude invasives including pathogens, and how should control efforts be monitored?	4
What is the ultimate fate of adult lake sturgeon that are successfully passed upstream versus those that fail, and what passage methods best time upstream migration with opportunities that achieve reproductive success?	4
How does the size, shape, slope, water depth, number of resting areas, or loops in volitional passageways relate to the behavior and physiological condition of adult lake sturgeon during and after upstream passage?	4
What are the physiological/reproductive consequences of single vs. multiple volitional passage attempts, and how does this compare with holding times associated with trap and transfer or elevator passage techniques?	4
What are the roles of impoundment and river size, natural abiotic variation including dissolved oxygen, and winter drawdown on probabilities of upstream/downstream passage and the survival rates of adult, juvenile, and larvae?	4
What engineering strategies (e.g., turbine design, trash-rack spacing, surface vs. subsurface passage, downstream bypass channels, power canals) reduce delay and impingement and increase survival of adults, juveniles, and embryonic larvae?	4
If annual flow levels (hydrologic year) are predictive of lake sturgeon recruitment, can operational flow rates/spillway modifications be timed to increase passage success and do the scenarios change during high water vs. low water years?	2
Do the abiotic (i.e., river flow) and biotic (i.e., presence/absence of other individuals) motivational cues to enter/exit passage structures vary as a function of sex, age or size, reproductive stage, and physiological condition of individuals?	2

Research Framework for Enhancing Passage Success

The knowledge gaps identified by discussion groups during the workshop were very similar despite the diverse background of participants. Our synthesis across knowledge gaps receiving the greatest attention during breakout discussions also indicated a consolidation of uncertainty into several programs of research (i.e., a framework) across the sequences of passage including (1) lake sturgeon behavior during migration and passage, (2) physiological consequences of passage, (3) passage design, technology, implementation, and development of operational windows, and (4) advancement of technologies that improve assessment and monitoring of passage efforts. We believe that an integrated research approach based on these fundamental program areas will enhance the probability of deploying successful passage efforts and promote collaboration and partnerships that can bridge the diversity of knowledge gaps in each area. Each can be also be supported by the Great Lakes Fishery Trust. The flow chart provided below (Exhibit 5) expands upon a few likely research priorities and highlights a number of fundamental questions/uncertainties discussed by workshop participants:

EXHIBIT 5. Programs of Research (top row) and General Uncertainties Regarding Lake Sturgeon Passage Efforts in the Great Lakes Discussed by Workshop Participants



SOURCE: U.S. Fish & Wildlife Service, Patrick Forsythe, March 2011.

Future Initiatives

The GLFT wishes to thank all the participants and those involved in the organization of this sturgeon passage workshop. A great group of experts was assembled and the GLFT sincerely appreciates your willingness to share your views on the unmet research needs to provide effective passage of lake sturgeon over dams and hydropower facilities.

Research needs identified by the workshop discussion groups share a common purpose, to identify and resolve impediments and knowledge gaps to rehabilitation of lake sturgeon in Lake Michigan and the Great Lakes and to assist the evaluation of priorities for their removal. The research needs and priorities identified during the workshop provide a range of alternatives for the support of sturgeon research and rehabilitation by the Great Lakes Fishery Trust.

Going forward, it is anticipated that the GLFT's Scientific Advisory Team will review the workshop proceedings with a view toward soliciting proposals that address knowledge gaps related to behavior, physiology, technology, and assessment/monitoring activities, and at the same time work to forge long-term partnerships among agencies, academia, and the private sector to the benefit of lake sturgeon restoration in the Great Lakes basin. The GLFT hopes to encourage collaborative efforts between research organizations and/or management agencies. The funding guidelines of the GLFT are sufficiently flexible to accommodate a wide range of cooperative arrangements under a single proposal or as a series of independent projects.

Because of the longevity of lake sturgeon and the complexity of its natural history, rehabilitation and management pose long-term challenges. The GLFT is confident, however, that its investments now in activities that lay a sound scientific foundation will help guide future management and rehabilitation decisions for decades to come.

Photo courtesy of Rob Elliott.

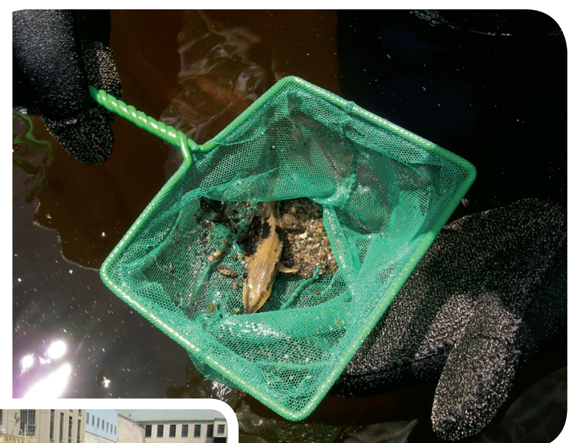


Photo courtesy of Rob Elliott.

Photo courtesy of Rob Elliott.

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Appendix A: GLFT-Sponsored Projects

Reports

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Peer-Reviewed Publications

Auer, N. A. and E. A. Baker. 2007. Assessment of Lake Sturgeon Spawning Stocks Using Fixed-location, Split-beam Sonar Technology. *Journal of Applied Ichthyology* 23 (2): 113–121.

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Appendix B: Agenda

Enhancing Lake Sturgeon Passage at Hydroelectric Facilities in the Great Lakes

A workshop sponsored by the Great Lakes Fishery Trust

February 1–2, 2011
Crowne Plaza – Detroit
8000 Merriman Road, Romulus, MI 48174

Tuesday, February 1

7:30 a.m.	Breakfast
9:00 a.m.	Welcome/Introductions
9:15 a.m.	Presentation: Global perspective of sturgeon passage efforts
10:00 a.m.	Presentation: Biological factors related to sturgeon passage
10:45 a.m.	Break
11:00 a.m.	Presentation: Technical challenges related to sturgeon passage
11:45 p.m.	Lunch
1:00 p.m.	Presentation: Population distribution and priority tributaries
2:00 p.m.	Breakout groups to discuss behavioral and technical aspects
4:15 p.m.	Re-convene and review breakout group discussions
5:00 p.m.	Evening social hour and poster session

Wednesday, February 2

7:00 a.m.	Breakfast
8:30 a.m.	Review Day 1 and determine what the priority research questions are and what can be achieved with greatest impact and where
9:00 a.m.	Breakout groups seek to identify knowledge gaps, and develop priorities for future research/funding
10:45 a.m.	Reconvene full group, discuss priorities, and make ecommendations for next steps

Appendix C: List of Participants and Organizers

Luther Aadland
Minnesota DNR
1221 East First Ave.
Fergus Falls, MN 56537
Phone: 218-739-7576
Luther.Aadland@dnr.state.mn.us

Greg Allen
Alden Research Laboratory
30 Shrewsbury St.
Holden, MA 01520
Phone: 508-829-6000
gallen@aldenlab.com

Chuck Alsberg
North American Hydro
116 North State St.
Neshkoro, WI 54960-0167
Phone: 920-293-4628
chuck@nahydro.com

Nancy Auer
Michigan Tech. University
1400 Townsend Dr.
Houghton, MI 49931
Phone: 906-487-2353
naauer@mtu.edu

Edward A. Baker
Michigan DNRE
488 Cherry Creek Rd.
Marquette, MI 49855
Phone: 906 249-1611 ext. 309
bakere1@michigan.gov

Derrick Beach
DFO - Canada
867 Lakeshore Rd.
Burlington, Ontario L7R 4A6
Phone: 905-336-4435
Derrick.Beach@dfo-mpo.gc.ca

Jonathan Black
Alden Research Laboratory
30 Shrewsbury St.
Holden, MA 01520
Phone: 508-829-6000
jblack@aldenlab.com

Joe Cech
Dept. of Wildlife, Fish,
and Conservation
University of California Davis
Davis, CA 95616
Phone: 530-752-3103
jjcech@ucdavis.edu

Michael Chelminski
Stantec Inc.
30 Park Dr.
Topsham, ME 04086
Phone: 207-729-1199
michael.chelminski@stantec.com

Steven J. Cooke
Carleton University
1125 Colonel By Dr.
Ottawa, ON Canada, K1S 5B6
Phone: 613-867-6711
steven_cooke@carleton.ca

***Mark Coscarelli**
Great Lakes Fishery Trust
600 W. Saint Joseph St., Suite 10
Lansing, MI 48933-2265
Phone: 517-484-4954
mcoscarelli@glft.org

***Gary A. Dawson**
Consumers Energy Services
1945 W. Parnall Rd.
Jackson, MI 49201
Phone: 517-788-2432
gadawson@cmsenergy.com

***Scott F. DeBoe**
Consumers Energy
1945 W. Parnall Rd.
Jackson, MI 49201
Phone: 517-788-0538
sfdeboe@cmsenergy.com

Mike Donofrio
Wisconsin DNR
101 N Ogden Rd.
Peshtigo, WI 54157
Phone: 715-582-5050
Michael.Donofrio@Wisconsin.gov

Paul Ducheney
Holyoke Gas & Electric
99 Suffolk St.
Holyoke, MA 01040
Phone: 413-536-9300
ducheney@hged.com

***Robert Elliott**
U.S. Fish and Wildlife Service
2661 Scott Tower Dr.
New Franken, WI 54229
Phone: 920-866-1762
robert_elliott@fws.gov

Chris Freiburger
Michigan DNRE
P.O. Box 30446
Lansing, MI 48909
Phone: 517-373-6644
freiburg@michigan.gov

Patrick S. Forsythe
U.S. Fish and Wildlife Service
2661 Scott Tower Dr.
New Franken, WI 54229
Phone: 920-866-1726
patrick_forsythe@fws.gov

Alex Haro
U. S. Geological Survey
1 Migratory Way, P.O. Box 796
Turners Falls, MA 01376
Phone: 413- 863-3806
Alex_Haro@usgs.gov

Tim Haxton
Ontario Ministry of
Natural Resources
300 Water St., 4th Floor S.
Peterborough, ON K9J 8M5
Phone: 705- 755-3258
tim.haxton@ontario.ca

***Mark E. Holey**
U.S. Fish & Wildlife Service
2661 Scott Tower Dr.
New Franken, WI 54229-9565
Phone: 920-866-1760
mark_holey@fws.gov

***Paul T. Jacobson**
Electric Power Research Institute
14820 View Way Court
Glenelg, MD 21737
Phone: 410-489-3675
pjacobson@epri.com

Yetta Jager
Oak Ridge National Laboratory
P.O. Box 2008 MS6036
Oak Ridge, TN 37831-6036
Phone: 865-574-8143
jagerhi@ornl.gov

Todd Jastremski
We Energies
800 Industrial Park Dr.
Iron Mountain, MI 49801
Phone: 906-779-4099
todd.jastremski@we-energies.com

***Joseph F. Koonce**
Case Western Reserve University
308 Clapp Hall
Cleveland, OH 44106-7080
Phone: 216-368-3561
joseph.koonce@case.edu

David McIntosh
Consumers Energy
1945 W. Parnall Rd.
Jackson, MI 49201
Phone: 517-788-0538
dcmcintosh@cmsenergy.com

Rob McLaughlin
Department of Integrative Biology
University of Guelph
Guelph, ON, N1G 2W1
Phone: 519-824-4120 ext. 53620
rlmclaug@uoguelph.ca

Alfred Nash
Renewable Power Consulting, PA
43 Spaulding Rd., P.O. Box 195
Palmyra, ME 04965
Phone: 207-992-3926
renewablepwr@yahoo.com

John M. Nestler
U.S. Army Engineer
Research Center
3909 Halls Ferry Rd.
Vicksburg, MS 39180
Phone: 601-634-2720
john.m.nestler@usace.army.mil

Tammy Newcomb
Michigan DNRE
P.O. Box 30446
Lansing, MI 48909
Phone: 517-373-3960
newcombt@michigan.gov

Curt Orvis
U.S. Fish and Wildlife Service
300 Westgate Center Dr.
Hadley, MA 01035-9589
Phone: 413-253-8288
curtis_orvis@fws.gov

Michael J. Parsley
U.S. Geological Survey
5501A Cook-Underwood Rd.
Cook, WA 98605
Phone: 509-538-2299 ext. 247
mparsley@usgs.gov

Thomas C. Pratt
DFO – Canada
1219 Queen St. East
Sault Ste. Marie, Ontario, P6A 2E5
Phone: 705-941-2664
thomas.pratt@dfo-mpo.gc.ca

Henry Quinlan
U.S. Fish and Wildlife Service
2800 Lake Shore Dr., East
Ashland, WI 54806
Phone: 715-682-6185
henry_quinlan@fws.gov

Ben Rizzo
U.S. Fish and Wildlife Service
One Gateway Center - Ste. 612
Newton Corner, MA 02458
Phone: 617-244-1368
ben_rizzo@fws.gov

Jeff Slade
U.S. Fish and Wildlife Service
229 S. Jebavy Dr.
Ludington, MI 49431
Phone: 617-244-1368
Jeff_Slade@fws.gov

David Stanley
Ontario Power Generation Inc.
14000 Niagara Parkway, RR #1
Niagara-on-the-Lake, ON, L0S 1J0
Phone: 905-357-0322 ext.7015
david.stanley@opg.com

Jason Thiem
Carleton University
1125 Colonel By Dr.
Ottawa, ON Canada, K1S 5B6
Phone: 613-520-4377
jthiem@connect.carleton.ca

Rob Tkach
Manitoba Hydro
360 Portage Ave.
P.O. Box 815 Stn. Main
Winnipeg, MB, R3C 0G8
Phone: 204-360-6383
rtkach@hydro.mb.ca

Chris Tomichek
Kleinschmidt Associates
35 Pratt St.
Essex, CT 06426
Phone: 860-767-5069
Chris.Tomichek@KleinschmidtUSA.com

Nicholas J. Utrup
U.S. Fish and Wildlife Service
2661 Scott Tower Dr.
New Franken, WI 54229
Phone: 920-866-1736
Nick_Utrup@fws.gov

Jesse E. Waldrip
Kleinschmidt Associates
141 Main St., P.O. Box 650
Pittsfield, ME 04967
Phone: 207-416-1256
Jesse.Waldrip@KleinschmidtUSA.com

Beth Wentzel
Inter-Fluve Inc.
3602 Atwood Ave.
Madison, WI 53714
Phone: 608-441-0342
bwentzel@interfluve.com

* Workshop organizer.

Appendix D: Evaluation and Emerging Issues

A post-workshop evaluation was provided to all 40 workshop participants via an online source. Eleven anonymous responses were received (28 percent of the total) to five questions regarding the goals, objectives, execution, and outcomes of the workshop, and the role that the GLFT can provide regarding future resources in addition to funding. The five survey questions and a short summary of responses are provided below.

1. **The primary goal of the workshop was to identify gaps in knowledge that limit our ability successfully pass adult, juvenile, and larval lake sturgeon upstream and downstream at hydroelectric facilities. Do you believe these gaps were identified? If not, please provide examples of those that were not adequately discussed.**

   Half of participants surveyed were fairly confident that the gaps in knowledge at hydroelectric facilities were adequately identified. However, the other half of participants felt that that many uncertainties where not addressed or adequately discussed, including the pressure effects on juveniles during downstream passage in relation to trash-rack spacing, the ability of lake sturgeon to use nature-like passage channels (e.g., natural rock arch rapids, bypass channels) as opposed to technical fishways (e.g., elevators), capture methods and tracking techniques for young-of-year and juveniles that can be used to measure spawning success, and swimming abilities, velocity criteria, and physical size requirements for passage of fish of in different reproductive condition (i.e., gravid females) or various life stages.

2. **Do you believe the workshop attendees represented an adequate cross section of disciplines and expertise to achieve desired outcomes? If not, what were the gaps in representation?**

   Most participants responding to this question viewed the workshop to have an excellent cross-section of sturgeon biologists, fisheries biologists, engineers, hydropower owners and researchers. However, since passage issues affect river ecosystems across the Great Lakes, several persons expressed an interest in having a greater representation of ecologists that have research interests at the stream, watershed, or ecosystem scales. Some participants also believed that a few experts in the general area of sturgeon passage were missing.

3. **In addition to serving as a source of funding, what ongoing role can the GLFT carry out to ensure successful sturgeon passage efforts?**

   Responses to this question varied considerably. Participants generally felt that the GLFT should take a lead role in tracking sturgeon passage activities/efforts in the Great Lakes, disseminate this information at regular intervals, and provide a venue for strategic meetings on upstream/downstream passage and/or habitat restoration for lake sturgeon and other target migratory fish species of conservation concern. A few others felt that the GLFT could assist in compiling a set of specific design criteria to be used by hydro owners to assess the need for sturgeon passage, and determine the most effective means for sturgeon passage at any given site. Finally, it was suggested that that the GLFT participate in the Species at Risk Act (SARA) review of Lake Sturgeon in Canada. Specifically, the GLFT could provide assistance in communication among proponents that are conducting work on lake sturgeon to ensure that the information is shared.

4. **Is there anything else you would like to offer to the workshop organizers about the workshop content, organization, and execution?**

   The workshop organizers were generally commended on a job well done by participants responding to this survey. However, some participants suggested that additional background material would have been helpful. Given that many sturgeon passage/habitat restoration projects are presently under way across the Great Lakes basin, more—and more frequent—workshops were encouraged, although participants did not recommend scheduling a workshop during the winter.

5. An important outcome of the workshop was the need to find and synthesize technical reports, laboratory and field studies, or computer modeling simulations that can serve to guide the construction and implementation of passageways for sturgeon at hydroelectric facilities or other barriers. Space was provided to list all citations participants felt were pertinent to this agenda.

Aadland, L. P. 2010. *Reconnecting Rivers: Natural Channel Design in Dam Removals and Fish Passage*. Minneapolis, Minn.: State of Minnesota, Department of Natural Resources.

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Contact Information

Great Lakes Fishery Trust
600 West Saint Joseph St., Suite 10
Lansing, MI 48933-2265
Phone: 517-371-7468
Fax: 517-484-6549
glft@glft.org
www.glft.org