Lake-Level, Five-Year Plans for Achieving Sea Lamprey Control Targets in each Great Lake

Great Lakes Fishery Commission

October 2012

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries between Canada and the United States, which was ratified on October 11, 1955. It was organized in April 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: first, develop coordinated programs of research in the Great Lakes, and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; second, formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes.

The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties. In fulfillment of this requirement the Commission publishes the Technical Report Series, intended for peer-reviewed scientific literature; Special Publications, designed primarily for dissemination of reports produced by working committees of the Commission; and other (non-serial) publications. Technical Reports are most suitable for either interdisciplinary review and synthesis papers of general interest to Great Lakes fisheries researchers, managers, and administrators, or more narrowly focused material with special relevance to a single but important aspect of the Commission's program. Special Publications, being working documents, may evolve with the findings of and charges to a particular committee. Both publications follow the style of the Canadian Journal of Fisheries and Aquatic Sciences. Sponsorship of Technical Reports or Special Publications does not necessarily imply that the findings or conclusions contained therein are endorsed by the Commission.

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Special Editors

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EXECUTIVE SUMMARY

Sea lampreys are an invasive species in the Laurentian Great Lakes that impede the restoration and sustainability of Great Lakes fisheries. The Great Lakes Fishery Commission (GLFC) was established in 1955 by the Canada-U.S. Convention on Great Lakes Fisheries to coordinate fisheries research, facilitate cooperative fishery management among state, provincial, tribal, and federal management agencies, and control invasive sea lampreys. Throughout the 56-year history of the GLFC, sea lamprey control has been based on the best science available. Decisions regarding the implementation of sea lamprey control are assisted by insights from experienced and knowledgeable fisheries biologists and technical staff in the Fisheries and Oceans Canada and the U.S. Fish and Wildlife Service, the agents who implement the sea lamprey control program, and with input from other state, provincial, tribal, and federal management agencies responsible for managing other fish stocks in the Great Lakes.

Together, the GLFC, its control agents, and other fishery-management agencies have agreed to targets for sea lamprey abundance that will reduce sea lamprey induced mortality on other fish species and enable the realization of common fish-community objectives, as set forth in A Joint Strategic Plan for Management of Great Lakes Fisheries (Great Lakes Fishery Commission 2007). The long-term average of sea lamprey abundance is higher than targets for each Great Lake. The GLFC, in collaboration with fisheries managers, has developed this lake-specific Five-Year Plan as an integrated sea lamprey control strategy that focuses on lakewide and locality-specific control tactics to maintain sea lamprey populations at or below target levels.

Each lake chapter provides options available for implementation of each component of the Five-Year Plan and concludes with recommended strategies and associated costs to achieve and maintain sea lamprey abundance and marking-rate targets. Chapter 7 (Summary) reiterates the economic importance of the Five-Year Plan, summarizes current costs and strategies, summarizes recommended costs and strategies to bring the sea lamprey population in each of the Great Lakes to targets, highlights the GLFC's decision-making structure and process, and briefly explores future directions of the Five-Year Plan. Compared to the fiscal year current budget, over the next five years, approximately $4.4 million in additional funds will be required to achieve and sustain sea lamprey control throughout the Great Lakes.

CHAPTER 1: SEA LAMPREY CONTROL IN THE GREAT LAKES BASIN

Katherine Mullett[1] and Paul Sullivan[2]

Purpose and Vision

The purpose of the lake-level, five-year plans for achieving sea lamprey (*Petromyzon marinus*) control targets (Five-Year Plan) in each Great Lake is to present an integrated sea lamprey control strategy that focuses on lakewide and locality-specific control tactics to maintain sea lamprey populations at or below target levels.

The Five-Year Plan was developed to be consistent with the Strategic Vision of the Great Lakes Fishery Commission 2011-2020 (Vision) (Great Lakes Fishery Commission 2012), which states that "The commission will suppress sea lamprey fish community objectives for each Great Lake." The Great Lakes Fishery Commission (GLFC) goals for sea lamprey control in the Vision are to:

1. Suppress sea lamprey populations to target levels.
2. Increase the effectiveness and efficiency of sea lamprey control to further reduce sea lamprey populations in each Great Lake.

Each goal has several strategies and related outcomes.

Authority and Program Delivery

Invasion and Fishery Impacts

The earliest record of sea lampreys in the Great Lakes was in 1835 in Lake Ontario (Lark 1973). Improvements to the Welland Canal in 1919 allowed sea lampreys to bypass Niagara Falls and enter Lake Erie where they were first observed in 1921. They spread throughout the upper Great Lakes and were first observed in Lake Michigan during 1936, Lake Huron in 1937, and Lake Superior in 1938 (Applegate 1950; Lawrie 1970; Smith 1971; Pearce et al. 1980; Smith and Tibbles 1980).

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Although excessive fishery exploitation and habitat alteration were considered the main causes for declines of lake trout (*Salvelinus namaycush*) stocks in Lakes Erie and Ontario (Elrod et al. 1995; Cornelius et al. 1995), sea lamprey predation played a varying role in lake trout declines in each of the upper Great Lakes (Eshenroder et al. 1995a; Holey et al. 1995; Hansen et al. 1995; Eshenroder and Ametangelo 2002) and contributed to widespread changes in each lake's ecosystem (Smith 1971; Hansen 1999). Commercial lake trout catch in Lake Huron fell from 2,268 tonnes during 1938 to 76 tonnes in 1954 and collapsed in 1959. Likewise, the catch in Lake Michigan fell from 2,948 tonnes during 1944 to 0.2 tonnes by 1953, and the Lake Superior catch had dropped from 2,041 tonnes to 227 tonnes by 1960 (Smith and Tibbles 1980). Lake trout were eradicated from Lakes Ontario, Erie, and Michigan and most of Lake Huron. Remnant native stocks persisted in a few inlets of Lake Huron's Georgian Bay and in Lake Superior.

Authority for Sea Lamprey Control

Concern for the damage inflicted by sea lampreys to fish stocks provided the impetus for the Convention on Great Lakes Fisheries (Convention) in 1954. The Convention established the GLFC and was ratified by the governments of Canada and the United States in 1955. The Convention mandated the GLFC "to formulate and implement a program for the purpose of eradicating or minimizing the sea lamprey populations" in the Great Lakes and to create and manage a fisheries research program focused on important fish stocks. The GLFC contracted the U.S. Fish and Wildlife Service (USFWS) and the Fishery Research Board of Canada to implement sea lamprey control. In Canada, this responsibility was transferred to the Department of Fisheries and Forestry in 1966 (currently the Department of Fisheries and Oceans Canada). Both countries passed enabling legislation for implementation through the Great Lakes Fisheries Convention Act in Canada and the Great Lakes Fisheries Act of 1956 in the United States.

2000 Consent Decree

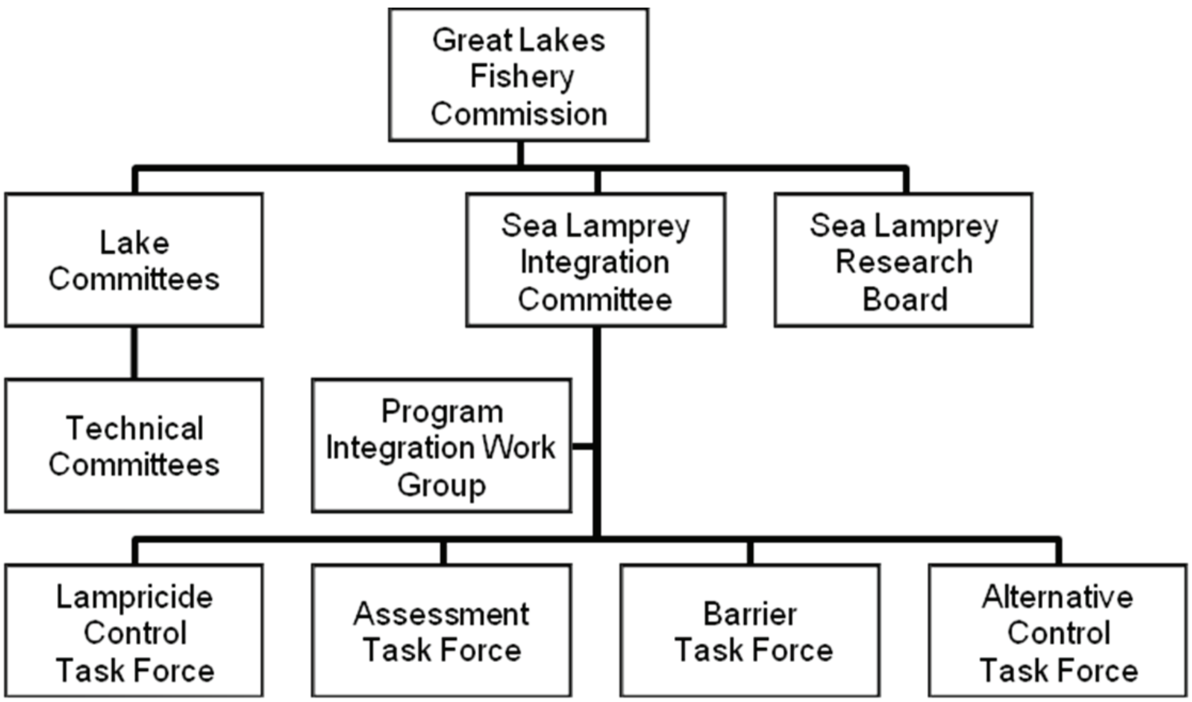
In August 2000, the U.S. District Court, Western District of Michigan Southern Division, issued a consent decree that specified how fishery resources would be managed in the portions of Lakes Superior, Michigan, and Huron, within ceded waters of the 1836 Treaty of Washington (Fig. 1). The 2000 Consent Decree (State of Michigan 2000), based on a settlement agreement among the United States, five tribal governments, and the State of Michigan, addresses lake trout rehabilitation and requires that "sea lamprey control efforts will significantly reduce sea lamprey induced lake trout mortality from 1998 levels." Failure to achieve a reduction in sea lamprey induced mortality on lake trout within the 1836 Treaty waters could result in a party requesting relief from the lake trout rehabilitation goals contained within the decree.

Fig. 1. 1836 Treaty waters of Lakes Superior, Michigan, and Huron (red).

Great Lakes Fishery Commission Committee Structure

The GLFC uses several standing committees to inform its decision making (Fig. 2). The Sea Lamprey Integration Committee (SLIC) was formed in the 1980s to serve in an advisory capacity to the GLFC on sea lamprey control issues. A Program Integration Work Group and technical task forces funnel information to SLIC to develop annual budget proposals and recommendations for an integrated control program. Guidance is provided by task forces representing assessment, barriers, lampricide control, and reproduction reduction (sterile male, trapping for control, and pheromones).

Fig. 2. Committee structure of the GLFC.



The GLFC maintains a comprehensive research program designed to provide immediate information for the control program and to develop the science needed to implement novel and effective strategies for controlling sea lampreys. The program includes internal partnerships with the U.S. Geological Survey (USGS), Hammond Bay Biological Station (HBBS), USGS Upper Midwest Environmental Science Center, and the Partnership for Ecosystem Research and Management scientists at Michigan State University and the University of Guelph. The Sea Lamprey Research Board provides guidance on the GLFC's research program and uses a series of research theme areas that describe important topics related to the control of sea lampreys in the Great Lakes. The themes are described in a series of papers published in the Journal of Great Lakes Research in 2007.

Lake committees are another advisory source to the GLFC and are the action arms for the Joint Strategic Plan for Management of Great Lakes Fisheries (Joint Plan) (Great Lakes Fishery Commission 2007). Each lake committee has technical subcommittees and work groups to investigate specific fishery issues. Based on science and technical information from subcommittees, work groups, and fish and sea lamprey control agencies, lake committee members develop common fish-community objectives, appropriate stocking levels, harvest targets, law enforcement capabilities, and management plans.

Collaboration

The value of operational fisheries-management plans is broadly recognized, particularly in mixed-stock and multi-jurisdictional contexts. Fisheries management and control of sea lampreys are inherently linked, and managers recognize that decisions on stocking, barrier removal, and habitat restoration also affect sea lamprey control. This Five-Year Plan was developed in collaboration with fisheries managers through the GLFC's Lake Technical Committees, Lake Committees, Council of Lake Committees, and SLIC.

Issues Affecting Achievement of Targets

Challenges to the delivery of an effective sea lamprey control program described below apply to all Great Lakes. In addition to these global challenges, additional topics under the same heading in each lake chapter provide details on lake-specific challenges, including protected species, species of special interest, treatment timing, discharge restrictions, treatment deferrals, pollution abatement, barrier removal, recruitment from other sources, fish-community interactions, and public use.

Protected Species

The governments of Canada and the United States have enacted the Species at Risk Act and the Endangered Species Act, respectively, to protect and recover species. Additional legislation in the United States through the National Environmental Policy Act requires federal agencies to review the effects of their proposed actions and to minimize and mitigate any potential effects on protected species. Operational elements of the sea lamprey control program have been modified in the United States where listed species are present, but similar changes have not yet been required in Canada.

In the United States, 23 federally listed species (eight plants, three mammals, three birds, two reptiles, four insects, and three mussels) inhabit streams or areas adjacent to streams where sea lamprey control is required. For most of these species, adverse effects are avoided through specified conservation measures that do not significantly disrupt scheduling of sea lamprey control activities. However, the effect of lampricide treatments on some listed or candidate species may be unknown, and formal consultation with the USFWS Ecological Services is required. These species include the clubshell mussel (*Pleurobema clava*), northern riffleshell mussel (*Epioblasma torulosa*), rayed bean mussel (*Villosa fabalis*), snuffbox mussel (*Epioblasma triquetra*), and Hungerford's crawling water beetle (*Brychius hungerfordi*). Formal consultation is also required for any listed species that may be affected by new initiatives or larger scale projects that are beyond the scope of typical annual operations (i.e., barrier or trap construction).

Besides concerns with federally protected species, individual states and provinces have their own endangered-species legislation. In addition, some agencies have required or requested that activities be scheduled to avoid other species without formal designation during spawning runs or sensitive life stages. Depending on the size of the river and the seasonal pattern of discharge, these restrictions can result in treatments when flow conditions are suboptimal. Spatial overlap between sea lampreys and species of interest has resulted in timing restrictions on lampricide treatments and other control activities. As requests to avoid certain areas and time periods increase, so does the challenge to adequately and optimally schedule sea lamprey control activities.

Treatment Effectiveness

Residual sea lamprey larvae (those that survive treatment) are a significant source of parasitic sea lampreys in the Great Lakes (Heinrich et al. 2003; Larson et al. 2003; Lavis et al. 2003; Morse et al. 2003; Sullivan et al. 2003). Treatments theoretically remove 99.9% of larvae in a stream when using lampricides applied at a concentration that meets or exceeds a minimum lethal concentration (MLC), which is the lowest concentration that causes 100% mortality during a nine-hour exposure in laboratory toxicity tests. Concentration and exposure times of lampricides are affected by several factors that vary among streams throughout the Great Lakes basin. While some factors (discussed below) are readily identified as contributing to reduced treatment effectiveness, measuring and quantifying their effects can be very difficult.

Geographic Refugia

Sea lamprey larvae survive a lampricide treatment when they occupy or enter areas that are not exposed to lethal lampricide concentrations. These refugia include seepages, springs, small feeder streams, backwater areas, and oxbows. Unless effort is targeted to treat these areas, residual larvae will remain.

Beaver Dams

Ponds upstream of beaver dams can hinder lampricide treatments in several ways. Lampricide-treated water flowing into an impoundment becomes diluted and may not penetrate all areas, especially along the stream edges. The movement of treated water is slowed by the pond, thereby altering flow times and potentially affecting treatment of reaches downstream. Furthermore, unless water leaving a dam is augmented or “boosted” with additional lampricide, the MLC will not be maintained downstream, thereby enhancing larval survival. The best approach to mitigate these issues is to open holes in the face of the dam prior to treatment, thereby lowering the impoundment and restoring flow to the natural channel. Beavers quickly repair breaches in active dams and deconstructed dams are typically rebuilt within 1-2 days following treatment. For dams that are too large to alter, a “boost” feeder must be set up at the outflow to ensure a sufficient lampricide concentration.

Unexpected Increase in Discharge

Rain events and subsequent runoff into a stream during treatment can affect both the water chemistry and the lampricide concentration such that lethality is lost. Furthermore, operators of water-control structures can release water unexpectedly, requiring an adjustment of the lampricide application to compensate for elevated flows. Depending on the success of compensation to increased discharges, sea lamprey larvae may survive.

Low Water Levels

Treatments during low water conditions that do not provide adequate flow to carry and distribute lampricides have a history of poor efficacy. Treating as many streams as possible in a given year results in a schedule with minimal latitude for rescheduling. When a treatment takes place during the assigned period and low water conditions inhibit the efficacy of the treatment, sea lampreys will likely survive, and re-treatment will be required.

Larval Sensitivity to 3-trifluoromethyl-4-nitrophenol (TFM)

In early spring, larvae are in relatively poor physical condition because they do not feed during winter. Conversely, larval condition improves from late spring to early fall as a result of increased feeding and improved diet quality. As a result, larvae show seasonal differences in their susceptibility to lampricide so that larval mortality is achieved at lower concentrations in spring than in autumn (Scholefield et al. 2008).The current lampricide toxicity charts used to determine a MLC do not account for seasonal variability in larval condition, which could contribute to under-treatment during the fall. Treatment supervisors are aware of this issue and make adjustments, but more research and attempts to quantify and adjust lampricide toxicity charts are needed.

Effect of pH on Water Chemistry and Toxicity

Stream alkalinity and pH affect TFM toxicity. Stream alkalinity is generally stable but diel fluctuations in pH can be significant, particularly in productive tributaries. Depending on the hours of the day when treatment occurs, a rise in pH may render the lampricide bank less effective, thereby resulting in higher survival of larvae. Conversely, pH suppression, usually between sunset and sunrise, increases the toxicity, which may increase nontarget mortality. Applications are done at lower concentrations over longer durations in streams that exhibit large diurnal shifts in pH so that a lethal exposure to lampreys is maintained and nontarget mortality is minimized.

Dam Deterioration and Removal

Many dams built for purposes other than blocking sea lamprey migrations provide a vital function to limit sea lamprey infestation and dam loss through neglect or removal to restore connectivity can seriously impede suppression of sea lamprey populations.

Lentic Treatments

Sea lamprey larvae found in lentic areas are more difficult to remove with lampricides than those living in river environments. Efficacy of treating lentic areas is estimated to be 75% compared with about 95% for conventional TFM treatments.

Classification of Lake Trout Marks

Inconsistency in the classification of marks among and within agencies is a challenge in interpreting marking rates. To improve consistency in the reporting of sea lamprey marking rates, several classification workshops were conducted in 2002–2003 (Ebener et al. 2006). Continuation of these workshops is necessary. Furthermore, the required amount of sea lamprey suppression is assumed to be positively related to prey abundance. Currently, lake trout abundance is estimated using data generated during the same surveys for monitoring sea lamprey marking rates. However, gear types vary along with the timing of surveys between agencies and lakes. Standardization of gear, methods, and timing of assessments is crucial to understanding interactions between sea lampreys and their prey.

Funding

The 2010 investment of approximately $26 million (USD) by both the Canadian and United States governments helps to protect a basinwide recreational and commercial fishery valued at more than $7 billion (USD). As with most fishery-management programs, sea lamprey control requires the allocation of resources among component sub-programs to enable goals to be realized. Ongoing evaluation of program components has resulted in numerous changes to the overall program in the past two decades, including changes to the spawning-phase assessment program (Bence et al. 1997), larval assessment program (Hansen et al. 2002), sterile-male release technique (SMRT) program (Koonce et al. 2003), and barrier program (Mullett et al. 2010). In addition to implementation of the control program, the GLFC is also responsible for ensuring that research and technical assistance are positioned to advance and maximize the effectiveness of sea lamprey control. These functions compete for the same funds, and, in a time of rising costs and tighter budgets, securing adequate funding becomes more challenging.

Target Setting

Fish-Community Objectives

Performance indicators used to evaluate the effectiveness of the sea lamprey control program were derived from fish-community objectives (FCOs) developed by individual lake committees as part of the Joint Plan. These FCOs are used to coordinate management of desirable fish communities across jurisdictions and to serve as the basis of periodic state-of-the-lake (SOTL) reports. The establishment of FCOs and the associated SOTL reporting process is a model of cooperative fishery management that serves to inform management agencies and the public about critical fisheries issues. Sea lamprey control is an integral part of many of the FCOs, and most lake committees have a specific FCO for sea lampreys.

Sea Lamprey Suppression Targets

During 2004, the lake committees agreed to explicit targets for sea lampreys that support fish-community objectives. Summaries of current spawning-phase sea lamprey abundance, counts of sea lamprey marks on lean lake trout >533 mm, and lake trout relative abundance in each lake are the primary metrics used to gauge success of the sea lamprey control program. The status of sea lampreys in each of the Great Lakes is measured by comparing annual abundance estimates with target levels.

Program Components

Lampricide Application

Of 487 tributaries to the Great Lakes that have historical records of sea lamprey production, about 169 are treated at regular intervals. The primary method to control sea lampreys is application of the lampricide TFM. Often, TFM treatments are augmented with a 70% wettable powder or 20% emulsifiable concentrate of granular Bayluscide (gB), which increases the toxicity of TFM to lampreys, thereby allowing the use of less TFM. Treatments with TFM and TFM-Bayluscide mixtures are estimated to eliminate about 95% of sea lamprey larvae while minimizing the risk to nontarget organisms. Bayluscide (without TFM) is also used in a 3.2% granular form to treat lentic areas. TFM and Bayluscide are registered pesticides with the U.S. Environmental Protection Agency (USEPA) and Health Canada.

Larval Assessment

The larval assessment program is designed to monitor the distribution and abundance of sea lampreys in tributaries and inshore areas of the Great Lakes to determine where, when, and how often lampricide treatments should occur; when treatments are required; and how effective past treatments have been (Slade et al. 2003). Survey tools include backpack electrofishers for waters that are wadeable, deep-water electrofishers, and gB for lentic areas. In addition, Rox Ann seabed classification sonar is used to identify and map larval habitat in lentic areas. Surveys identify the presence, abundance, and size structure of sea lamprey populations according to the following sampling protocols:

1. Each tributary to the Great Lakes with potential for producing sea lampreys but with no record of sea lamprey infestation is sampled at least once every ten years.
2. Each tributary to the Great Lakes with a history of sea lamprey production is sampled at least once every three to five years to document potential recruitment to the parasitic-phase population and sizes of larvae.
3. Each tributary to the Great Lakes containing larvae ≥100 mm in length at the end of the growing season is sampled to rank it for possible treatment the following year.
4. Tributaries are sampled within one year of treatment to determine if larvae survived treatment.
5. Areas upstream of barriers to spawning-phase sea lampreys are sampled once every three to ten years to detect whether breaches have allowed passages.

Selection of Streams for Lampricide Treatment

During 1996–2007, the Empiric Stream Treatment Ranking (ESTR) model (Christie and Goddard 2003) was used annually to rank streams for treatment based on the ratio of individual treatment costs to the projected number of metamorphosing sea lampreys killed. Beginning in 2008, the ESTR model was modified to incorporate the estimated number of larvae ≥100 mm rather than the projected number of metamorphosing sea lampreys that could be killed by a treatment. Furthermore, Quantitative Assessment Surveys were replaced by ranking surveys, which are less precise but less labor intensive. The reduced survey effort was re-directed towards treating additional streams. Because all infested streams cannot be annually treated with current funding and staffing levels, this approach ensures that an expanded number of treatments will target those populations most likely to cause damage to fish stocks.

Other streams, in addition to top-ranked streams, are added to the treatment schedule when they meet any of the following criteria:

- Lentic producers: Small, high-gradient streams treated annually to reduce recruitment to lentic areas. Treating the lentic area is less effective than treating the source stream before lentic populations establish.
- Special cases: Expert judgment:
  - Streams that, in the past, required treatment every three to five years.
  - Streams with consistent annual recruitment.
  - Streams where a year-class re-established immediately following a treatment.
  - Streams where larval assessment costs exceed treatment costs.
  - Streams in areas having high marking rates.
  - Streams where catch-per-effort surveys indicate large larvae are present.
  - Where research requires treatment.
- Deferrals: Streams ranked for treatment the previous year but not treated because of complicating factors, such as high flows.
- Geographic efficiency: Streams not ranked for treatment but deemed cost-effective to treat based on proximity and larval abundance.

Trapping

Sea lampreys are trapped during two of their life stages: upstream-migrating adults (spawning phase) and downstream-migrating young juveniles undergoing metamorphosis. Trapping of spawning-phase sea lampreys serves three purposes: to assess their abundance, which is used to evaluate the overall effectiveness of control; to provide male sea lampreys for sterilization; and to remove sea lampreys from the spawning population. Trapping of young juveniles also serves three purposes, which are to:

- Assess the number of metamorphosing lampreys recruiting to the parasitic population in a lake.
- Remove sea lampreys from a stream during their downstream migration to the lake just prior to their parasitic phase.
- To provide sea lampreys to researchers.

Metamorphosing sea lampreys were trapped in tributaries of Lake Superior during 1998-2003, of Lake Michigan periodically during 2004-2007, and of Lake Huron during 1997-2007 to estimate their abundance in each lake. However, this method of estimating abundance was discontinued after 2007. Metamorphosing sea lampreys are now trapped only for special needs.

Spawning-phase lampreys are trapped annually from about 72 tributaries. Data from trap catches are used to generate estimates of abundance, which are used to evaluate the effectiveness of sea lamprey control. Abundance estimates are derived individually for each lake as a composite of stream-specific estimates from mark-recapture, of historical trap efficiency information, and of model predictions based on tributary-specific values for drainage area, geographic region, larval sea lamprey production, timing of the last lampricide application, and year (Mullett et al. 2003). During 2010-2012, the factors that influence the precision and accuracy of the spawning-phase model will be evaluated. Results of this evaluation should improve estimates of spawning-phase sea lamprey abundance for all of the Great Lakes.

Lampreys that are trapped for control during their spawning-phase are either used as source animals for the SMRT program or are killed. Removal of spawning-phase sea lampreys to reduce reproduction has not been an explicit strategy in any river other than the St. Marys until recently.

Trapping for control is optimized when trap placement and capture efficiency result in reduced spawner densities (<0.2 spawning pairs per 100 m^{-2} of larval habitat) (Dawson 2007). Trapping efficiencies needed for control are usually higher than those needed for assessment.

Effort directed at metamorphosing lampreys is less than that directed at adults. Although trapping of metamorphosing lampreys has been used as a population-assessment method, it is now used for reducing outmigration to the lake or to provide sea lampreys for research. Inclined plane traps (Manion and McLain 1971), fykenets, and screw traps (U.S. Fish and Wildlife Service, unpublished data) have all been used to capture metamorphosing sea lampreys during their downstream migration. Electrofishing has also been used, but this method is typically very labor intensive.

Alternatives to Lampricides

Sterile-Male Release

The SMRT program aims to reduce the success of sea lamprey reproduction, and the first field study for its potential use began in 1974 (Hanson and Manion 1980). Laboratory and field studies have shown that chemically sterilized male sea lampreys are sexually competitive (produce mating pheromones and exhibit typical spawning behaviors) but do not produce viable offspring so fewer sea lamprey eggs hatch in streams where the technique is used (Hanson and Manion 1980; Bergstedt et al. 2003).

Since 1997, the SMRT program has been used only in the St. Marys River as part of an integrated control plan (the river is too large to be treated traditionally with lampricides). Male sea lampreys are collected from about 25 trapping locations on tributaries to four of the five Great Lakes, transported to a sterilization facility at the USGS HBBS where they are sterilized with the chemosterilant bisazir (Twohey et al. 2003). The sterilized males are then released into the St. Marys River where they compete with fertile males for mates. On average, 24,000 sterilized sea lampreys are released into the St. Marys River annually. The theoretical reduction in the number of spawning-phase female sea lampreys from trapping and sterile-male release averaged 86% during 1997-2010.

Pheromones

The application of sea lamprey pheromones is being developed as a potential alternative control method for sea lampreys (Twohey et al. 2003; Li et al. 2007). Several components of two pheromones that regulate migration and reproduction have been identified and synthesized: petromyzonamine disulfate (PADS), petromyzosterol disulfate (PSDS), and petromyzonal sulfate (PS) affect migration; 3-ketopetromyzonol sulfate (3kPZS) affects mating.

PADS, PSDS, and PS are believed to play a role in stream selection for lake-dwelling adults in search of a suitable stream, while the male pheromone 3kPZS has been shown to lure up to 60% of females into traps set in rivers in certain environments (Johnson et al. 2009). Field trials began during 2009 to test the efficacy of 3kPZS in barrier-integrated traps, and additional studies continue to test its effect on sea lamprey behavior and trapping efficiency when deployed on spawning grounds below a barrier.

Potential strategies that will be practical, effective, and economical on a basinwide scale are being explored by a hypothesis-driven approach that integrates concepts and experimental methods from several disciplines to elicit the exact function of the identified pheromones (Li et al. 2007). Sea lamprey pheromones are the first vertebrate pheromones permitted by the USEPA for experimental release into streams.

Barriers

Barriers are effective control devices that contribute to sea lamprey suppression in many streams across the Great Lakes basin by preventing access to suitable spawning habitat, thereby eliminating or reducing larval sea lamprey production and the need for lampricide treatments.

Barriers important for sea lamprey control include those specifically constructed to block sea lamprey spawning migrations and those constructed for purposes other than sea lamprey control. In some situations, sea lampreys may spawn downstream from barriers, but these stretches of streams are usually short and, therefore, easier and less expensive to treat. Potential drawbacks to constructing barriers in new locations or to replace deteriorated barriers include escalating construction and maintenance costs, safety concerns related to the creation of dangerous hydraulic conditions during high water, restrictions to fish passage that cannot be fully mitigated through fish-passage devices or manual transfer operations, and impediments to navigation.

The barrier program has three priorities:

1. Operate and maintain existing GLFC structures.
2. Cooperate with partners to ensure sea lampreys are blocked at non-GLFC structures.
3. Construct new structures in streams where they:
   a. Provide control where other options are not possible or effective.
   b. Provide a cost-effective alternative to lampricide control.
   c. Provide cost-effective control in conjunction with pheromone-based control methods, trapping, sterile-male release, and lampricide treatments.
   d. Are compatible with a system's watershed plan.

Other Methods of Alternative Control

New initiatives have been proposed to reduce larval production by intensively removing adult lampreys (with methods other than trapping) in streams with small populations of spawning-phase sea lampreys. The goal of the strategy is to supplement trapping with manual removal and nest destruction to further reduce reproductive success after the spawning-phase population has already been reduced. Other methods of alternative control may eventually include areas under research, such as genetic manipulation, agonists and antagonists to pheromones, and repellents.

Measures of Success and Progress

Metrics and Measures of Success

Current metrics of program success are annual:

1. Lakewide estimates of spawning-phase sea lamprey abundance.
2. Counts of sea lamprey marks on lake trout.
3. Lakewide estimates of lake trout abundance.

These metrics represent the interplay of the predator (sea lamprey abundance), its primary prey (lake trout abundance), and the predator/prey ratio (marking rate).

Basinwide Trends Relative to Targets

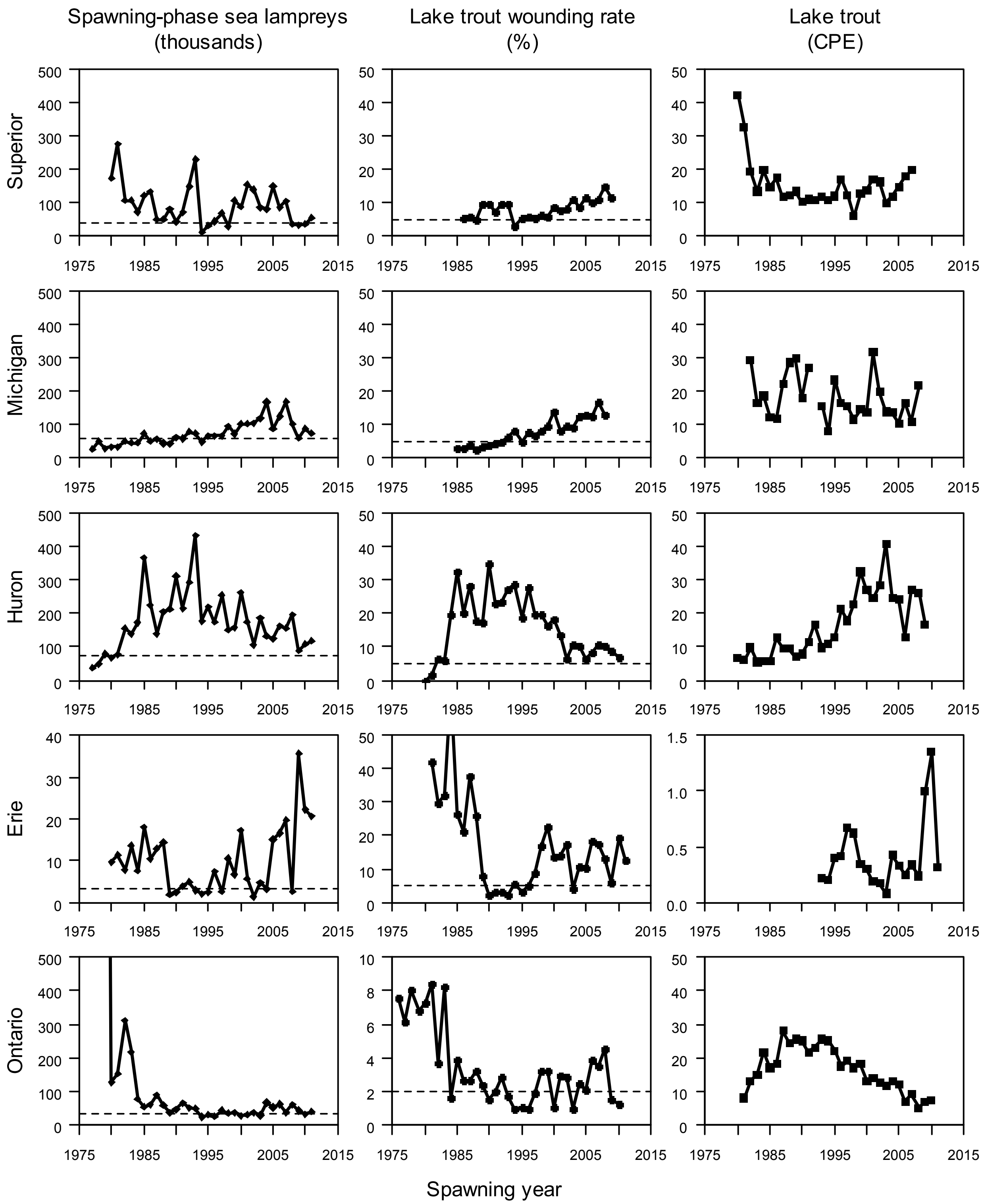
Since the onset of sea lamprey control and the application of selective lampricides that target larval populations in Great Lakes tributaries, spawning-phase sea lamprey abundance across the Great Lakes has declined by about 90%. The present cost-benefit approach to prioritizing stream selection has reduced the number of adult sea lampreys to a relatively constant 400,000, but it has been insufficient to reach and maintain target levels in individual lakes for extended periods.

Lake-Specific Trends Relative to Targets

Spawning-Phase Sea Lamprey Abundance

Annual estimates of spawning-phase sea lamprey abundance are generated from spawning-phase assessment data collected from traps, and they are the primary performance indicator to evaluate the success of the sea lamprey control program (Fig. 3). Targets for spawning-phase sea lamprey abundance represent the abundance of sea lampreys during years when marking rates were tolerable, that is, causing <5% annual mortality on lake trout. These targets were estimated from historical sea lamprey abundance estimates and from lake trout marking data.

Fig. 3. Estimates of spawning-phase sea lamprey abundance, lake trout marking rates (Type A, Stages I-III marks per 100 lake trout >433 mm; Stage I marks only for Lake Ontario), and lake trout relative abundance (lake trout >532 mm per kilometer of survey gillnet set) in each of the Laurentian Great Lakes. Note the different scales for Lake Erie sea lampreys, Lake Erie lake trout, and Lake Ontario marking rate.



Spawning-phase sea lampreys (thousands)
Lake trout wounding rate (%)
Lake trout (CPE)
Superior
Michigan
Huron
Erie
Ontario
Spawning year

Lake Trout Marking Rates

Annual data on sea lamprey marking of lake trout are collected by provincial, state and tribal management agencies associated with each lake. Marks on fish are classified based on the system developed by King and Edsall (1979) and Ebener et al. (2006) that identified the severity and stage of healing of observed marks. The number of Type A, Stages I-III marks observed in ongoing assessments is compared to a target of 5 marks per 100 lake trout >533 mm in all lakes except Lake Ontario, where the number of Type A, Stage I marks is compared to a target of 2 marks per 100 lake trout >431 mm (Fig. 3).

Lake Trout Relative Abundance

During 2007, relative lake trout abundance was added as a metric used to monitor the success of the sea lamprey control program (Fig. 3). Like spawning-phase sea lamprey abundance, the number of lake trout can influence marking rates and must be considered when interpreting marking rates as a performance indicator. Lake trout relative abundance estimates also provide performance measures that indicate increasing or decreasing survival of lake trout. Lake trout relative abundance is estimated for each lake from assessments conducted by management agencies and is updated as more data becomes available.

Research Needs

Numerous sea lamprey control research needs have been identified in a series of five research themes published in the Journal of Great Lakes Research in 2007 and are intended to benefit sea lamprey control in the Great Lakes. The most relevant of these include:

- Identify sources of parasitic sea lampreys, including treatment variables that enable sea lampreys to survive treatment.
- Develop decision analyses to support sea lamprey treatment prioritization.
- Assess spawning-phase sea lamprey abundance in large rivers and rivers that are otherwise not trappable.
- Increase understanding of variation in parasitic sea lamprey survival among and within lakes.
- Deploy pheromone technologies.
- Develop novel approaches to trapping in large rivers and streams without barriers.
- Develop fish-passage options that prevent upstream passage of sea lampreys.
- Develop methods that minimize effects of sea lamprey control on nontarget organisms.
- Increase knowledge of sea lamprey feeding, marking, and host mortality in relation to variable host abundance and size structure.
- Increase understanding of survival and compensatory actions of newly metamorphosed sea lampreys.
- Increase understanding of linkages between sea lamprey abundance, the control program, and fish-community responses.
- Investigate new techniques and technologies, such as pheromone assays of river water or environmental DNA analysis to quantify treatment effectiveness.

Reporting and Updating

Reporting

Control agents will continue to draft an annual report to the GLFC and its committees that describes control actions taken and the status of sea lampreys in the Great Lakes. A summary of this information is typically presented to the lake committees and the GLFC during their annual meetings.

Five-Year Plan Review and Revision

This plan will be reviewed and revised on a five-year basis. The plan is expected to adapt to changes in both the fish community and funding opportunities. The plan is envisioned as a working plan that will be changed continuously in response to a growing understanding of how best to suppress sea lampreys in each Great Lake.

More information on sea lamprey and fisheries management in the Great Lakes can be obtained from www.glfc.org.

CHAPTER 2: FIVE-YEAR PLAN FOR LAKE SUPERIOR

Mike Steeves[3]

Introduction and History

This chapter provides a specific plan for sea lamprey (*Petromyzon marinus*) control in Lake Superior that builds on the general basinwide discussion of sea lamprey control outlined in Chapter 1 (Sea Lamprey Control in the Great Lakes Basin). The most recent synthesis of sea lamprey control in Lake Superior (Heinrich et al. 2003) was published in the Journal of Great Lakes Research in 2007 as a contribution to the Sea Lamprey International Symposium II. This paper is a good document to review for those interested in additional information on sea lamprey control in Lake Superior. The Great Lakes Fishery Commission (GLFC), in collaboration with fisheries managers, has developed this lake-specific Five-Year Plan as an integrated sea lamprey control strategy that focuses on lakewide and locality-specific control tactics to maintain sea lamprey populations at or below target levels.

Sea lamprey control began on Lake Superior in 1950 with installation of mechanical weirs on two tributaries to block spawning migrations of adult sea lampreys (Lavis et al. 2003) and expanded further in 1954 through the use of traps and electrical barriers (Smith et al. 1974). However, electrical barriers were costly, prone to failure, sometimes unsafe, and did not prevent sea lamprey larvae that were already in the stream from metamorphosing and migrating to the lake to inflict damage on fish. By 1979, use of electrical barriers was discontinued on tributaries to Lake Superior.

Use of lampricides as a control tool began in 1958 when 12 Lake Superior tributaries were treated with 3-trifluoromethyl-4-nitrophenol (TFM) (Smith et al. 1974). By 1961, 72 streams were treated. The effects were immediately obvious when 86% fewer sea lampreys were captured during spawning runs, the marking rate declined on host species (Fig. 4), fewer larvae were collected from streams, fewer streams were used for spawning, and the abundance of fish increased in the lake (Smith et al. 1974).

The dramatic decline in spawning-phase sea lamprey abundance from the pre-control estimate of 780,000 (85% by 1961 and 90% during 2004-2008) is attributed to the effects of lampricide

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treatments that reduced recruitment of parasitic sea lampreys to the lake population. Since 2005, increased control effort reduced sea lamprey abundance, and, during 2008–2009, spawning-phase sea lamprey abundance was within the target level for the first time since 1998 (Fig. 5). However, the general trend in sea lamprey marking rates continues to increase (Fig. 6), and sea lamprey induced mortality on lake trout (*Salvelinus namaycush*) continues to exceed fishing mortality.

Fig. 4. Catch of spawning-run sea lampreys at 16 U.S. barriers in Lake Superior during 1959-1971 (scale at top) and corresponding marking rates on lake trout 610-632 mm (24.0-24.9 in) during 1958-1970 (scale at bottom). Marking rates from the fall of the year are set forward one year to correspond with the catch of sea lampreys that caused the marking (reproduced from Fig. 17 in Smith et al. 1974).

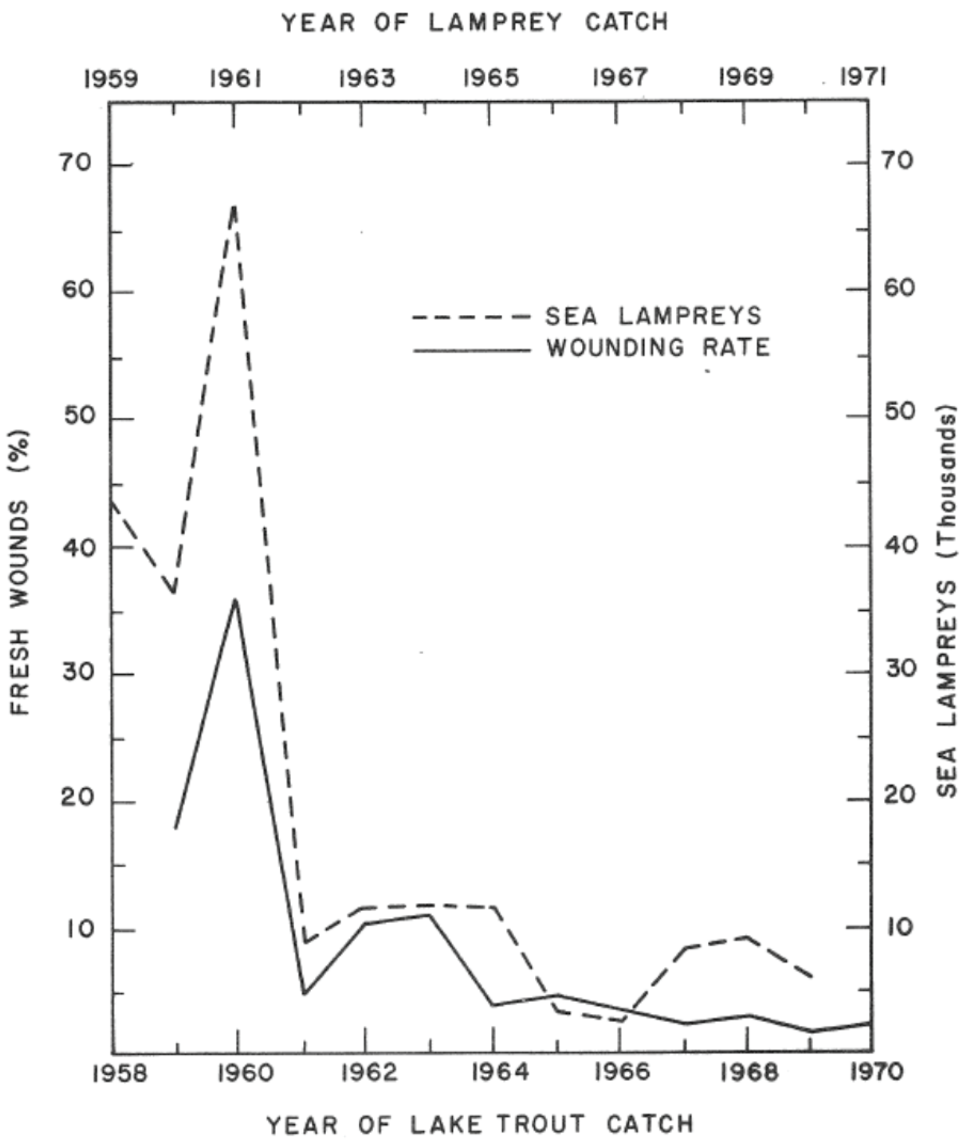


Fig. 5. Annual lakewide estimates of sea lamprey abundance (+95% confidence intervals) in Lake Superior during 1980-2010. The solid horizontal line represents the abundance target of 34,000 spawning-phase sea lampreys, and the dashed horizontal lines are the 95% confidence interval for the target.

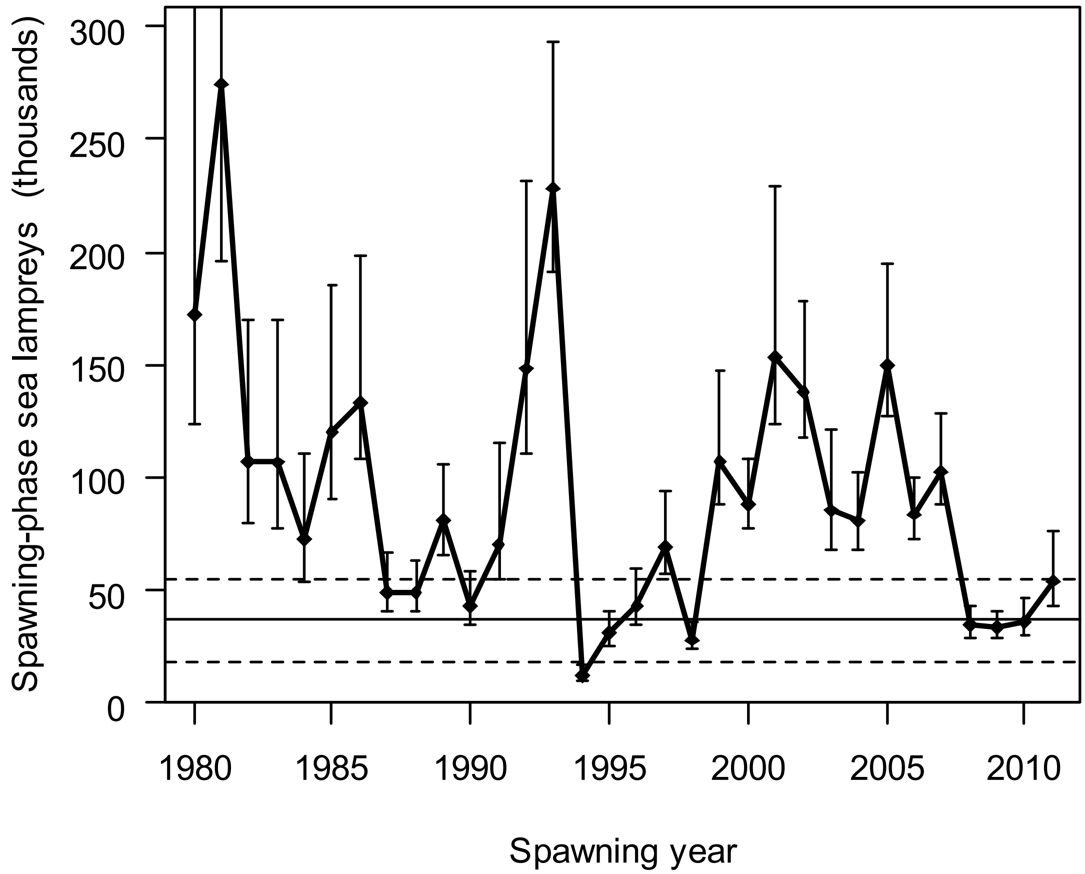
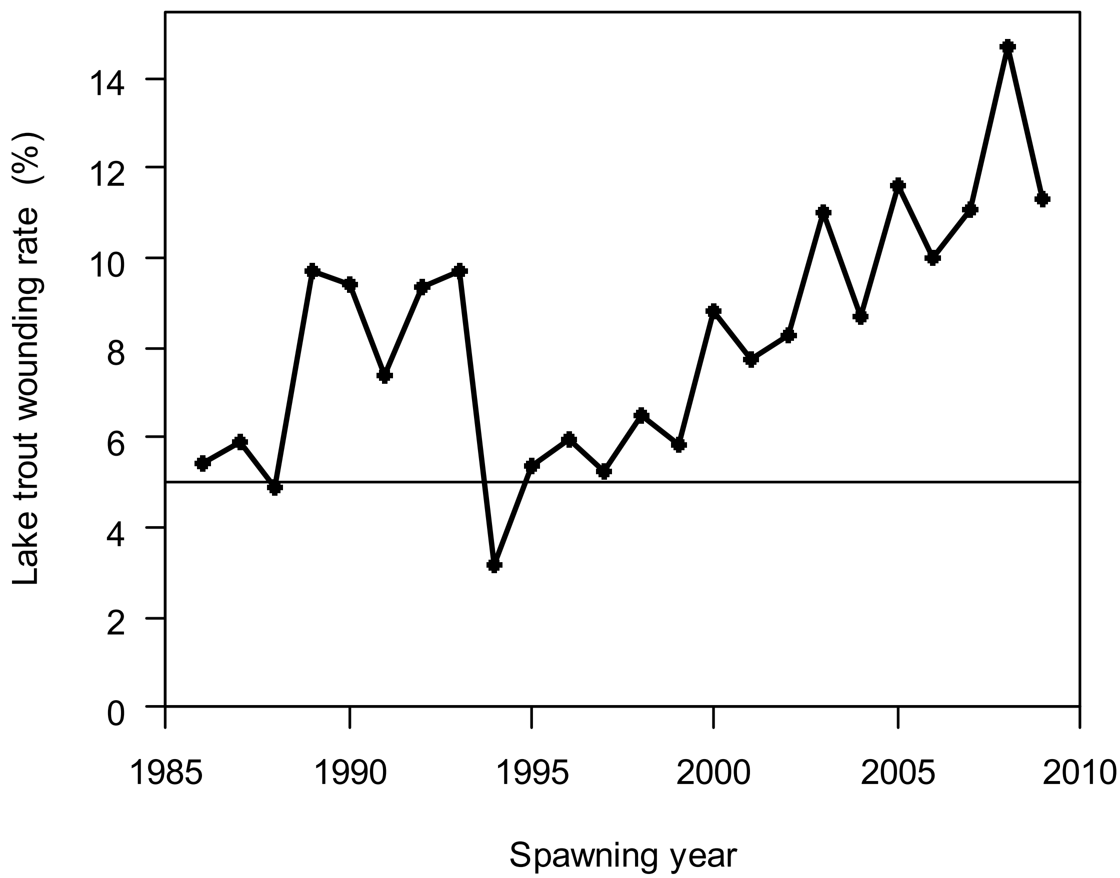


Fig. 6. Annual lakewide estimates of sea lamprey marking rates on lake trout 533 mm or larger in Lake Superior during 1985-2007. The solid horizontal line represents the marking-rate target of 5 marks per 100 lake trout.



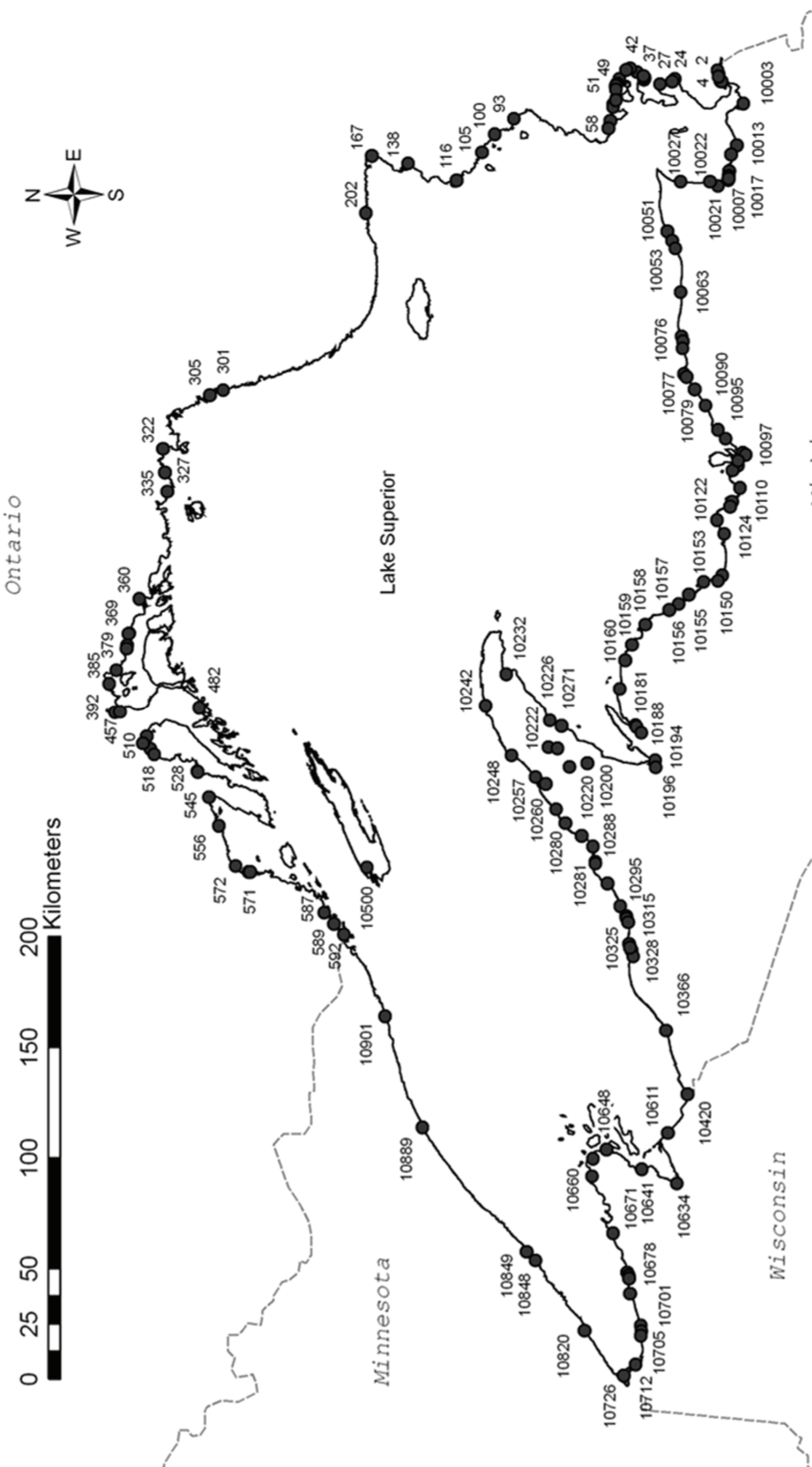
Features of the Lake

Lake Superior is the world's largest freshwater lake by area and geographically the most northerly of the Laurentian Great Lakes (Smith and Tibbles 1980). The International Boundary divides the surface area between the two countries (65% United States, 35% Canada). Lake Superior's primary source of water is from precipitation and runoff, while groundwater inflow is negligible (Matheson and Munawar 1978). Lake Superior is considered a highly oligotrophic lake, but total yield to fisheries has been relatively high because of the enormous surface area of the lake (Lawrie 1978).

Lake Superior has the coldest summer surface temperature and average annual temperature of all the Great Lakes, where the average lake temperature does not rise above 6°C, but the surface water temperature ranges 10°-16°C (Bennett 1978). Lake temperature, particularly in the summer months, does not likely limit the distribution of parasitic sea lampreys and their primary salmonid hosts (Swink 1993; Coutant 1977). However, cold water temperatures affect the metabolism of both sea lampreys and their hosts to potentially reduce predation mortality in Lake Superior compared to other lakes. Furthermore, when spawning streams do not warm rapidly, sea lampreys may abandon an initially selected stream in favor of a more suitable stream (Applegate 1950). Effects of climate change that may increase seasonal or annual temperatures of Lake Superior could affect the metabolism of parasitic-phase sea lampreys, alter reproductive success of spawning-phase sea lampreys, and decrease the time to metamorphosis of larval sea lampreys through increased growth rate.

Streams that attract sea lampreys are distributed throughout the Lake Superior basin (Fig. 7), but are most numerous along the south shore and least numerous along the Minnesota and northeastern Ontario shores (Morman et al. 1980). Toxicity of lampricide is inversely related to pH and alkalinity, and, because Lake Superior tributaries have lower alkalinity and pH than other Great Lakes, less lampricide per unit of discharge is required for effective control. However, Lake Superior's great size and numerous large tributaries containing sea lampreys lead to high treatment costs because of high flow volumes and the large geographic area.

Fig. 7. Location and number of Lake Superior streams with records of larval sea lamprey infestation. Numbers correspond to Appendix B.


Ontario
Lake Superior
Michigan
Wisconsin
Minnesota
Kilometers
0 25 50 100 150 200
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W
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49
51
58
93
100
105
116
138
167
202
301
305
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327
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360
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385
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510
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10901
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Unique Issues

Lake Superior has 1,566 tributaries, of which 153 have records of larval sea lamprey production (Fig. 7). Stream-specific estimates of spawning-phase sea lamprey abundance vary widely among streams (Fig. 8) and generally correspond to stream-specific estimates of maximum larval sea lamprey production (Fig. 9). For example, the Bad and Ontonagon Rivers have a high abundance of both larval sea lampreys and spawning-phase sea lampreys.

Fig. 8. Five-year average stream spawning-phase abundance estimates in Lake Superior during 2005-2009. Streams with the highest five-year average that combine for more than half the Lake Superior total are identified by name. Colors indicate whether the source of most (at least three of the five) of the annual estimates were from mark-recapture (blue) or not (orange). For reference, the five-year average of spawning-phase sea lamprey abundance for the Bad River is 13,000. Estimates for all streams are listed in Appendix B.

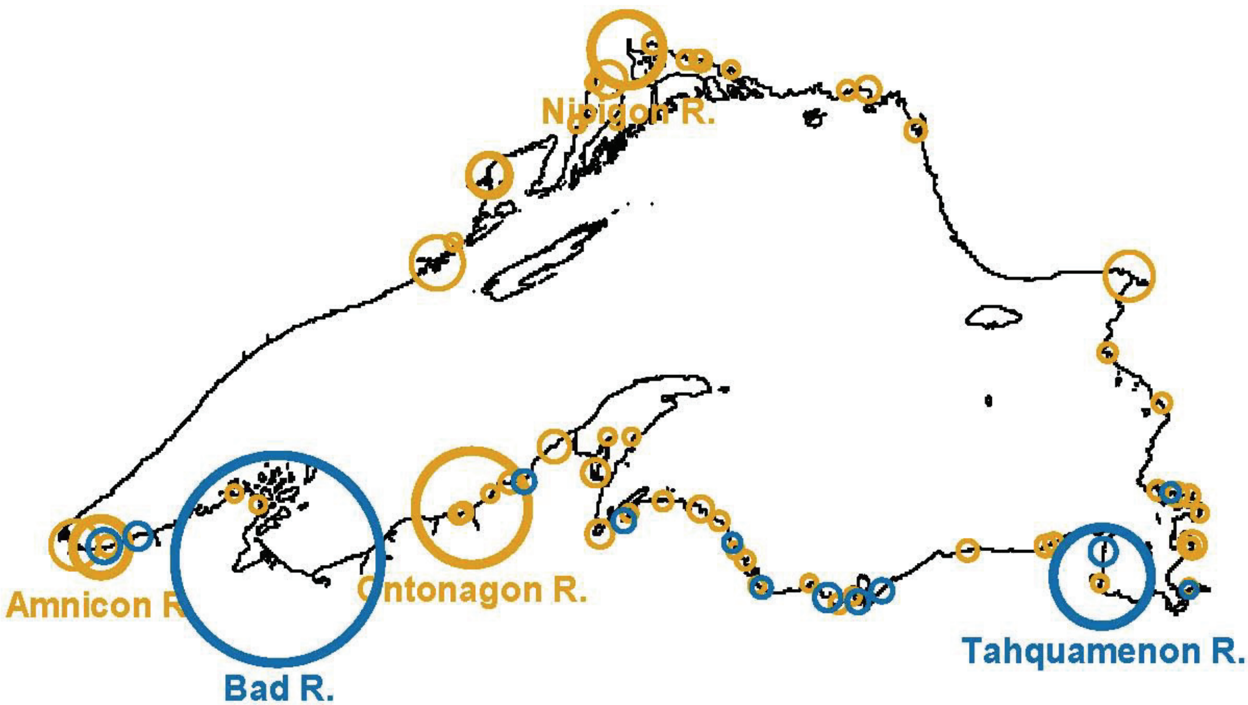
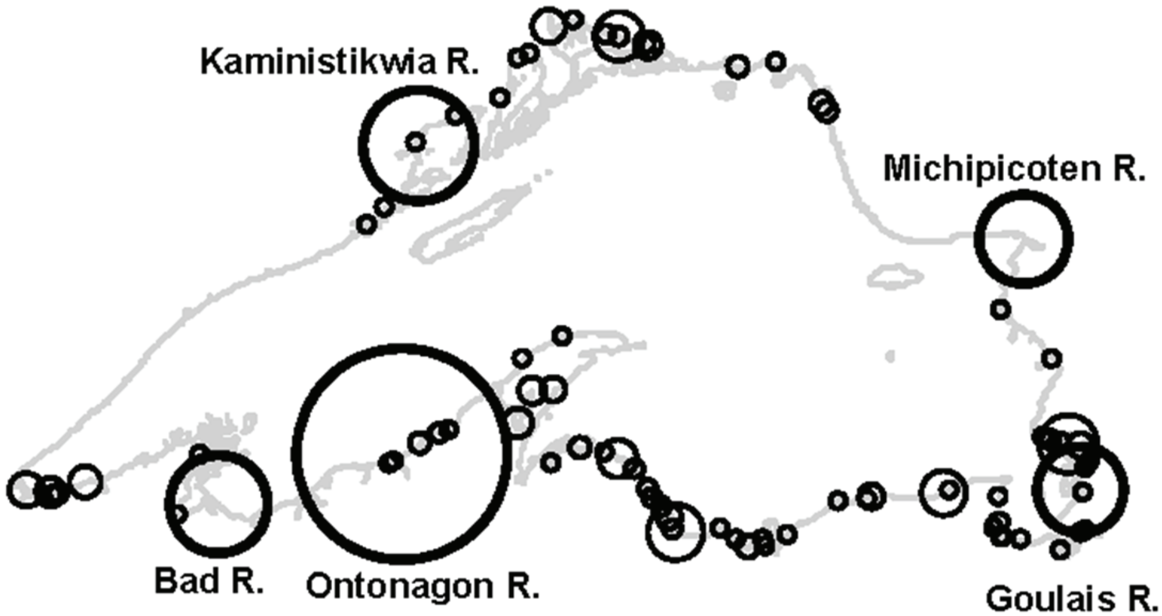


Fig. 9. Maximum estimates of larval-phase sea lamprey abundance in Lake Superior tributaries during 1996-2008. Streams with the highest estimates that combine for more than half the Lake Superior total are identified by name. For reference, the maximum estimate for larval-phase sea lamprey abundance in the Ontonagon River is 4.03 million. Estimates for all streams are listed in Appendix B.



Streams that have the potential to produce large numbers of parasitic-phase sea lampreys and provide unique treatment challenges are summarized in Table 1 and discussed in detail below:

- Nipigon River: Application of TFM to the river is unique because flow must be regulated for three days to allow Lake Helen, an intermediate lake in the Nipigon River system, to drain and create stable flows from the upper river. Nonetheless, control agents have been successful in partnering with Ontario Power Generation to control sea lampreys in the river.
- Kaministiquia River: This river supports a large larval sea lamprey population, estimated via mark-recapture at 1.2-million larvae during treatment in 2006. Remediation of the lower 8.4 km of the river has improved habitat and thereby increased subsequent infestation of sea lampreys, where sea lampreys were not detected in sampling conducted prior to 2005. The lower portion of the river is primarily at lake level, inhibiting the ability of TFM treatments to effectively reach sea lampreys in this area. The best available treatment method for the lower Kaministiquia River is to treat high density areas with granular Bayluscide (gB), a bottom-release toxicant, at a lower efficacy than a conventional lampricide treatment.
- St. Louis River: This border stream between Wisconsin and Minnesota has the potential to produce a large number of larval sea lampreys. Poor water quality and contaminated sediments are suspected as primary impediments to successful sea lamprey recruitment in the

river. A comprehensive survey using a habitat inventory system and gB during 2006 captured <20 sea lamprey larvae in a limited number of locations throughout the river. The river is surveyed every few years to monitor recruitment changes, but is not considered currently to be a significant producer. RoxAnn© sonar was used in 2010 to classify substrates for suitability as larval sea lamprey nursery habitats in the estuary. Sampling of these substrates for the presence of sea lampreys was conducted in 2011, subsequent to substrate classification.

- Black Sturgeon River: The barrier on this river, known as the Camp 43 dam (Fig. 10), was constructed as a control structure for the timber industry and was refitted to block all fish passage, including sea lampreys, in 1966. The barrier is expected to need significant repair within the next 20 years. Options to enable passage of migratory fish, including walleye and lake sturgeon, while minimizing additional sea lamprey production, are being evaluated by the Ontario Ministry of Natural Resources (OMNR), Fisheries and Oceans Canada, and other stakeholders. The two options being evaluated are refurbishment of the current barrier with the inclusion of trap-and-sort fish passage and decommissioning the current barrier after constructing a new barrier at the site of a former barrier, the Camp 1 site (Fig. 10). The Camp 1 option is expected to allow walleye (*Sander vitreus*) and lake sturgeon (*Acipenser fulvescens*) access to 50 additional km of potential spawning habitat to increase production of these species in Black Bay at the expense of increased sea lamprey production and exposing over 14-million northern brook lampreys (*Ichthyomyzon fossor*) to lampricide. The trap-and-sort option does not increase sea lamprey production, but fewer walleye and lake sturgeon are likely to pass above Camp 43. The number of walleye and lake sturgeon adults that must be passed to significantly increase Black Bay fishery production is uncertain. As of June 2010, the recommendation of the Fisheries Management Zone 9 (FMZ9) Advisory Council, a consultation group of stakeholders in the Black Bay area, is to put both options forward for an environmental assessment with Camp 1 as the preferred option and trap and sort as an alternate option. More information on the OMNR consultation regarding Black Bay and the Black Sturgeon River can be found in the FMZ 9 Recommendations and Rationale document (Bobrowicz et al. 2010).
- Bad River: This river is a complex, dendritic system that drains about 267,000 ha and provides more than 533 km of cold- and cool-water fish habitat. Sea lampreys infest about 203 km with an estimated larval population exceeding 1.6-million larvae, the second-largest larval sea lamprey population along the south shore. The Bad River is treated, on average, every three years with all sea lamprey control activities in the Bad River coordinated through negotiations with the Bad River Band of Lake Superior Chippewa Indians. The Marengo River, a tributary to the Bad River, consistently produces residual larvae because of its plentiful groundwater seeps and other refugia. The challenge for the Bad River is to develop strategies that effectively reduce recruitment and residual lampreys with an emphasis on increasing the use of alternative control methods.
- Ontonagon River: This highly dendritic river is considered to be the most productive sea lamprey producing river in the Lake Superior basin (Fig. 8). Larval abundance is estimated at more than 4-million larvae at full recruitment. The river is also considered to be a lake sturgeon producing river, so gB surveys and lampricide treatments are constrained to periods after the first of August each year, as specified by permits granted by the State of Michigan.

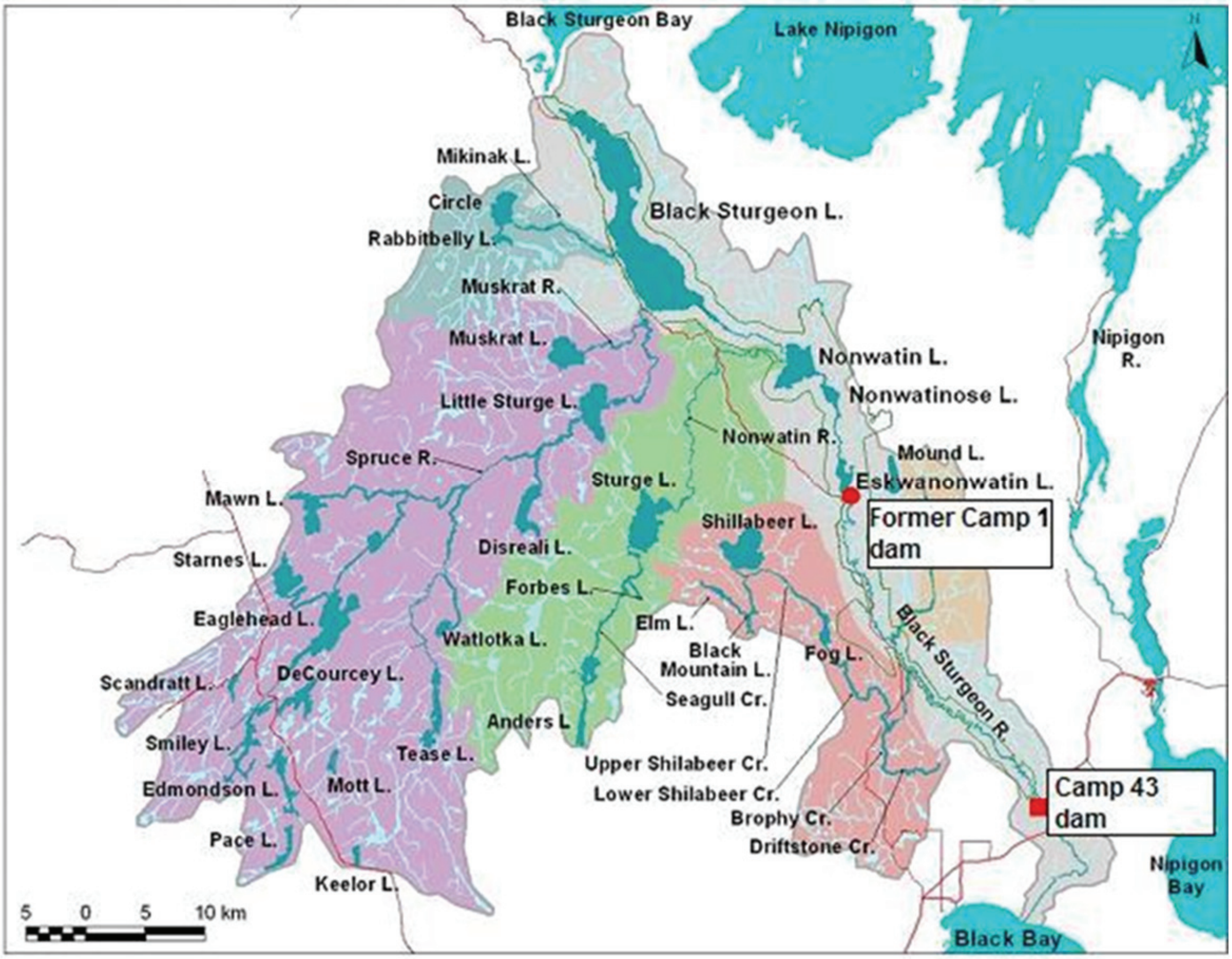
Effective treatments can be difficult to achieve because of unfavorable water conditions during the time available for treatment. Incorporating a method to trap the spawning migration may reduce larval sea lamprey recruitment, provide mark-recapture estimates of spawning-phase abundance on a large river, and provide male sea lampreys for the sterile-male release technique (SMRT) program.

Table 1. Summary of challenges to effective treatment of sea lampreys in Lake Superior. Sensitive species and variable discharge limits the period available for treatment

Stream	Sensitive species	Discharge	Secondaries*	Dendritic	Lentic	Access	Beaver dams
Batchawana River			X		X		
Goulais River			X				
Michipicoten River		X	X				
White River						X	
Pic River			X			X	
Pays Plat River			X			X	
Gravel River					X		
Big Trout Creek			X			X	X
Nipigon River		X	X		X		
Kaministiquia River		X	X		X		X
St. Louis River				X			
Bad River				X		X	
Ontonagon River	Salmon	X		X			
Tahquamenon River					X		

*Secondary lampricide treatments focus chemical application in areas of potential refuge such as backwaters, oxbows, or beaver dams. Treatment of these areas is labor intensive but improves treatment effectiveness.

Fig. 10. The Black Sturgeon River watershed. Locations of the current sea lamprey barrier at Camp 43 (square) and the former Camp 1 barrier (circle) are shown.



Potential Sources of Parasitic-Phase Sea Lampreys

Potential sources of sea lamprey production include larvae that escape a lethal dose of lampricide during treatment (residuals), untreated populations (including deferred treatments), and undetected populations.

Residuals are likely the most significant source of transformers in Lake Superior (Heinrich et al. 2003). In streams with large larval populations, even a small percentage of residuals can contribute to a high abundance of transformers before the next treatment occurs. Strategies to address both deferred treatments and residuals in large streams are addressed later in this plan.

Lake Superior has more areas of lentic infestation than any other Great Lake, such as sheltered embayments on Batchawana Bay and Mountain Bay (Gravel River), but also estuarine areas, such as the lower Nipigon and Kaministiquia Rivers. These areas provide refuge for sea lamprey larvae but are untreatable with conventional lampricide application techniques. In the 1970s and 1980s, gB was regularly used to treat lentic areas, but applications declined in the 1990s. Since the early 2000s, an increase in gB applications and a commensurate increase in staff to complete these applications resulted in renewed focus on controlling sea lampreys in lentic environments. The suitability of substrates to serve as larval sea lamprey habitat in these lentic areas is assessed using RoxAnn© sonar. Areas of potential infestation are identified, and gB is used to determine the presence, abundance, and size structure of sea lamprey populations. Areas with sufficient infestation are delineated and treated with gB, albeit at a much larger scale than the sampling effort.

Control agents routinely monitor streams and lentic areas that have the potential to produce sea lampreys. These include areas of former sea lamprey production that have not been re-infested and areas of suitable spawning and nursery habitat that have never produced sea lampreys. Since 2000, only five new streams in Lake Superior have been found with sea lampreys: the Little Cypress River and Coldwater, Unger, Big Trout and D'Arcy Creeks. Other sources include small populations that are not cost effective to treat, such as lampreys produced above breeched barriers and those that migrate upstream from Lakes Huron and Michigan. None of these sources are considered significant (Heinrich et al. 2003).

Special Concerns

Protected Species

Protected species, such as piping plover (*Charadrius melodus*), lake sturgeon, and northern brook lamprey can potentially be affected by sea lamprey control activities, and work is planned to minimize adverse effects (Table 2). The Canadian control agent does not currently alter sea lamprey control activities to accommodate protected species, but the United States control agent adjusts field schedules and takes specific conservation measures to protect species at risk.

Table 2. Protected species that may require sea lamprey control personnel to avoid certain areas and periods in Lake Superior. Formal federal, state, and provincial designations of species are E (endangered), T (threatened), and SC (special concern).

Species	Federal		State/Provincial			
	U.S.	Canada	MI	WI	MN	ON
Piping plover	E	E	E			E
Lake sturgeon		SC*	T	SC	SC	T
Northern brook lamprey		SC				SC

*Anticipated listing.

Piping Plover

Piping plovers nest and feed around the mouths of tributaries and have the potential to feed on aquatic invertebrates that have been exposed to lampricides. To protect the population from possible adverse effects of lampricides, treatment of tributaries where nesting is observed is restricted to occur after September 1 when birds are not likely present. In Lake Superior, the timing of lampricide treatments has been modified because of concern for piping plover in seven tributaries, including the Au Train, Sucker, Blind Sucker, Big Two Hearted, and Little Two Hearted Rivers and Carpenter and Chipmunk Creeks.

Lake Sturgeon

The most direct effect that sea lamprey control has on lake sturgeon biology is the construction of barriers that impede sea lamprey migration but also prohibit lake sturgeon migration. Of 22 Lake Superior tributaries in the United States and Canada that have historically supported lake sturgeon, nine continue to support self-sustaining lake sturgeon spawning runs (Auer 2003). Sea lamprey barriers are on three of these 22 streams, including Stokely Creek and the Wolf and Black Sturgeon Rivers. Removing these barriers would enable sea lampreys to access 9 km of river containing larval and spawning habitats on Stokely Creek, 11 km on the Wolf River, and 2,560 km on the Black Sturgeon River.

A protocol for application of lampricides with populations of young-of-the-year lake sturgeon was developed to treat rivers used by spawning lake sturgeon, including the Bad, Ontonagon, Sturgeon, and Tahquamenon Rivers. This protocol restricts the treatment date until after August 1 and limits the concentration of TFM to 1.2 times the minimum lethal concentration (MLC) required to kill sea lamprey larvae in the river. Because these rivers tend to be large tributaries to Lake Superior, the treatment protocol increases the risk that flow conditions will not be suitable for lampricide application and that lampricide concentration will drop below the MLC due to the influx of water. In 2005, the GLFC suspended the use of the lampricide concentration protocols and directed control agents to use standard lampricide applications where sea lampreys are above targets.

Northern Brook Lamprey

In Canada, the northern brook lamprey has been listed as a species of special concern under the Species at Risk legislation, both federally and provincially. Like all native lamprey species, the northern brook lamprey is susceptible to lampricide applications where natal habitats of native lamprey and sea lamprey overlap. The current listing does not affect sea lamprey control operations.

Timing and Discharge Restrictions

Lampricide applications in some large Lake Superior tributaries must be coordinated with hydroelectric companies to ensure that a consistent and manageable volume of water is provided during the lampricide application. The Kaministiquia, Nipigon, Michipicoten, Au Train, and White (tributary to the Bad River) Rivers are regulated rivers that require such coordination before treatment. Although potentially challenging, coordination has not deferred scheduled treatments to date.

Stream-Treatment Deferrals

Most stream-treatment deferrals on Lake Superior since 1987 (Table 3) were caused by either excessive or insufficient stream discharge. Treatments of deferred streams are most often completed in the following year, but some streams have not been treated within two years of deferral (e.g., Pic River in 2004–2005, Cloud River in 2006–2007, Agawa River in 2009–2010). Recent deferrals can be partly attributed to a lack of flexibility in treatment schedules. When suboptimal flows are encountered, treatment crews must either wait for flows to change (either by waiting out a flood crest or for rains to increase flows) or transfer effort to another stream treatment. However, the treatment schedule is determined prior to the field season, thereby limiting the opportunity to compensate by either waiting for optimal flows (another stream later in the schedule might remain untreated due to time spent waiting) or to return to the stream at a later date to treat. Scheduling fewer streams prior to the field season increases the likelihood of treating a stream when suboptimal flows are encountered.

Table 3. Stream-treatment deferrals in Lake Superior during 1987–2010. Code definitions are H (excessive stream discharge), L (insufficient volume), D (permission denied by landowner), R (Ministry Natural Resources request), F (flood-destroyed larval habitat), C (cold weather), P (treatment priority of large stream), and W (required potable water supply).

No.	River	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	Total
5	Big Carp R.														L											1
23	Cranberry Cr.																								L	1
24	Goulais R. (Sheppard Cr.)																							H	L	2
52	Batchawana R.		H	L																						2
93	Agawa R.																					L	L		L	3
301	White R.	H																	H							2
305	Pic R.			L							H								H	H						4
360	Pays Plat R.						W														L					2
361	Little Pays Plat R.																				L					1
385	Jackfish R.																					L				1
392	Nipigon R.					R														H						2
457	Big Trout Cr.																							L		1
519	Black Sturgeon R.							H	H																	2
528	Pearl Cr.																						L			1
587	Cloud R.																				L	L				2
10021	Galloway Cr.		P																							1
10022	Tahquamenon R.															H										1
10053	Dead R.																	F								1
10053	Two Hearted R.																							H		1
10065	Sucker R.		P																							1
10188	Ravine R.																						L			1
10226	Traverse R.			L																						1
10611	Bad R.								D													H				2
10679	Brule R.																							H		1
10703	Middle R.			L																		L				2
10705	Amnicon R.	L																								1
10712	Nemadji R.		C																							1
10901	Arrowhead R.		C																							1
Total		**2**	**5**	**4**	**0**	**1**	**1**	**1**	**2**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**1**	**2**	**2**	**3**	**6**	**2**	**4**	**3**	**42**

Pollution Abatement

Pollution abatement can increase habitat quality and thereby increase sea lamprey production. For example, in the Kaministiquia River, improved water quality increased sea lamprey production and associated assessment and control costs. A lack of sea lamprey production in the St. Louis River is associated with poor environmental conditions, so this river will need to be closely monitored if water quality or physical habitat improves.

Barrier Removal

Balancing the benefit of enhancing connectivity of tributaries to Lake Superior with goals of managing sea lamprey are challenges for the future because enhancing spawning and nursery habitat for native fishes increases the likelihood of sea lamprey recruitment and survival. The public debate surrounding the barrier on the Black Sturgeon River demonstrates a need to manage these structures for the benefit of the entire fish community, not just the needs of one species, interest group, or management agency.

Recruitment from Other Sources

Given the geographic position of Lake Superior, the contribution of sea lampreys from other sources is typically limited to the movement of spawning-phase sea lampreys through the St. Marys rapids, compensating works, and locks. These lampreys may contribute to recruitment of larvae in rivers in the eastern end of the lake, but production of parasitic-phase sea lampreys from this recruitment is not quantified.

Parasitic-phase sea lampreys are also known to pass through the locks while attached to lake freighters, but, as with the contribution from spawning-phase sea lampreys, the increase in predation from these migrants is unknown.

Fish-Community Interactions

Sea lampreys prey upon a wide variety of fish species in the lake, including salmonines, coregonines, catastomids, burbot (*Lota lota*), walleye (Harvey et al. 2008) and lake sturgeon (Chase 2006). Because sea lampreys do not require specific intermediate or terminal hosts, sea lamprey control affects and is affected by the entire fish community in Lake Superior. Consequently, effects of sea lamprey control are difficult to interpret when exclusively evaluated through estimates of spawning-phase sea lamprey abundance and the marking rate on lean lake trout >533 mm. The full effect of sea lamprey control should be measured throughout the fish community and not restricted solely to lean lake trout. Strategies to address damage assessment are discussed later in this plan.

Public Use

Tributaries located throughout the Lake Superior watershed support a variety of public uses, particularly during summer months and on weekends when water-related activities peak. Treating during times of high public use can result in negative public perception of the sea lamprey control program. Swimming, boating, and fishing are not restricted during lampricide applications, but the public is advised to minimize unnecessary exposure to lampricides through news releases and personal contact with user groups. Agricultural irrigators are informed of treatment dates in case they prefer to avoid use of river water during that time. Treatment supervisors can adjust treatment timing to minimize times of peak river use by the public, but accounting for all activities is nearly impossible.

Fish-Community Objectives

Fish-community objectives (FCOs) for Lake Superior are used by agencies to guide and coordinate management of fish populations and habitat both inside and outside their political jurisdiction (Horns et al. 2003). The FCO for sea lampreys in Lake Superior is:

> *Suppress sea lamprey to population levels that cause only insignificant mortality on adult lake trout.*

The FCO for lake trout is:

> *Achieve and maintain genetically diverse self-sustaining populations of lake trout that are similar to those found in the lake prior to 1940, with lean lake trout being the dominant form in nearshore waters, siscowet lake trout the dominant form in offshore waters, and humper lake trout a common form in eastern waters and around Isle Royale.*

Sea Lamprey Suppression Targets

Current metrics for evaluating the success of the sea lamprey control program are annual lakewide estimates of spawning-phase sea lamprey abundance and counts of sea lamprey marks on lean lake trout >533 mm. Relationships between the marking rate, abundance of host species, abundance of sea lamprey causing marks, and control efforts are not as direct as might be expected. Understanding linkages between control efforts and predator-prey dynamics would enable a more complete understanding of the effects of sea lamprey control efforts, and may enable these efforts to be targeted to lakes, regions of lakes, or fish stocks to maximize overall benefits.

The Lake Superior Committee (LSC) has agreed that an annual abundance of 36,000 + 18,000 spawning-phase sea lampreys should lead to the target of 5 Type A, Stages I-III marks per 100 lake trout and achievement of the fish-community objective for Lake Superior. The target number of 36,000 was calculated from the average number of sea lampreys estimated during 1994-1998 when marking rates were closest to 5 marks per 100 lake trout. The range of +18,000 represents the variability of spawning-phase sea lamprey abundance during that period. Marking rates of less than 5 per 100 lake trout indicated that sea lampreys were inflicting acceptable mortality on lake trout.

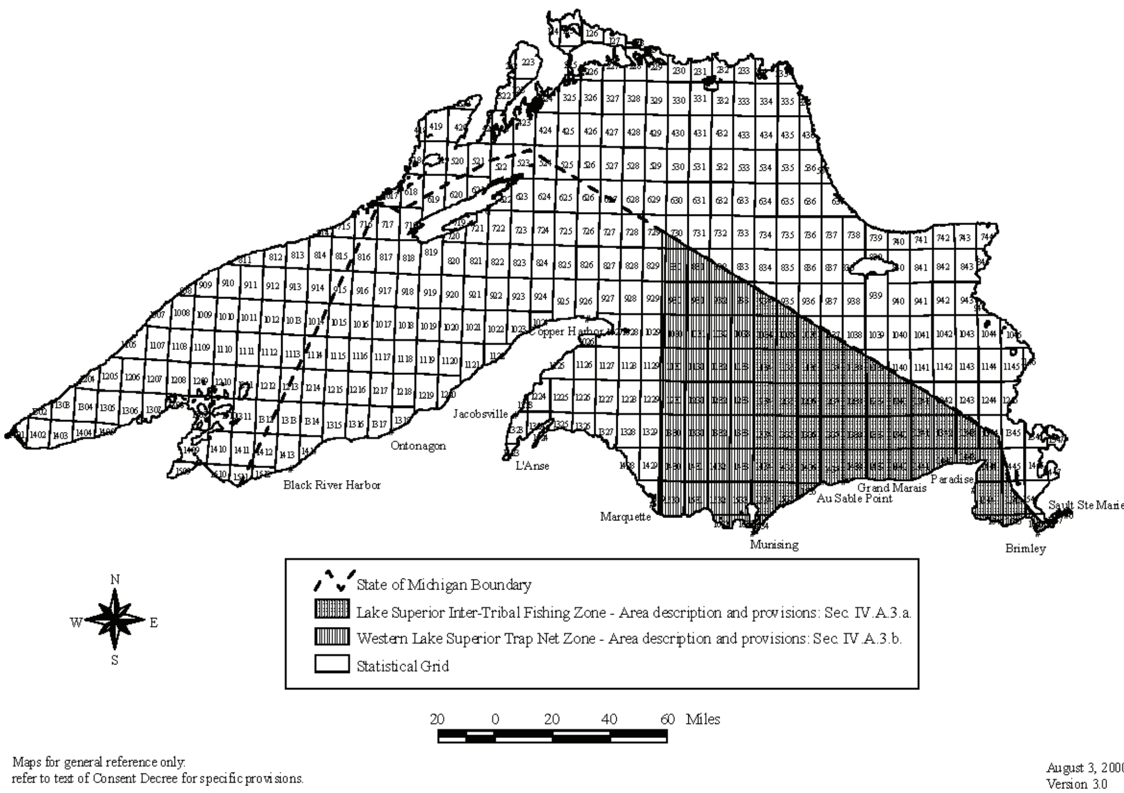
The overall goal for sea lamprey control in this Five-Year Plan is:

> *Reduce sea lamprey abundance to the target level established by the Lake Superior Committee and maintain that level through time, resulting in insignificant sea lamprey induced mortality of all fish species in Lake Superior.*

The goal for sea lampreys in this plan is similar to that stated in the FCOs but also includes all species within the fish community as targets, not just lean lake trout.

Reductions in sea lamprey induced lake trout mortality are also an important stipulation in the 2000 Consent Decree (State of Michigan 2000). The decree is a federal court order that specifies how fishery resources are managed and allocated among five tribal governments and the State of Michigan within the Michigan waters of the 1836 Treaty, an area that extends from Whitefish Bay to a north-south line just east of Marquette, Michigan (Fig. 11). The decree, based on a settlement agreement among the United States, five tribal governments and the State of Michigan, embraces goals of lake trout rehabilitation while requiring effective control of sea lamprey and the associated mortality on lake trout. To adopt goals of lake trout rehabilitation and management within the decree, the parties stipulated that "sea lamprey control efforts will (would) significantly reduce sea lamprey induced lake trout mortality from 1998 levels." Failure to achieve a reduction in sea lamprey induced mortality on lake trout within the 1836 Treaty waters in Lake Superior could result in a party requesting relief from the lake trout rehabilitation goals contained within the decree.

Fig. 11. The 1836 Treaty waters for Lake Superior.



Objectives and Strategies within Program Components

Lampricide Control

Concerns about effects of lampricides on nontarget organisms, use of pesticides in the environment, and increasing costs of TFM resulted in a desire to reduce dependency on chemical lampricides during the 1990s (Brege et al. 2003), including a reduction in the amount of TFM applied to Lake Superior tributaries. Concerns about the increase in spawning-phase sea lampreys in Lake Superior, beginning in the mid-1990s, was part of a decision to increase the amount of lampricide applied to tributaries beginning in 2001.

In the past decade, 91 Lake Superior tributaries have been treated, with an average of 37 tributaries treated per year since 2007 (Table 4). An average of 18 tributaries was treated annually between 1999 and 2006.

Table 4. Sea lamprey treatment information for Lake Superior during 1999-2010. TFM and Bayluscide are reported as kilograms of active ingredient used.

Year	Number of treatments	TFM (kg)	Stream length (km)	Bayluscide (kg)	Bayluscide area (ha)
1999	13	10,526	367	108.7	19.41
2000	19	2,084	285	136.6	24.39
2001	21	6,404	539	38.0	6.79
2002	14	6,313	409	33.0	5.89
2003	13	6,872	228	209.6	37.43
2004	20	4,824	267	22.8	4.07
2005	24	11,200	724	484.1	86.45
2006	21	18,532	615	805.3	143.80
2007	36	4,848	253	208.7	37.27
2008	32	14,178	721	232.7	41.55
2009	38	11,828	528	649.9	116.05
2010	40	8,301	500	1,085.0	193.75

Populations of sea lamprey larvae in lentic areas are controlled through application of gB. Lentic treatments declined during the 1980s and 1990s were from more concerted efforts in the 1970s, but the importance of treating lentic areas has become a priority more recently.

Objective 1: By 2011, increase the proportion of sea lampreys killed by the lampricide control program within all tributaries (stream- and lentic-specific strategies).

Strategy: Identify streams where treatment effectiveness may be improved and develop and implement strategies to treat more effectively, such as maintaining concentrations in excess of MLC for at least nine hours; increasing the duration of application by one-three hours; applying lampricide to backwaters, rivulets, and seepage areas that would otherwise remain untreated during the primary treatment and, thereby, provide refuge to larvae; treating at the optimal time of the year to ensure appropriate discharges; and treat when larval sea lamprey fitness is lowest. Candidate streams include the Pic, Little Pic, White, Black Sturgeon, Kaministiquia, Nemadji, Bad, and Ontonagon Rivers and Big Trout Creek.

Cost: Included in the base program.

Strategy: Annually identify tributaries from the stream-treatment ranked list where treatment effectiveness can be increased by inventorying geographic features and increasing effort to conduct secondary lampricide applications. Candidates include the Ontonagon and Bad Rivers.

Cost: Stream dependent and will vary among years. Will be completed through the base program.

Strategy: Coordinate with state, provincial, and tribal management agencies to address challenges to successful treatment, including the communication of risks, goals, and benefits of lampricide control to stakeholders; requirements to protect species at risk through formal biological assessments, evaluations and opinions; and ensure that the entire infested area of a stream is treated.

Cost: Included in the base program. May require GLFC consultation.

Strategy: By 2014, develop treatment strategies that address potential changes in sea lamprey distribution and production as a result of removal or remediation of barriers to sea lamprey migration, including the Black Sturgeon Dam.

Cost: Included in the base program. Completed as part of planning operations.

Strategy: Continue to conduct lentic treatments during or immediately following stream treatments with known lentic populations. Candidates include the MacKenzie, Upper Nipigon, Batchawana, Gravel, Cypress, Falls, Ravine, Big Trout, Big Garlic, Kaministiquia, and Dead Rivers.

Cost: Included in the base program.

Strategy: Continue annual TFM treatments to the Silver, Falls, and Ravine Rivers to reduce sea lamprey recruitment to associated lentic areas.

Cost: Included in the base program.

Strategy: Beginning in 2011, use nets to capture and remove larvae activated during treatments of tributaries to larger untreated systems or tributaries that enter a lake when sea lamprey larvae have been observed in the associated estuarine area. Candidates include the Little Gravel River and Cash and Stillwater Creeks.

Cost: An additional four staff days per stream: two to set nets prior to treatment and two to retrieve nests post-treatment.

Strategy: Continue to coordinate with states and tribes to negotiate implementation of the lake sturgeon protocol with respect to lakewide target levels of suppression in the Bad, Ontonagon, Sturgeon, and Tahquamenon Rivers.

Cost: Included in the base program. May require GLFC consultation.

Objective 2: By 2014, modify lakewide stream-treatment strategies to reduce transformer escapement (whole-lake strategies).

Strategy: Beginning in 2012, identify and treat, on a shorter rotation, at least three large sea lamprey producing streams so fewer transformers escape if a treatment is deferred. Candidates include the Ontonagon, Kaministiquia, Goulais, Batchawana, Chocolay, Two-Hearted, Salmon-Trout, and Michipicoten Rivers.

Cost: Included in the base program. Opportunity costs (foregone treatments of other streams at the bottom of rank list) of an accelerated schedule will depend upon the streams selected.

Strategy: Beginning in 2012, reduce the largest residual populations by implementing treatments in consecutive years on the streams that account for 50% of residual larval population. The initial treatment will be planned on schedule as larval sea lamprey populations warrant treatment. Candidate rivers include the Ontonagon, Kaministiquia, Goulais, and Michipicoten Rivers.

Cost: Included in the base program. Opportunity costs of an accelerated schedule will depend upon the streams selected.

Strategy: Beginning in 2015, periodically implement treatments in two consecutive years in streams with a history of significant residual sea lampreys. For example, a stream with a three-year treatment cycle would be treated in years one, two, five, six, nine, and ten. Candidates include the Amnicon and Traverse Rivers.

Cost: Included in the base program. Opportunity costs of an accelerated schedule will depend upon the streams selected.

Strategy: Treat all streams with regular annual recruitment on a three- or four-year cycle.

Cost: Analyses are currently being conducted. Assessment resources would be reallocated among program elements.

Strategy: Reduce the contribution of sea lampreys from lentic areas and estuaries by treating any lentic area containing larvae >100 mm with gB.

Cost: Included in the base program.

Objective 3: By 2012, develop a regional treatment strategy that will not only kill sea lampreys, but also reduce the long-term need for continuous treatment based on recolonization strategies.

Strategy: By 2012, review mark-recapture information on recently metamorphosed sea lampreys in the context of recolonization strategies and evaluate how sea lamprey reduction at a regional level might affect and be affected by the regional fish community. Establish regional goals for reduction in spawning-phase sea lamprey abundance.

Cost: Included in the base program.

Strategy: Identify a subset of streams that produce the largest number of sea lampreys to a lake region and treat the subset of streams in two consecutive years. Use information from the Lake Huron North Channel control efforts to inform the deployment of this strategy.

Cost: Included in the base program.

Larval Assessment

Larval assessment uses a standardized set of protocols to determine the presence, abundance, size structure, and limits of infestation of sea lamprey larvae within streams and lentic areas of Lake Superior. Assessment information is used to prioritize treatment effort among streams throughout the Great Lakes basin. In addition, larval assessment is used to assess treatment success and determine if new areas of a stream have been infested since the last treatment.

Lake Superior has more areas of lentic infestation than any other Great Lake, such as sheltered embayments on Batchawana Bay and Mountain Bay (Gravel River), but also estuarine areas, such as the lower Nipigon and Kaministiquia Rivers. These areas provide refuge for sea lamprey larvae but are untreatable with conventional lampricide applications.

Objective 1: By 2012, maximize effectiveness of the larval assessment program so that it provides enough among-stream information to prioritize streams for lampricide application and sufficient within-stream information to effectively plan a lampricide application.

Strategy: Continue to use expert judgment (EJ) based on knowledge of recruitment, growth rate, and time to metamorphosis to prioritize streams with multiple years of recruitment for treatment. Allocate effort saved to post-treatment assessments within one year of treatment to determine residual abundance and the potential for re-treatment. Candidates include the Tahquamenon, Chocolay, Ontonagon, Bad, Amnicon, Kaminsitiquia, Wolf, Cypress, Gravel, Michipicoten, Batchawana, and Goulais Rivers.

Cost: Included in the base program. Already being implemented.

Strategy:	Ensure that detection surveys for new populations of sea lamprey larvae are conducted every 5+ years in streams with suitable spawning and nursery habitats and evaluation surveys are conducted every three years in previously infested streams.
Cost:	Increased the cost to conduct detection surveys. Evaluation surveys are already included in base budget.
Strategy:	Ensure upstream and downstream limits of sea lamprey infestation are accurately determined either the year prior to or the year of treatment for each stream scheduled for lampricide application.
Cost:	Included in the base program.
Objective 2:	By 2015, prioritize and treat lentic and estuarine areas that regularly recruit larval sea lampreys.
Strategy:	Continue to use RoxAnn© mapping to quantify substrates in lentic and estuarine areas.
Cost:	Included in the base program.
Strategy:	Continue to assess at least three new potential lentic areas annually (e.g., St. Louis River, Huron Bay, Black Bay, and lentic areas associated with new infestations of a river) until all are accounted for.
Cost:	Included in the base program.
Strategy:	Evaluate the feasibility of implementing annual TFM treatments on streams with lentic populations larger than 500 larvae/ha.
Cost:	Included in the base program.
Strategy:	Revisit known infested lentic areas every two to three years to determine the need for treatment.
Cost:	Included in the base program.
Objective 3:	By 2013, maximize the implementation of alternative methods to prioritize streams and lentic areas for lampricide application.
Strategy:	Develop additional criteria to prioritize streams for treatment based on expanded EJ criteria or other non-ranking survey data in hand. Candidates include the Little Pic, Cloud, and MacKenzie Rivers.
Cost:	Included in the base program. Planning for upcoming treatment.

Strategy: Consult with Lake Technical Committees to prioritize lampricide applications higher in areas where sea lampreys are more likely to survive and damage fish by incorporating host abundance in the prioritization method. Begin with streams west of the Keweenaw Peninsula in 2012. Coordinate this strategy with strategies in Objective 3 of Lampricide Control and Objective 1 of Metrics and Measures of Success.

Cost: Included in the base program as part of annual planning.

Strategy: By 2011, have the Assessment Task Force evaluate the potential to treat streams or lentic areas on a fixed cycle from the maximum historical points of infestation.

Cost: Analysis is in progress. Savings to be reallocated to other program elements.

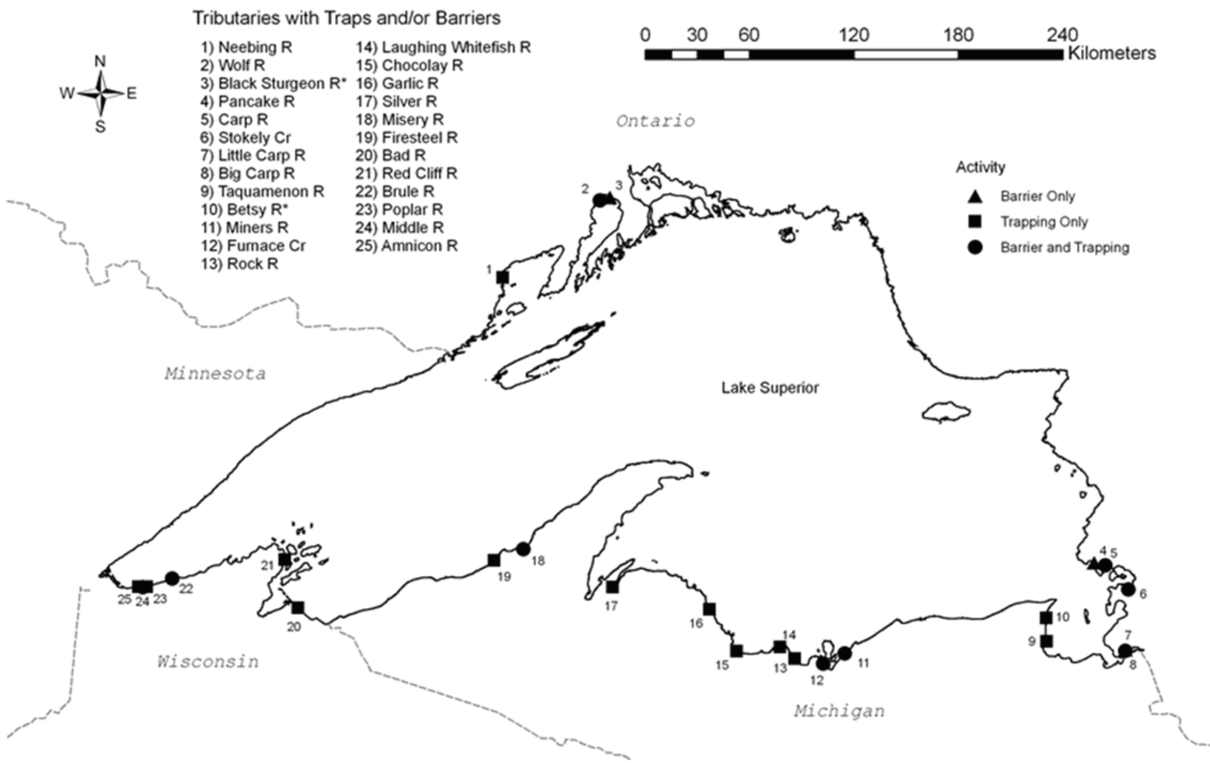
Trapping

Trapping of spawning-phase sea lampreys during their spawning migration addresses three goals: assessing spawning-phase sea lamprey abundance, removing sea lampreys from the spawning population, and providing male sea lampreys for the SMRT program used in the St. Marys River. Sterile-male release is discussed further in Alternative Control.

Spawning-phase sea lampreys are currently trapped in 22 tributaries to Lake Superior (Fig. 12). Total annual catch has averaged 9,184 since 1999 with most being used for assessment purposes and an average of 1,000 males contributing to the SMRT program.

Large rivers, particularly rivers without barriers, pose a challenge for capturing spawning-phase sea lampreys. A review of the adult assessment program in 1997 identified a need to trap more tributaries where large spawning runs are expected (Bence et al. 1997). Expanding the current trap network to more large rivers will improve spawning-phase abundance estimates for runs that are currently estimated through an extrapolation of the spawner-discharge model (Mullett et al. 2003), provide further control through trapping and removal of spawning-phase sea lampreys, and could provide more sea lampreys for the SMRT program.

Fig. 12. Locations of Lake Superior tributaries with barriers and traps. Tributaries with asterisks identify barriers that were built for other purposes but have been modified to block sea lampreys.



Spawning-Phase Assessment

Lakewide spawning-phase sea lamprey abundance is estimated from a combination of mark-recapture estimates conducted at trap sites; historical estimates of trapping efficiency at sites where mark-recapture is not conducted; and modeling of expected spawning runs based on tributary-specific values for drainage area, geographic region, larval sea lamprey production, timing of the last lampricide application, and year (Mullett et al. 2003).

Objective 1: By 2015, determine the optimum level (suite of streams, size of streams, geographic coverage) of trapping spawning-phase sea lampreys needed to obtain accurate estimates of lakewide abundance with a precision of 20%.

Strategy: By 2012, evaluate factors that will improve the accuracy and precision of annual estimates of abundance. Use this information to determine if improvements are necessary, and identify and recommend which factors will improve accuracy and precision.

Cost: Included in the base program.

Strategy: By 2013, based on previous analyses, recommend the optimum suite of streams to be trapped to estimate lakewide spawning-phase sea lamprey abundance. Candidates include the Ontonagon, Pic, Nipigon, Michipicoten, and Kaministiquia Rivers.

Cost: Included in the base program. Streams will be identified after analyses are complete.

Objective 2: By 2015, investigate innovative trap designs and other techniques and technologies to obtain spawning-phase abundance estimates, especially in large rivers and streams without barriers and, if feasible, implement at least one new method.

Strategy: By 2012, develop a list of rivers where alternate methods can be evaluated and correlated with mark-recapture estimates of spawning-phase abundance. Candidates include Tahquamenon, Betsy, Miners, Rock, Misery, Bad, Brule, Middle, and Carp Rivers, where the coefficient of mark-recapture estimates is lowest.

Cost: Included in the base program as part of planning.

Strategy: By 2014, determine the ability of DIDSON™ camera technology to estimate the spawning-phase sea lampreys in one or more rivers.

Cost: $80K for DIDSON™ + $20K per stream for operations.

Strategy: By 2014, based on correlation of spawning-phase abundance with nest counts (Lake Erie data), develop a list of streams where nest counts may be an effective assessment tool, and implement in at least one stream by 2015.

Cost: Included in the base as part of planning. Implementation of nest counts would incur additional cost.

Strategy: By 2015, evaluate the ability of pheromone and eDNA assays to quantify spawning-phase sea lamprey abundance in rivers.

Cost: Covered in research funding.

Trapping for Control

Trapping for control is primarily used on the St. Marys River to limit larval sea lamprey recruitment through removal of spawning-phase sea lampreys. At other trap sites, the portion of the catch that is not directed towards mark-recapture or to supply the SMRT program is removed to reduce recruitment of larval sea lampreys in these rivers. Trapping for control is optimized when trap placement and trap retention results in a sufficient proportion of the run of the spawning-phase sea lampreys being captured to cause very low spawner densities (<0.2 spawning pairs per $100m^{-2}$ of larval habitat) (Dawson 2007). Trapping efficiencies to affect control are usually higher than those necessary for assessment.

An alternative application of trapping for control targets out-migrating, newly metamorphosed sea lampreys in the fall and early spring to limit recruitment of sea lampreys to the parasitic population in the lake. This method has been implemented to capture transformers for mark-recapture studies, provide transformers for research, monitor effects of sea lamprey control in the St. Marys River, and to reduce recruitment from tributaries to Lakes Ontario, Huron, and Superior.

Objective 1: By 2015, increase the proportion of the spawning run that is captured in traps by 20%.

Strategy: By 2015, increase annual effectiveness of traps to at least 25% of the estimated spawning run or 20% more than the 2006-2010 average catch in at least 2 of the 12 streams currently trapped through trap improvements and management-scale application of pheromones. Candidates include the Betsy, Tahquamenon, Miners, Furnace, Rock, Misery, and Bad Rivers.

Cost: Funding for mechanical modifications, if required. Pheromone application costs are dependent upon the streams selected (e.g., operated by control agents from headquarters, requirement for travel, hiring of contractor).

Strategy: By 2020, incorporate permanent or semi-permanent traps into present or planned barriers. Candidates include the Black Sturgeon, Betsy, Tahquamenon, Miners, Furnace, Rock, Misery, and Bad Rivers.

Cost: The construction cost will vary among rivers and barriers.

Strategy: Investigate and implement novel technologies and techniques to capture more sea lampreys.

Cost: Cost dependent upon technology/technique selected, hardware and staff requirements, and opportunities to partner.

Objective 2: By 2015, develop a trapping-for-control strategy where spawning-phase sea lamprey populations have been reduced through regional or lakewide control efforts or in areas that are not currently being trapped.

Strategy: Evaluate the ability to maintain low recruitment to the larval-phase by trapping low-abundance spawning runs with a combination of traditional and novel traps, manual removal, and nest destruction.

Cost: Cost will depend upon the stream(s) selected, novel technologies implemented, and construction and deployment of traps.

Objective 3: By 2013, reduce recruitment by capturing newly metamorphosed sea lampreys during their downstream migration to the lake.

Strategy: By 2011, develop criteria for stream selection and gear placement to capture out-migrating sea lampreys.

Cost: Included in the base program as part of planning.

Strategy: By 2012, capture out-migrating sea lampreys from streams where large numbers of metamorphosing-phase sea lampreys are known or suspected.

Cost: Increased cost of purchasing/manufacturing and operating gear. Stream dependent.

Alternative Control

Techniques used to control sea lamprey populations other than lampricide control are considered alternative control methods. Presently, the alternative control methods that are implemented in the field are sterile-male release, pheromone application, and barriers. However, alternative control methods may eventually include current research areas, such as genetic manipulation, agonists and antagonists for chemical cues, manual destruction of sea lamprey nests, and repellents.

Sterile-Male Release

Lake Superior was the initial site for an experimental application of the SMRT program during 1991-1996 (Twohey et al. 2003). The experiment tested the effect of the SMRT program on a whole-lake population. Sterilized males were released into a subset of streams that were believed to collectively be the primary source of sea lampreys that survived chemical treatments. The number of streams varied annually from 10-27 streams. The average annual release of sterile males was about 16,100, the average predicted number of resident males was about 10,600, and the average ratio of sterilized to untreated males was 1.5:1, which resulted in a theoretical reduction in larval production of 59%. However, neither reductions in lakewide abundance of parasites and lake trout marking, nor improvement in lake trout abundance could be correlated with sterile-male releases. Low ratios of sterile to normal males and assumptions on the sources of residual larvae were deficiencies in the lakewide experiment (Twohey et al. 2003).

Beginning in 1997, all sterile males were reallocated to the St. Marys River except for 1,500 released into the Bad River for an additional year of releases. This technique was not continued in the Bad River after 1997. All available sterile-male sea lampreys remain dedicated to the St. Marys River through 2011. Future re-allocation of sterile males could be considered in a stream with low spawner densities and effective trapping.

Objective 1:	Reduce larval sea lamprey production through the introduction of sterile-male spawning-phase sea lampreys.
Strategy:	By 2012, implement the SMRT program in two streams within the upper Great Lakes.
Cost:	Included in the base program as reallocation of the current SMRT program effort.

Pheromones

Pheromones are promising tools for integrated control of sea lampreys (Li et al. 2007). While pheromones have been envisioned in a variety of suppression techniques, their first use will likely be to aid in trapping. Field trials using the pheromone 3kPZS to attract migrating sea lampreys to traps were initiated in the Tahquamenon, Betsy, Miners, Rock, and Misery Rivers in 2009 and expanded into the Carp, Stokely, and Big Carp Rivers in 2010. Preliminary results indicate that more sea lampreys were attracted to pheromone baited traps than un-baited traps. Additional pheromone components are being investigated for exploitable behavior responses. A detailed plan to implement pheromones in control applications will be developed after the ability to manipulate lamprey migratory behavior through *in situ* pheromone application is better understood.

Objective 1:	By 2013, develop a lakewide integrated pheromone plan for Lake Superior.
Strategy:	Continue researcher and agent coordination and implementation of pheromone field studies to build expertise in pheromone handling, deployment, and application.
Cost:	One to two staff per station to oversee pheromone deployment during sea lamprey spawning run. $10-20K.
Strategy:	As efficacy of various pheromone compounds is demonstrated, evaluate proposed strategies for integration with other control techniques and consider implementation of at least one such strategy by 2013.
Cost:	To be determined. Potential technical assistance or research proposal.
Strategy:	Register (or secure experimental use permits for) pheromone compounds to ensure the ability to implement new pheromone methodologies as they become available.
Cost:	Approximately $40K.

Barriers

Currently, barriers to sea lamprey migration are on 27 sea lamprey producing tributaries, of which 11 were constructed for the purpose of stopping sea lamprey migration. The barrier on the Black Sturgeon River was originally constructed by the logging industry but now serves solely as a sea lamprey barrier (Fig. 11; Table 5). Construction of new barriers requires negotiations with land owners, consultation with stakeholders, design, and partnering agreements during construction; which typically takes three to six years to complete.

Blockage of sea lamprey migration is also ensured at barriers other than those built for sea lamprey control, often referred to as *de facto* barriers. Between 2007 and 2009, 101 *de facto* barriers were evaluated for their ability to block sea lamprey migration in Lake Superior, and records of these barriers are used to inform decisions about future projects at these sites.

Table 5. Location, date of construction, and distance upstream for sea lamprey barriers built exclusively to block sea lamprey migrations on Lake Superior tributaries.

Stream	Date of construction	Distance from stream mouth (km)	Comments
Wolf River	1987	4.0	Integrated trap
Pancake River/Gimlet Creek	1979	1.0	Rebuilt 2008, includes integrated trap
Carp River	1983	1.0	Integrated trap
Stokely Creek	1980	0.8	Rebuilt 2007, includes integrated trap
Big Carp River	1995	1.0	Inflatable crest barrier with fishway
Little Carp River	2001	2.5	Integrated trap
Miners River	1978	1.6	Repaired 2008
Furnace River	2004	0.6	
Misery River	1984	2.7	Rebuilt ~1999, increased height
Brule River	1984	9.7	Integrated trap
Middle River	1983	6.9	

Objective 1: Maintain the ability of the 11 purpose-built and 2 modified non-purpose-built sea lamprey barriers to block spawning-phase sea lampreys.

Strategy: Conduct larval assessments upstream of barriers consistent with the treatment cycle to ensure that sea lampreys have not breeched the barriers.

Cost: Included in the base program.

Strategy: Conduct annual inspections and repair or replace worn, broken, or missing parts before they affect barrier performance.

Cost: Inspections included in the base program. Cost of repairs will be barrier specific.

Strategy: Evaluate and fix barriers that fail to block spawning-phase sea lampreys consistent with their design objectives.

Cost: Included in the base program. Cost of barrier maintenance.

Strategy: By 2011, coordinate with the OMNR and other stakeholders to develop a trap-and-sort facility integrated into a sea lamprey barrier on the Black Sturgeon River. Coordinate this strategy with spawning-phase assessment and trapping for control strategies.

Cost: Included in the base program as part of program planning. Construction costs of the trap-and-sort facility will depend upon design parameters.

Objective 2: Beginning in 2011, annually investigate areas where barriers can be effectively constructed consistent with the Barrier Strategy and Implementation Plan.

Strategy: By 2011, complete the environmental assessment for constructing a barrier on the Whitefish River.

Cost: Included in the base program.

Strategy: Meet with the U.S. Army Corps of Engineers and Great Lakes Fishery and Ecosystem Restoration Program semi-annually to discuss funding, research, and expertise to design, plan, and fund barriers in the United States. Candidate rivers include the Ontonagon River, tributaries to the Bad River, and Harlow Creek.

Cost: Included in the base program as part of annual planning.

Strategy: Develop partnerships with the states of Michigan, Wisconsin, and Minnesota, and tribal agencies Chippewa Ottawa Resource Authority, Keweenaw Bay Indian Community, Great Lakes Indian Fish and Wildlife Commission (Bad River Band of Lake Superior Chippewa, Red Cliff Band of Lake Superior Chippewa), and Grand Portage Band of Lake Superior Chippewa to obtain funding and support for barrier projects.

Cost: Included in the base program as part of annual planning.

Strategy: By 2013, develop a new process for selecting and ranking proposed sites for barriers.

Cost: Included in the base program.

Objective 3: Ensure spawning-phase sea lampreys remain blocked at important non-purpose-built barriers.

Strategy: By 2012, include non-purpose-built barriers in the barrier database, and, by 2013, develop a ranking method to prioritize their importance to sea lamprey control with condition and future maintenance issues noted.

Cost: Included in the base program.

Strategy: By 2013, develop a policy to work with partners to preserve the integrity of the furthest downstream barriers that currently block sea lampreys.

Cost: Included in the base program. May require GLFC participation/negotiation.

Strategy: By 2013, use the barrier database to develop a list of structures that currently do not block sea lampreys but have the potential to be converted to blocking structures and pursue modification through the ranking process.

Cost: List development included in the base program. Cost of repairs will depend upon streams selected.

Strategy: By 2012, establish a review process with state, provincial, tribal, conservation authorities, and First Nations regulators to notify sea lamprey control managers of in-stream fish passage or dam removal projects before permits are granted.

Cost: Included in the base program as part of planning activities.

Strategy: Update the GLFC website to include a barrier map and list of inventoried barriers, a contact list for barrier removals, and a concurrence request form.

Cost: Included in the base program.

Strategy: By 2013, develop a ranked list of barrier repair and rebuild projects.

Cost: Included in the base program as part of planning activities.

Objective 4: Integrate barriers with other methods of control to achieve more effective sea lamprey control.

Strategy: By 2011, identify potential sites where barriers, in combination with alternative controls, can contribute to effective control or suppression.

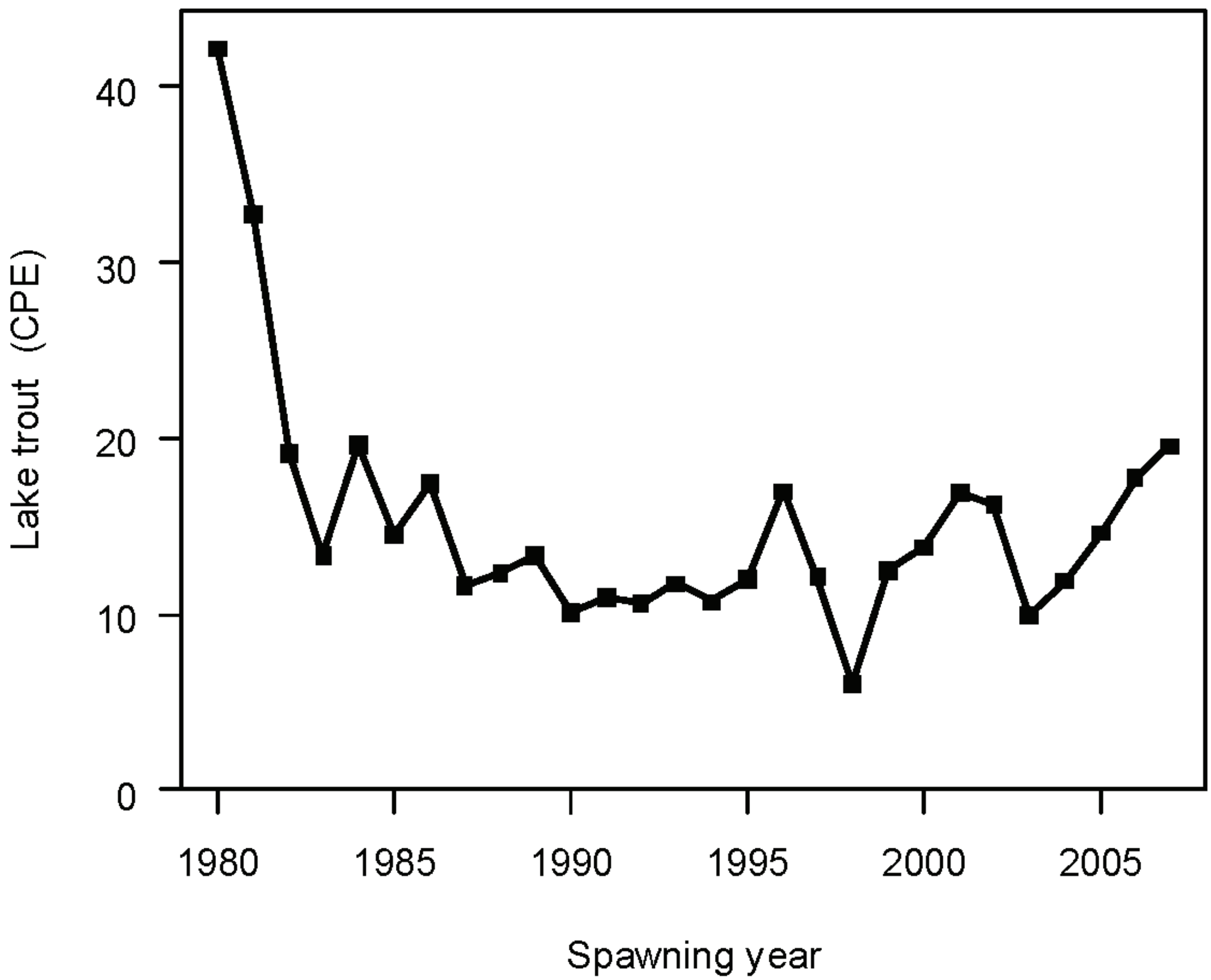
Cost: Included in the base program. Barrier cost will depend upon the stream selected.

Metrics and Measures of Success

Overall abundance of lean lake trout in Lake Superior has been relatively stable for the past 20 years (Fig. 13) coincident with an increase in wild fish and a decrease in hatchery fish. Lake trout stocking continues in only a small portion of Ontario, Minnesota, and Wisconsin waters where wild lake trout have not completely colonized historic spawning areas. Lean lake trout abundance and reproduction in Michigan waters are currently near historic highs (Wilberg et al. 2003; Richards et al. 2004). However, lean lake trout yields are far below historical levels in large part due to mortality inflicted by sea lampreys and a reduction of commercial harvest of lake trout to sustainable levels.

The most abundant form of lake trout in Lake Superior is the siscowet (*Salvelinus namaycush* siscowet) (Bronte et al. 2003a). The abundance of siscowet lake trout likely masks the full impact of sea lamprey predation on lean lake trout, because siscowet lake trout may buffer mortality on lean lake trout. Up to 80 marks per 100 siscowet lake trout >600 mm have been reported for all depth strata in Lake Superior (Sitar et al. 2008), which is just one example of the need to include the entire fish community in damage assessment measurements instead of only lean lake trout.

Fig. 13. Catch per effort (CPE) of lean lake trout >533 mm in Lake Superior during 1980-2007. CPE = fish/1000 meters of net per night.



Objective 1: By 2012, use sea lamprey marking rates to develop sea lamprey abundance targets for all species vulnerable to sea lamprey attack in the Lake Superior fish community starting with lean lake trout, siscowet, lake whitefish (*Coregonus clupeaformis*), and cisco (*Coregonus* spp.).

Strategy: By 2013, provide data and advice to Ted Treska, U.S. Fish and Wildlife Service, Green Bay Fishery Resource Office, to help develop predator-prey models that link the effects of sea lamprey control to as many species as practical.

Cost: Included in the base program.

Strategy: Standardize sea lamprey mark identification through periodic workshops at intervals of no more than five years.

Cost: Approximately $4K for Lake Superior. Could be linked to Lake Superior Technical Committee (LSTC) meetings. Requires new specimens or standardized set of marking images.

Strategy: By 2012, develop regional targets west of Keweenaw for both sea lamprey marking on the fish community and abundance of spawning sea lampreys.

Cost: Included in the base program. Requires consultation with the LSC and LSTC.

Strategy: By 2013, evaluate present sea lamprey targets (five Type A, Stages I-III marks per 100 lake trout, 36,000 spawning-phase sea lampreys) to determine if fishery managers agree that fish-community objectives are being met.

Cost: Included in the base program. Requires consultation with the LSC.

Strategy: By 2014, analyze data to quantify the effects of climate change on sea lamprey length, weight, growth, feeding duration, fecundity, and host mortality.

Cost: Research the topic. Data provision and agent support are included in the base program.

Objective 2: By 2012, reevaluate the targets for abundance of spawning-phase sea lampreys, and, if necessary, develop new targets.

Strategy: By 2012, develop regional targets for sea lamprey abundance based on marking in the entire fish community and the revised objectives proposed in this plan.

Cost: Specific costs are unknown. Requires consultation with lake fishery-management agencies.

Strategy: Reevaluate methods used to determine the abundance of spawning-phase sea lampreys, and measure the influence of climatic factors, such as temperature and precipitation (flow), on annual variation in trap catchability. Coordinate with Objective 1 in Trapping.

Cost: In progress.

Recommended Strategies to Achieve Targets

The Five-Year Plan implements a base program of lampricide control, assessment, and alternative controls designed to support the fish-community objectives for Lake Superior at an annual cost of about $5,022,000 (based on the fiscal year 2011 budget). Despite these efforts, the abundance of spawning-phase sea lampreys, as measured by the current five-year average abundance of spawning-phase sea lampreys (57,000), continues to exceed the target (37,000). Achieving target levels of sea lamprey abundance in Lake Superior will clearly require additional control actions.

Historical lampricide treatment and larval assessment data suggest that the most likely source of parasitic-phase sea lampreys is larvae that survive lampricide applications (residuals) from streams that contain the greatest numbers of larvae. Analyses designed to forecast the effects of various treatment scenarios suggest that lakewide spawning-phase sea lamprey abundance can most reliably be affected through whole-lake selection of streams to treat for residuals. Lakewide spawning-phase abundance was used to measure program success because this is currently the best measure available. In addition, the construction, maintenance, and repair of both purpose-built and *de facto* barriers are direct actions that aim to minimize spawning-phase sea lamprey abundance. Recommended strategies to reach targets within the next five years are listed below.

Lampricide Control

Annual effort: Lake Superior accounts for 28% of the lampricide control effort expended throughout the Great Lakes basin, based on an average of control expenditures during 2005-2009. This effort will result in $3.25M being spent on lampricide control in Lake Superior in 2011 and represents the level of control required to maintain long-term average abundance of spawning-phase sea lampreys in Lake Superior.

To get to targets (Option A):	Beginning in 2012, or within the next five years, allocate approximately 1,500 additional staff days of effort to treat large sea lamprey producing streams in consecutive years. Treatments would be conducted in two consecutive years in the Ontonagon, Kaministiquia, Michipicoten, and Goulais Rivers. Although the long-term average of spawning-phase sea lampreys is only 35% over target, this strategy is expected to reduce the residual population by 51% over a two-year period. This treatment regime should also result in a commensurate reduction of marking on lake trout to target levels beginning two years after treatments are completed.
Additional cost:	Approximately $1.01M and 578 staff days.
Assumption:	This recommendation is based on the assumption that spawning-phase sea lampreys are a single population within Lake Superior, and this population derives from larval lampreys that survive lampricide applications, metamorphose, and migrate into the lake. We also assume that we have accounted for all sources of sea lamprey production, that production has been quantified correctly in relation to other streams, that sea lampreys randomly disperse throughout the lake, and that a reduction in residual larval populations will have a commensurate effect on spawning-phase sea lamprey abundance and lake trout marking.
To get to targets (Option B):	Should the Lake Superior spawning-phase sea lamprey population be comprised of multiple sub-populations, a sub-basin approach may result in significant local reductions in sea lamprey predation to protect fish stocks in more discrete areas of Lake Superior. This hypothesis may be evaluated for Lake Superior west of the Keweenaw Peninsula by observing localized changes in stream-specific spawning-phase sea lamprey abundance and in marking rates of local fish stocks following treatment of the Ontonagon and Kaministiquia Rivers. The addition of other western-basin rivers, such as the Bad, Brule, and Amnicon Rivers and portions of the Nemadji river system, would result in further reductions in residual populations and a greater opportunity to detect a change.
Additional cost:	The treatment cost for these rivers would be $909K and 747 staff days because treatment costs for the Michipicoten and Goulais Rivers would not be expended in this scenario.

Larval Assessment

Annual effort:	Current assessment supports stream prioritization and within-stream targeting of lampricide control activities, including evaluating treatment effectiveness, assessing barrier success, and detecting new infestations of sea lampreys. The average cost of larval assessment to direct the current level of lampricide control in Lake Superior is $901,400 for 2011. Presently, the effort to detect new infestations does not keep pace with the life cycle of sea lampreys. For example, streams with a potential to produce parasitic-phase sea lampreys but have not been infested to date are surveyed every five to ten years. On average, five years are required after egg deposition for sea lampreys to metamorphose in Lake Superior tributaries. Consequently, streams that recruit within one year of a survey could produce four or five years of transformers if the stream is not revisited for ten years. To reduce the potential for increased sea lamprey production, detection surveys for new populations of sea lamprey larvae should be conducted at least once every five years in streams with suitable spawning and nursery habitats.
Additional cost:	$27,000 each year to increase the frequency of surveys on streams that have not been infested in the past to ensure sources of sea lampreys are known.
To get to targets:	Ensure upstream and downstream limits of sea lamprey infestation are accurately determined for the Ontonagon, Kaministiquia, Bad, Brule, Amnicon, and Michipicoten Rivers and portions of the Nemadji river system, depending upon the selection of option A or B (above).
Additional cost:	Assessment in support of consecutive treatments that include the Bad River would require an additional $50K for additional distribution and treatment-evaluation surveys. If a regional approach is pursued, the additional survey cost is estimated to be $84K for distribution and treatment evaluations of the Brule, Amnicon, and Nemadji Rivers.

Adult Assessment

Annual effort:	Sea lampreys are currently trapped in 22 tributaries to Lake Superior. This effort provides mark-recapture estimates of spawning-phase sea lamprey abundance, male sea lampreys to the SMRT program, and a modest amount of control by removing spawning-phase sea lampreys from rivers prior to being able to spawn.
Cost:	The annual cost to operate traps on Lake Superior tributaries is $484,700.

To get to targets:	Increased trapping on Lake Superior tributaries is not expected to result in a sufficient reduction in recruitment to significantly reduce lakewide spawning-phase sea lamprey abundance. Increased lampricide control is more cost effective and would cause more immediate reductions in recruitment of parasitic-phase sea lampreys to Lake Superior.
Additional cost:	None at present.

Alternative Control

Annual effort:	Maintenance of the current barrier network, both purpose-built and *de facto* barriers, limits sea lamprey recruitment and helps to maintain current spawning-phase sea lamprey abundance.
Cost:	The cost of barrier inspection and maintenance is forecast to be $381,500 for Lake Superior sea lamprey barriers in 2011.
To maintain current control:	Support the development and planning for a trap-and-sort fishway on the Black Sturgeon River. This strategy will maintain sea lamprey control on the Black Sturgeon River while enabling passage of migratory native fish, particularly walleye and lake sturgeon.
Additional cost:	Dependent upon design.
To get to targets:	No new barriers are proposed for Lake Superior tributaries within the next five years.
Additional cost:	The cost of new barriers is case specific, and negotiation, agreement, and design are protracted processes spanning multiple years. The cost or timing of the next proposed barrier for Lake Superior tributaries cannot be determined at this time.

Metrics of Success

Annual effort:	Stream-specific mark-recapture estimates of spawning-phase sea lamprey abundance are provided through the adult assessment program and are the foundation for a model that uses stream discharge, treatment history, and production potential to calculate regional and whole-lake population estimates. The evaluation of model performance is an ongoing task and benefits lake-specific estimates across the Great Lakes basin.
To get to targets:	Re-assess and develop regional targets for spawning-phase sea lamprey abundance and integrate with a metric based on marking in the entire fish community. This plan will result in a more precise estimation of spawning-phase sea lamprey abundance coupled with localized effects of host-species abundance to enable better interpretation of lamprey control efforts at a scale smaller than the lake basin.
Additional cost:	$27K annually.

Maintaining Target Levels and the Judicious Use of Lampricides

Advancing alternative control technologies and techniques and applying lampricides in a judicious manner is critical to maintaining targets. Strategies, such as the application of pheromones to improve trap efficiency, are currently being evaluated, while others, such as incorporating traps into planned barriers, are closely associated with strategies yet to be implemented (i.e., barrier construction). Additional strategies, such as increasing trapping effectiveness, reducing recruitment by manual removal of spawning-phase sea lampreys, and developing improved methods to evaluate program success, rely on research designed to evaluate their potential. New alternative controls will benefit actions designed to reduce or maintain sea lampreys at target levels throughout the Great Lakes and are not necessarily specific to Lake Superior. However, costs of implementing these strategies are not well defined. Estimated costs to advance these technologies and techniques are included in Chapter 7 (Summary) and will require research related to these four general areas: application of pheromones, trapping techniques, methods to reduce recruitment, and sea lamprey-host interactions.

Communication

The control agents will continue to annually draft a report to the GLFC and its committees that describes control actions implemented in the previous year, progress made on the plan, and the current and past status of sea lampreys in Lake Superior. A summary of this information is typically presented to the LSC during its annual meeting. In addition to the annual report, the control agents will coordinate publishing a short (<2 pages) semi-annual newsletter that describes progress made on the plan and developments or insights into the control program. The newsletter will be made available on the GLFC website so that agencies can access, reference, or copy the report for anglers, commercial fishers, and other interested citizens.

This plan is envisioned as a working plan and will be reviewed and revised every five years. The plan is expected to be flexible and to adapt to changes in both the fish community and funding opportunities. Results of implementing the plan will be analyzed and documented as stated above. Changes will be implemented and monitored as required.

See Appendix A for information about who to contact about the sea lamprey control program.

CHAPTER 3: FIVE-YEAR PLAN FOR LAKE MICHIGAN

Jeff Slade[4]

Introduction and History

The purpose of this chapter is to build on the general, basinwide discussion of sea lamprey (*Petromyzon marinus*) control outlined in Chapter 1 (Sea Lamprey Control in the Great Lakes Basin). The most recent synthesis of sea lamprey control in Lake Michigan (Lavis et al. 2003) was published in the Journal of Great Lakes Research in 2007 as a contribution to the Sea Lamprey International Symposium II. This paper is cited often in this plan and is a good document to review for those interested in additional information on sea lamprey control in Lake Michigan. The Great Lakes Fishery Commission (GLFC), in collaboration with fisheries managers, has developed this lake-specific Five-Year Plan as an integrated sea lamprey control strategy that focuses on lakewide and locality-specific control tactics to maintain sea lamprey populations at or below target levels.

Sea lampreys were first documented in Lake Michigan in 1936 and spread rapidly throughout the basin (Applegate 1950; Smith and Tibbles 1980). In combination with overfishing, sea lamprey predation led to the extirpation of lake trout (*Salvelinus namaycush*) (Coble et al. 1990; Hansen 1999) and the near disappearance of burbot (*Lota lota*) (Smith 1971). As abundance of predators declined, abundance of chubs (deepwater ciscoes) (*Coregonus* spp.) increased and eventually became important hosts for sea lampreys. As a result of this predation and commercial fishing, two species of chubs were nearly extinct and four other species were severely depleted by the early 1960s (Smith 1971).

In 1946, Michigan conservation officers reported that 68 Lake Michigan tributaries contained spawning runs of sea lampreys (Shetter 1949), and, by 1949, sea lampreys were documented in 79 streams (Lavis et al. 2003). Initial efforts to control sea lampreys in Lake Michigan consisted of mechanical weirs placed in spawning streams to capture spawning-phase sea lampreys (Applegate 1950). To control sea lampreys, mechanical weirs were installed in seven Lake Michigan tributaries by 1951 (Smith 1971). Mechanical weirs were discontinued in 1952 and replaced by electromechanical barriers. By 1958, electromechanical barriers were in operation in 65 Lake Michigan tributaries. Limited effectiveness of electrical barriers and development of the

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lampricide 3-trifluoromethyl-4-nitrophenol (TFM) (Applegate et al. 1961) accelerated their abandonment, and all electromechanical barriers had been removed from Lake Michigan tributaries by 1966 (Smith 1971). Lampricide treatments in tributaries were initiated in 1960, and, by 1965, most sea lamprey producing tributaries had been treated (Smith and Tibbles 1980). Following the first round of lampricide treatments, spawning-phase sea lamprey abundance decreased by about 85% (Smith 1971; Smith and Tibbles 1980).

Spawning-phase sea lamprey abundance remained within or near target range (57,000 ± 13,000) but then increased during 2000-2007 (Fig. 14). Possible reasons for this increase include increased production from the Manistique River due to deterioration of the dam, changes in lampricide application strategies that led to decreased treatment efficacy (Brege et al. 2003), implementation of new stream-treatment selection criteria, concerns for nontarget species, and increased survival of newly metamorphosed sea lampreys due to changes in the prey base (fish community). The increase in spawning-phase sea lamprey abundance was preceded by an increase in lake trout marking rates. Lake trout marking rates have been greater than the target value of 5 marks per 100 lake trout >532 mm since 1996 and have demonstrated an increasing trend (Fig. 15). Spawning-phase sea lamprey abundance declined sharply during 2007-2009 to within target range in 2009 but increased above target range slightly in 2010 (Fig. 14). Increases in lampricide control effort and measures to improve efficacy of lampricide applications are believed responsible for the reduced abundance since 2007.

Fig. 14. Annual lakewide estimates of spawning-phase sea lamprey abundance ±95% confidence interval (CI) in Lake Michigan during 1977-2010. The solid horizontal line represents the abundance target of 57,000 spawning-phase sea lampreys. The dashed horizontal lines the 95% CI for the target.

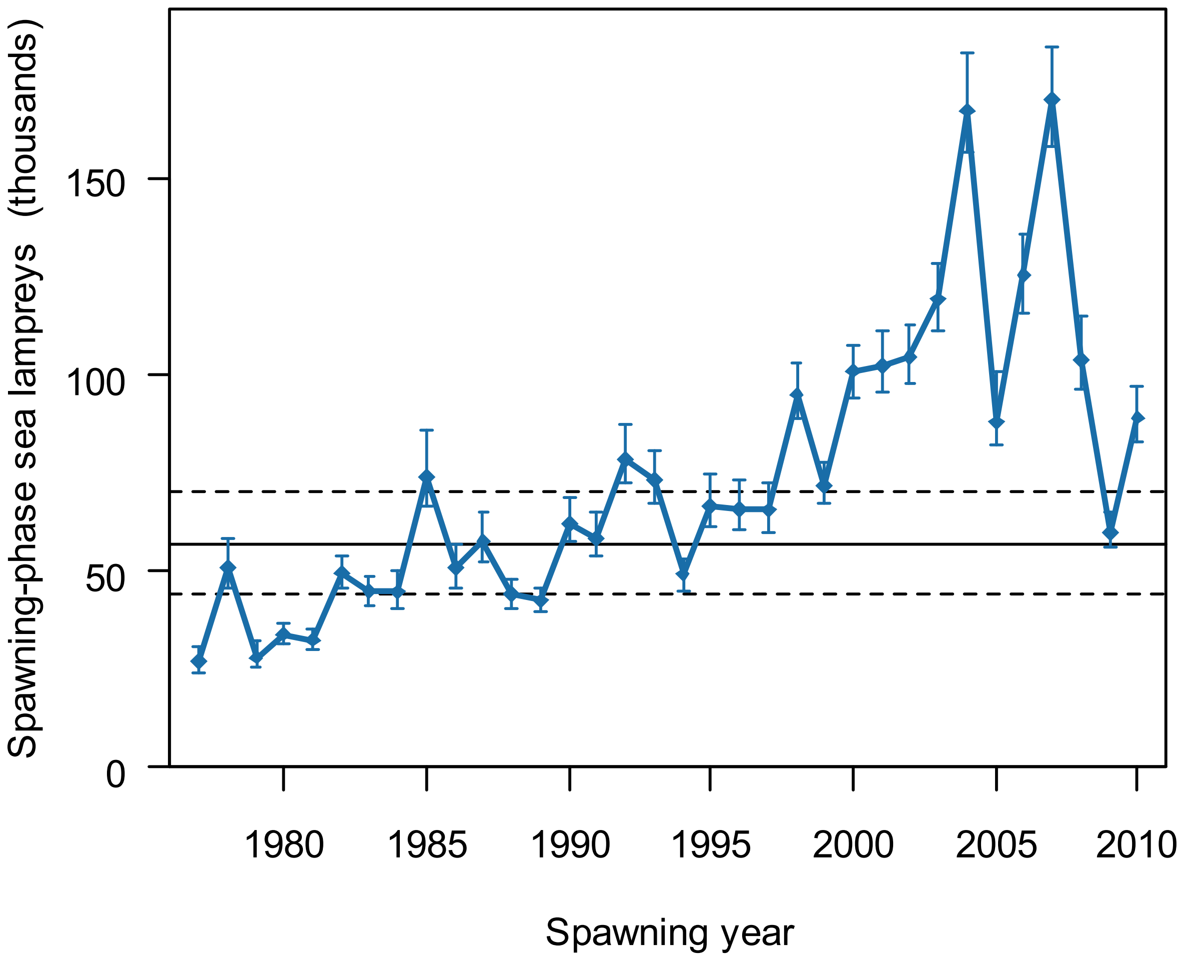
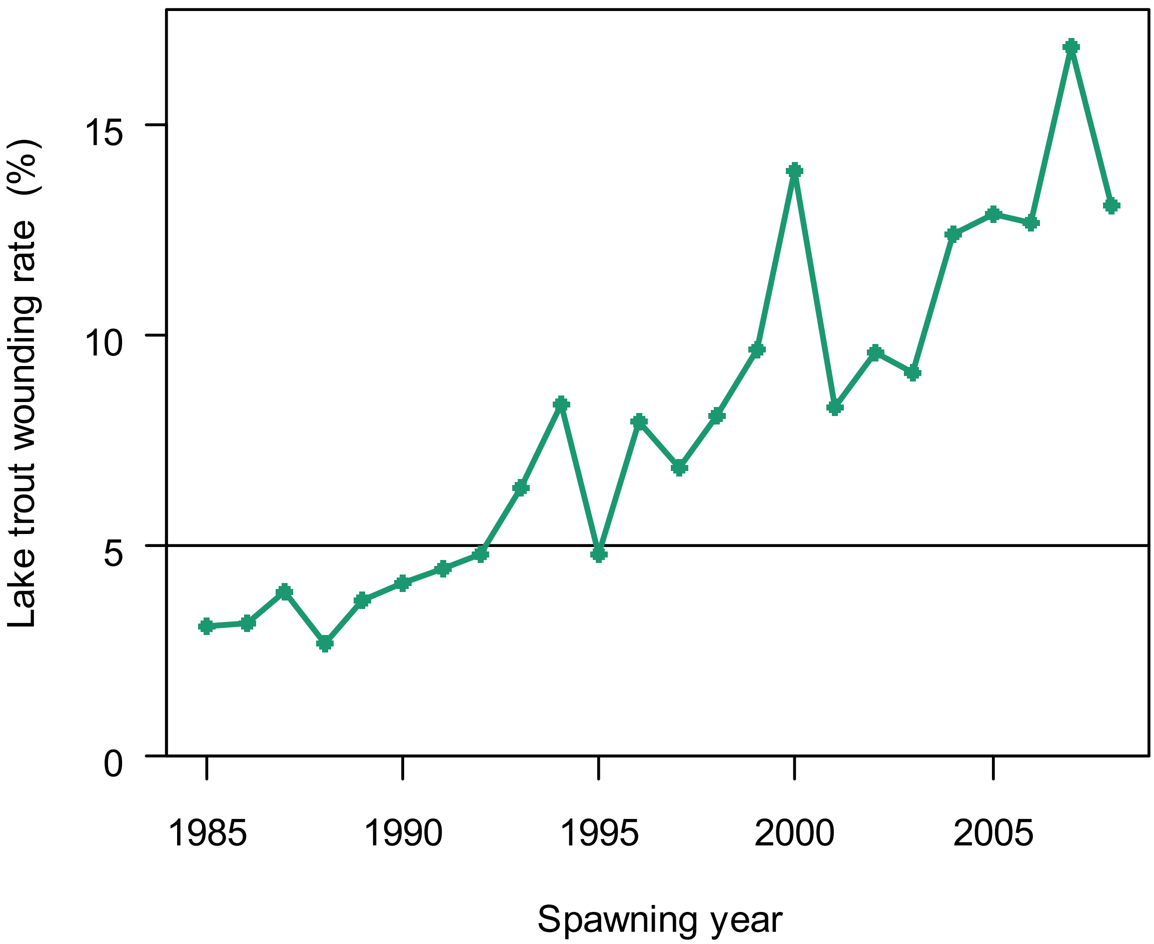


Fig. 15. Number of Type A, Stages I-III marks per 100 lake trout of total length >532 mm from standardized fall assessments plotted on sea lamprey spawning year in Lake Michigan during 1985-2008. The horizontal line represents the target marking rate of 5 marks per 100 fish.

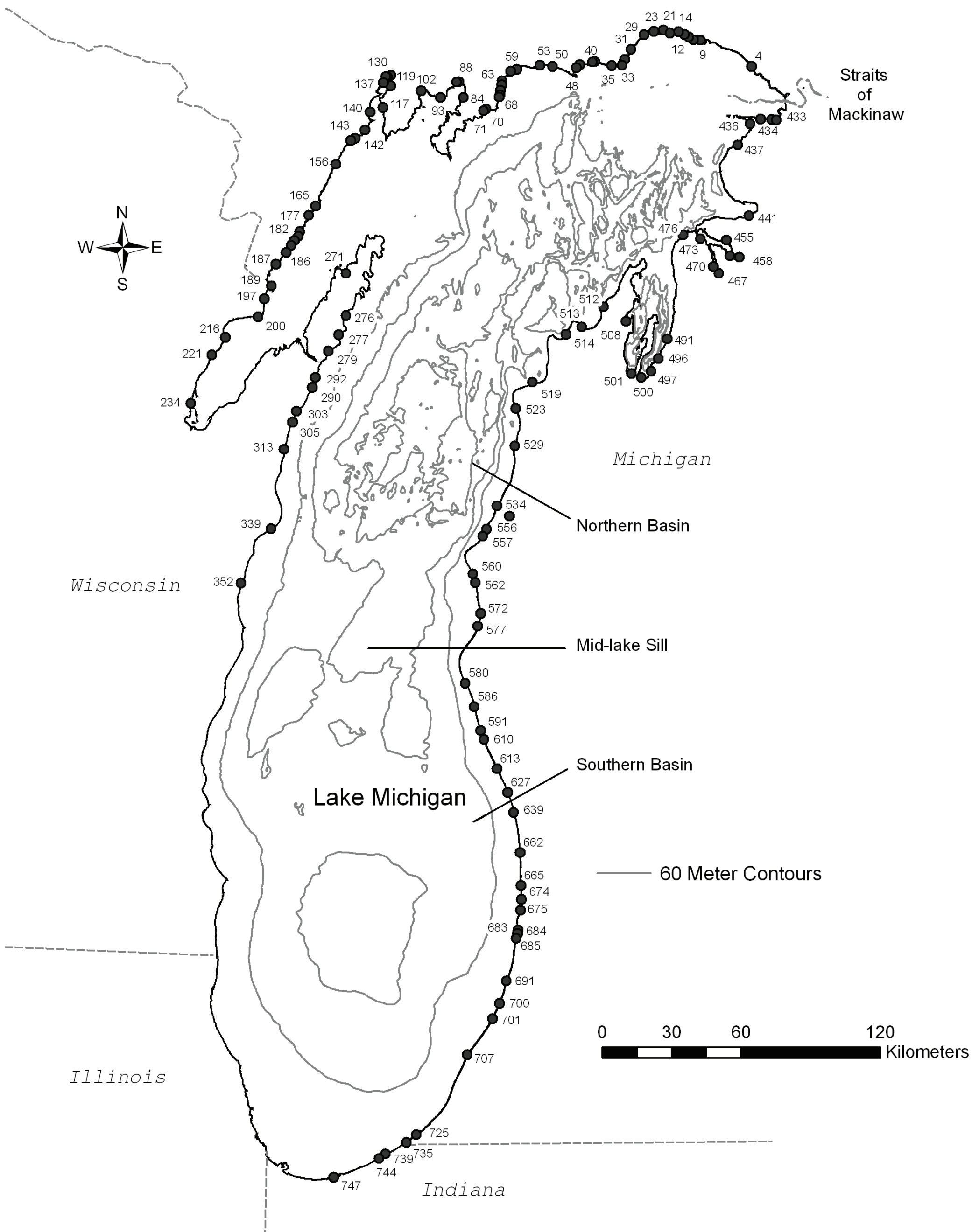


Features of the Lake

Lake Michigan is the second-largest Great Lake by volume, third-largest Great Lake by surface area, traverses the longest latitudinal gradient of any of the Great Lakes and is the largest lake within the continental United States (Wells and McClain 1973; Lavis 2005). Lake Michigan's primary source of water is from precipitation over the lake and land basin, but it may also receive significant groundwater fluxes (Croley and Luukkonen 2003; Lavis 2005). The only natural outlet is through the Straits of Mackinac into northern Lake Huron (Fig. 16). Lake Michigan has a mean depth of 84 m and contains two distinct basins separated by a mid-lake sill. The northern basin containing numerous valleys and ridges with a maximum depth of 281 m and the relatively smooth-bottomed southern basin with a maximum depth of 170 m (Fig. 16; Wells and McLain 1973). Green Bay is considered a shallow sub-basin separated from the northern basin by the Door Peninsula and is generally more eutrophic (Wells and McClain 1973; Lavis 2005). The offshore pelagic zone of the historically mesotrophic southern basin is now similar to oligotrophic Lake Superior (Mida et al. 2010).

Streams with a history of sea lamprey production are distributed throughout Lake Michigan (Fig. 16; Appendix B), but are most numerous in the northern basin and least numerous along the western shore of the southern basin (Morman et al. 1980). Alkalinity and pH in United States tributaries to Lakes Michigan and Huron average higher than in the other Great Lakes. Since the toxicity of lampricide is inversely related to pH and alkalinity (Bills and Johnson 1992), more lampricide per unit of discharge is required for effective treatment of Lakes Michigan and Huron tributaries. In addition, many of the Lake Michigan tributaries infested with sea lampreys have a relatively high discharge requiring additional lampricide and application effort.

Fig. 16. Primary basins of Lake Michigan and geographic location and stream number for tributaries with records of larval sea lamprey infestation. Stream name and sea lamprey control-related data can be cross-referenced in Appendix B.



Sea lamprey spawning tributaries in the northern basin generally drain heavily forested, unpopulated watersheds, whereas, those in the southern basin drain predominantly agricultural and more populated areas. Pollution, sedimentation, hard bottom, and low and unstable flows are major factors limiting the number of streams containing sea lampreys in the southern basin and the abundance of larval sea lampreys in these streams (Morman 1979).

Previously determined average summer surface temperatures of about 20°C and hypolimnetic temperatures near a constant 4°C should not limit the distribution of sea lampreys and their primary hosts in Lake Michigan (Coutant 1977; Morman et al. 1980; Swink 1993). However, the effects of climate change may increase the seasonal or annual temperature and could have implications for the metabolism of parasitic-phase sea lampreys and reproductive success of spawning-phase sea lampreys and decrease the time to metamorphosis for larval sea lampreys through increased growth rate.

Unique Issues

Sea lamprey larvae have been found in 122 of the 511 tributaries to Lake Michigan, and 116 of the 122 tributaries have contained larval populations that have warranted lampricide application. Larval sea lamprey abundance was estimated for most infested tributaries. These estimates were based on the larval habitat area and larval density (Slade et al. 2003). The maximum estimated larval abundance during 1996-2008 varied widely among streams (Fig. 17; Appendix B). Stream-specific estimates of maximum larval sea lamprey abundance in tributaries ranged from <100 to >3.2 million, and 15 streams account for 90% of the total estimated larval sea lamprey production. Estimates of larval sea lamprey abundance did not always correspond to stream-specific estimates of spawning-phase sea lamprey abundance (Figs. 17, 18). The lack of correlation is likely influenced by the presence of barriers that block access to spawning and larval habitat on some streams, and small to moderate spawning-stock abundance can produce large numbers of larvae (Jones et al. 2003).

Fig. 17. Maximum estimates of larval sea lamprey abundance in Lake Michigan tributaries during 1996-2008. Streams with the highest estimates, combining for more than half the Lake Michigan total, are identified by name. For reference, the maximum estimate of larval-phase sea lamprey abundance for the Muskegon River is 3.12M. Estimates for all streams are listed in Appendix B.

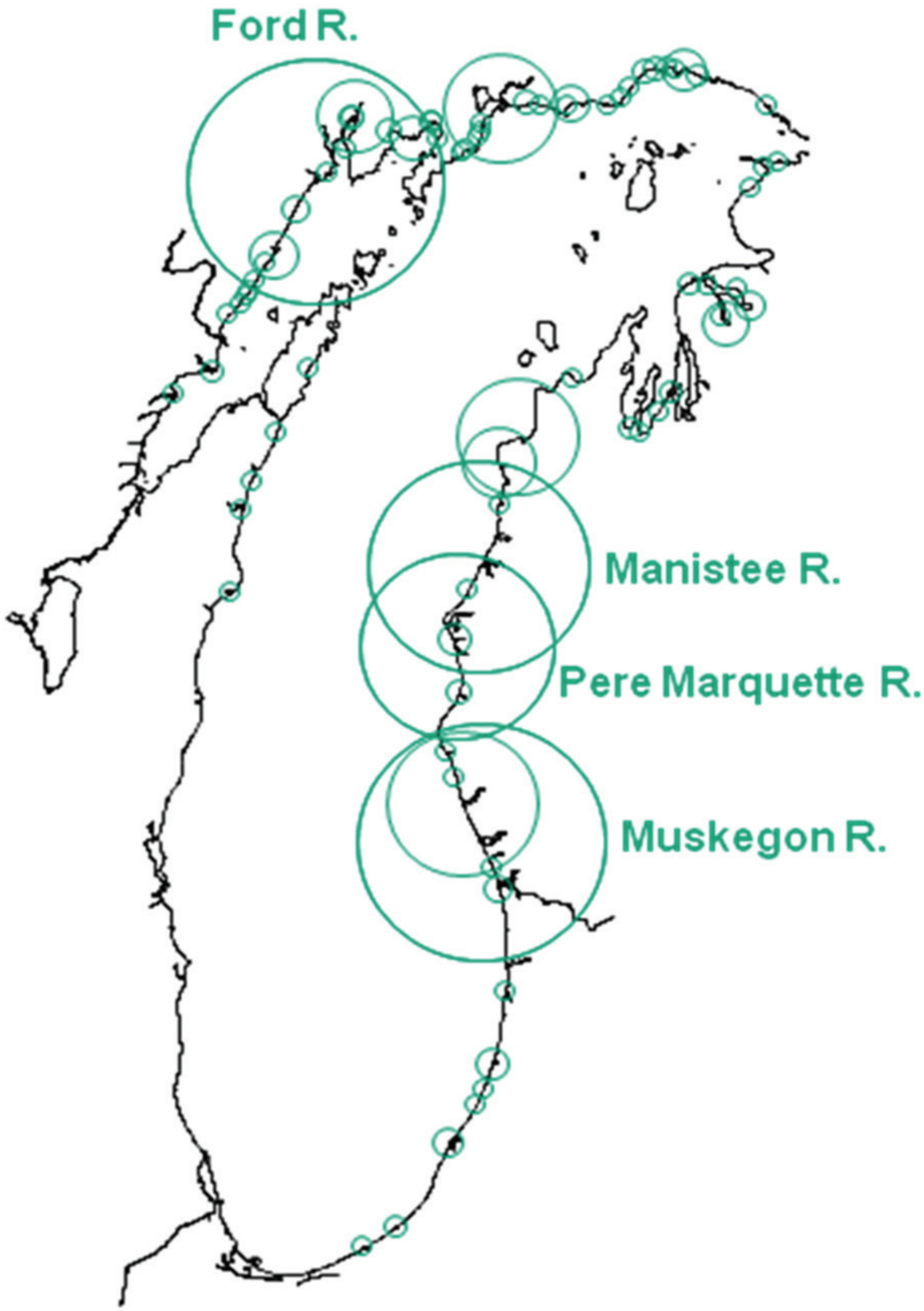
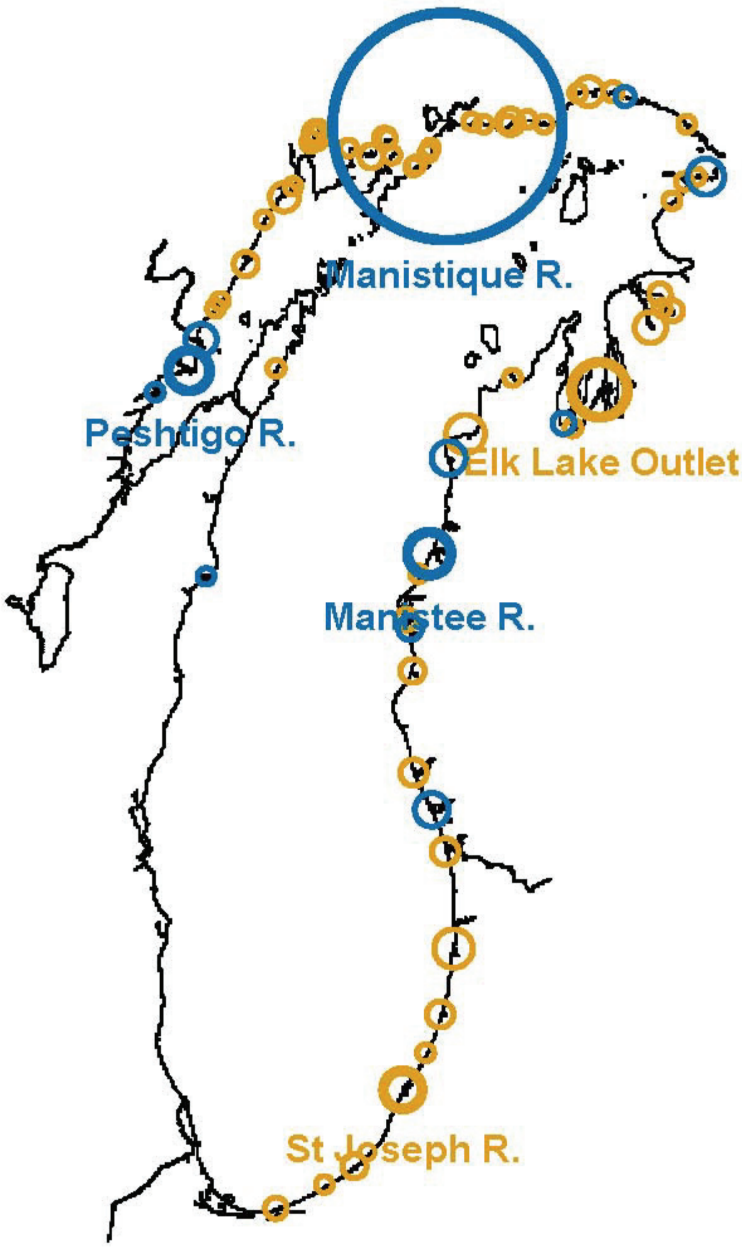


Fig. 18. Five-year average of spawning-phase abundance estimates in Lake Michigan tributaries during 2005-2009. Streams with the highest five-year average combined for more than half the Lake Michigan total and are identified by name. Colors indicate whether the source of most (at least three of the five) of the annual estimates were from mark-recapture (blue) or not (orange). For reference, the five-year average of spawning-phase sea lamprey abundance for the Manistique River is 36K. Estimates for all streams are listed in Appendix B.



Larval sea lampreys have been detected in 34 lentic areas, 8 have been treated with granular Bayluscide (gB), 18 are low in abundance and monitored regularly by surveys with gB, and 8 have not been positive for sea lampreys in the past 20 years (Fig. 16; Appendix B).

Streams that produce large numbers of larval sea lampreys and are especially challenging to treat effectively with lampricides are listed in Table 6. Factors that complicate and create challenges to effective control are presence of sensitive species; high discharge from hydro facilities or low midsummer discharge that reduce the days a stream can be treated (i.e., narrow treatment window); numerous backwaters, beaver impoundments, oxbows, and rivulets requiring secondary lampricide applications (secondaries) to these refuge areas; and the dendritic and complex nature of some streams. The objectives and strategies to address these challenges are discussed later in this document. In addition, several streams have unique challenges and include:

- Peshtigo River: Estimates of larval abundance in this system have been compromised by sampling conditions and access, therefore, estimates of larval abundance have likely been underestimated.
- Manistique River and lentic area: Larval abundance has been underestimated by poor sampling conditions and access. A dam located about one mile upstream of the mouth is owned and operated by Manistique Papers, Inc., Manistique, Michigan. Prior to 2003, this stream was treated from the dam downstream to the mouth. However, the dam deteriorated allowing for the increased migration of spawning-phase sea lampreys to areas upstream of the dam and increased larval production. Since 2003, the stream has been treated four times with a typical cost of about $525,000 per treatment. The U.S. Army Corps of Engineers (USACE) is planning to replace the failing dam by 2012. Once the new dam is in place, lampricide treatments will again be confined to the stream and lentic area downstream of the dam. Surficial substrate in the lentic area has been surveyed using the RoxAnn© seabed classification device (Fodale et al. 2003), and a map of larval habitat has been created.
- Platte River: This river is a source stream for coho salmon (*Oncorhynchus kisutch*) broodstock in Michigan. Typically, the broodstock collection weir at the Michigan Department of Natural Resources (MIDNR) Platte River hatchery acts as a barrier and limits the upstream distribution of sea lampreys, but larvae have been detected upstream of the hatchery requiring treatment upstream of the weir since 2009.
- Little Manistee River: A broodstock collection weir operated by the MIDNR is located less than six river miles upstream of Manistee Lake and occasionally blocks the upstream migration of sea lampreys. This facility collects steelhead (*Oncorhynchus mykiss*) eggs for Michigan, Ohio, and Indiana, and Chinook salmon (*Oncorhynchus tshawytscha*) eggs for Michigan and Illinois hatcheries. The 2008 lampricide application covered over 50 river miles upstream of this weir site where the stream is very dendritic and difficult to treat. Surveys in 2010 indicate sea lampreys continue to breech the weir, so continued treatment will be necessary.
- Muskegon River: Some tributaries are not treated in conjunction with the main stream, allowing for potential escapement of larvae to the main stream between treatment years.

Table 6. Summary of challenges to effective lampricide treatment in Lake Michigan tributaries. Sensitive species and variable discharge limits the time period available for treatment. Streams requiring secondary treatment applications are identified in the Secondaries column.

River	Sensitive species	Discharge	Secondaries*	Dendritic	Lentic	Access	Beaver dams	pH
Cedar	Sturgeon	Low flows	X	X	X			
Jordan	Salmon		X	X	X			
White	Salmon		X	X				
Ford	Salmon	Low flows	X	X		X	X	
Muskegon	Salmon, sturgeon	Hydro	X	X				
Big Manistee	Salmon, sturgeon	Hydro	X	X				
Pere Marquette	Salmon, burrowing mayflies (*Hexagenia* spp.)		X	X				
Little Manistee	Salmon		X	X	X			
Millecoquins		Low flows	X		X	X	X	X
Manistique	Salmon		X	X	X	X	X	
Whitefish	Salmon, burrowing mayflies		X	X		X	X	
Sturgeon	Sturgeon		X	X			X	
Platte	Salmon, piping plover (*Charadrius melodus*)		X					
Carp Lake	Hungerford's crawling water beetle (*Brychius hungerfordi*)	Low flows	X					
Peshtigo	Sturgeon	Hydro						X
Oconto	Sturgeon	Hydro						X
Menominee	Sturgeon							

*Secondary lampricide treatments focus chemical application in areas of potential refuge such as backwaters, oxbows, or beaver dams. Treatment of these areas is labor intensive but improves treatment effectiveness.

Potential Sources of Parasitic-Phase Sea Lampreys

Potential sources of parasitic sea lampreys include those that escape a lethal dose of lampricide during treatment (residuals) and those that are produced from untreated or undetected populations.

Because of the high number of sea lamprey larvae produced by many Lake Michigan tributaries and because most lampricide applications do not kill all larvae, residuals are likely the most significant source of parasitic-phase sea lampreys. In streams with large larval populations, even a small percentage of residuals can contribute to a high abundance of transformers before the next treatment occurs. Strategies to address both deferred treatments and residuals in large streams are presented later in this plan. Residuals from lentic areas contribute little to the parasitic population because most infested lentic areas are small areas with low larval density and are treated regularly with gB. In recent years, many lentic areas have been treated shortly after the adjacent source stream was treated, reducing the potential survival of larvae that drifted into the lentic area during treatment. In addition, new technologies have allowed for more effective lampricide applications in areas with the greatest potential for parasitic-phase production. RoxAnn© sonar is used to map substrate in lentic areas suspected of harboring larval lamprey populations, and state-of-the-art navigational and product delivery systems are being used to more accurately and efficiently treat large lentic areas.

Streams and lentic areas with the potential to produce sea lampreys are monitored on a regular basis. These include areas that formerly produced sea lampreys but have not been re-infested and areas that contain suitable spawning and nursery habitat that have never produced sea lampreys. Since 2000, new infestations have only been identified in two small tributaries, Cooper and Mattix Creeks (Appendix B), and these were treated.

Other sources of parasitic-phase sea lampreys include small populations that are not cost-effective to treat, populations that go undetected due to gear limitations, and those that migrate from Lake Huron. Of these sources, only the contribution from northern Lake Huron is believed to be significant, but it remains unquantified.

Special Concerns

Protected Species

The Endangered Species Act of 1973 and the National Environmental Policy Act of 1969 require federal agencies to review the effects of their proposed actions and take steps to comply with the laws governing endangered species and environmental protection. This requirement involves coordination with many state, tribal, and federal agencies to minimize risk to nontarget organisms. Compliance with the laws may require scheduling sea lamprey control activities to avoid certain areas and time periods. Protected species that may be affected by sea lamprey control activities are listed in Table 7 with their formal federal or state-listed designation.

Table 7. Protected species that may be affected by sea lamprey control in Lake Michigan and tributaries. Formal federal and state designations of species are denoted as E (endangered), T (threatened), SC (special concern), and C (candidate).

	Federal	State			
Species	**U.S.**	**MI**	**WI**	**IN**	**IL**
Lake sturgeon (*Acipenser fulvescens*)		T	SC	E	E
Northern brook lamprey (*Ichthyomyzon fossor*)				E	E
Piping plover (*Charadrius melodus*)	E	E	E	E	E
Hungerford's crawling water beetle	E	E			
Snuffbox mussel (*Epioblasma triquetra*)*		E	E	E	E

*Snuffbox mussel expected to be proposed for federal listing in the United States in 2010.

Piping Plover

The piping plover (*Charadrius melodus*) is federally listed as endangered in the Great Lakes. Piping plovers typically nest and feed around the mouths of rivers from May 1 to September 1. To avoid adversely affecting piping plovers, lampricide treatments are currently scheduled after September 1 in United States streams near successful nesting areas.

In Lake Michigan, the mouths of 12 tributaries that have been treated for sea lampreys (Milakokia, Brevort, Crystal, Platte, Pere Marquette, Muskegon, and Galien Rivers; Big Sucker, McGeach, and Cooper Creeks; and Gulliver Lake and Wycamp Lake outlets) are associated with historical piping plover nesting sites or are located in designated piping plover critical habitat. From 2006-2010, the Platte, Pere Marquette, Milakokia, and Brevort Rivers; Big Sucker Creek; and Gulliver Lake and Wycamp Lake outlets have had nesting piping plovers within two miles of the stream mouth and have been subject to the schedule restriction.

Lake Sturgeon

The lake sturgeon (*Acipenser fulvescens*) is state listed as endangered in Illinois and Indiana, threatened in Michigan, and of special concern in Wisconsin. Of the 29 Lake Michigan tributaries estimated to be historically used by lake sturgeon, the species remains extant in 11, extirpated in 15, and of unknown status in 3 (Auer 2003). Lakewide abundance is estimated at well below 10,000 adults, less than 1% of the most conservative historical abundance estimates (Elliott et al. 2009).

The decline of lake sturgeon throughout the Great Lakes was a consequence of intensive fishing, degraded water quality, and loss of habitat associated with settlement and development of the region (Elliott et al. 2009). Dams on tributaries buried high-gradient habitat under their impoundments and prevented upstream migration to spawning habitat (Hay-Chmielewski and Whelan 1997). These dams were built for purposes other than sea lamprey control, but most function to block the upstream migration of spawning-phase sea lampreys. No sea lamprey barriers have been constructed on streams with resident spawning populations of lake sturgeon in the Lake Michigan watershed.

Through reductions in parasitic sea lampreys, sea lamprey control provides a direct benefit to lake sturgeon recovery (Patrick et al. 2009). Sea lamprey induced mortality on large juvenile and adult lake sturgeon has been found to have a greater impact on the long-term population viability than factors that may affect early life stages, such as lampricide applications (Sutton et al. 2004). Therefore, lampricide control strategies designed to protect young lake sturgeon at the expense of increased production of sea lampreys may not be optimal for rehabilitating self-sustaining lake sturgeon populations (Patrick et al. 2009).

However, lake sturgeon <100 mm were found to be sensitive to lampricides at or near the minimum lethal concentrations (MLC) required for effective control of larval sea lampreys (Boogaard et al. 2003). These findings led to the adoption in 2002 of an interim protocol*,* which stipulates using reduced lampricide concentrations in streams where lake sturgeon are known to spawn (McDonald and Kolar 2007). In addition, treatments with TFM and the liquid or powder forms of bayluscide must occur after August 1 when juvenile lake sturgeon reach 100 mm in length (U.S. Fish and Wildlife Service, Marquette Biological Station, unpublished data; D. Caroffino, unpublished data; Benson et al. 2006).

Streams with spawning lake sturgeon that are treated with lampricide include the Millecoquins, Manistique, Menominee, Peshtigo, and Oconto Rivers and tributaries to the St. Joseph, Kalamazoo, Grand, Muskegon, and Manistee Rivers (Elliott 2008). Lake sturgeon are being reintroduced into some other rivers, including the regularly treated Whitefish, Cedar, and Kewaunee Rivers and the untreated Milwaukee River. These are larger systems and some are very dendritic and, delaying treatments until fall to avoid mortality of young-of-the-year lake sturgeon, increases the risk that flow conditions will not be suitable for successful treatment. The use of lower lampricide concentrations in these streams also increases the probability of lower treatment efficacy. The use of gB to sample or treat larval sea lampreys in these streams is also restricted until after July 1, and this restriction could compromise the quality of assessments and efficacy of treatments in areas prone to heavy weed growth.

During 2005, the GLFC, the control agents, and the states and tribes of Wisconsin and Michigan, with the support of the Lake Michigan Committee (LMC), agreed to temporarily modify the lake sturgeon protocol in Lake Michigan because sea lamprey abundance was greater than target levels. The modified protocol allowed the application of lampricides at normal concentrations required to effectively kill sea lampreys but adhered to the post-August restriction.

Northern Brook Lamprey

The northern brook lamprey (*Ichthyomyzon fossor*) is endangered in the states of Indiana and Illinois. In the larval stage, the northern brook lamprey is nearly indistinguishable from the chestnut lamprey (*Ichthyomyzon castaneus*), which makes documentation of its distribution and its protection during treatments challenging. Northern brook lamprey have not been discovered in Indiana streams currently infested with sea lampreys. However, to aid in protecting this species, U.S. Fish and Wildlife Service (USFWS) staff have assisted the Indiana Department of Natural Resources (INDNR) with documentation of the distribution of the northern brook lamprey in Indiana tributaries to the Great Lakes with no records of sea lamprey infestation. Historically, larval assessment and lampricide applications have been closely coordinated with the INDNR.

Freshwater Mussels

The snuffbox mussel (*Epioblasma triquetra*) is listed as endangered by all four states bordering Lake Michigan and is proposed for federal listing during 2010 (Table 7). The mussel is found in the St. Joseph, Grand, and Muskegon Rivers. Prior to treatment of these rivers, formal consultation with the USFWS's Ecological Services (ES) branch will be required. This consultation involves the drafting of a biological assessment and a biological opinion by the USFWS that serves as legal documentation of the review process to evaluate the proposed action (treatments) and its effect on the snuffbox mussel. During consultation, conservation measures are developed to avoid and protect the species and critical habitat.

Hungerford's Crawling Water Beetle

The Carp Lake River is the only Lake Michigan tributary treated with lampricide that is known to contain the endangered (federal- and Michigan-listed) Hungerford's crawling water beetle (*Brychius hungerfordi*) within the treatment area. A sea lamprey barrier was built on the Carp Lake River in 2005 and modified in 2006 after sea lampreys were found upstream of the barrier. As a result of the modifications, the barrier now successfully blocks the upstream migration of sea lampreys, and treatment of the river, where the Hungerford's crawling water beetle is known to exist, is no longer necessary.

The Carp Lake River was successfully treated (due to escapement and residual lampreys from the 2004 treatment) in 2009 under a strict list of conservation measures developed by the USFWS and ES designed to avoid and protect the beetle. If sea lampreys breech the barrier in the future, further consultation with the ES branch will be necessary prior to treating the river.

Timing and Discharge Restrictions

While there is general support for sea lamprey control, lampricide applications can be viewed negatively, especially if done during spawning migrations of Pacific salmon (*Oncorhynchus* spp.) on heavily fished streams. In an attempt to reduce negative public response and to protect spawning Pacific salmon and resident brown trout (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*), the State of Michigan permit stipulations have included protection for these species during their spring- and fall-spawning migration periods when, due to the stress from spawning, they can be susceptible to lampricides. Permits for sea lamprey control require that lampricide applications be done after June 1 but before September 1, 15, or October 1, depending on the stream. These restrictions are requested for most streams in Michigan that have moderate to heavy fishing pressure and spawning migrations of Pacific salmon or streams that support spawning populations of brook and brown trout. Streams where these restrictions are requested include the Big Manistee, Little Manistee, White, Muskegon, Platte, Betsie, Boyne, Ford, and Pentwater Rivers.

Lampricide applications in some large Lake Michigan tributaries must be coordinated with hydroelectric companies to ensure that a consistent and manageable volume of water is provided during the lampricide application. The Big Manistee, Muskegon, Oconto, and Peshtigo Rivers are all regulated rivers that require such coordination before treatment. Releases of water from other water-retaining devices, such as dikes and dams not associated with power generation, can also impose restrictions on treatment timing; for example, the water-control devices in the Seney National Wildlife Refuge on the Manistique River system are used to control water levels in refuge impoundments. While regulated water levels have the potential to be a challenge, it has not deferred scheduled treatments to date.

Stream-Treatment Deferrals

Treatment deferrals typically occur when stream discharge is too high or low for successful treatment, but treatments are most often completed the following year. Low discharge often requires numerous application points, can be labor intensive, and, thus, more expensive. Low discharge may leave portions of streams disconnected from the main stream channel containing lampricide, which leaves infested areas untreated. High discharge can be costly in terms of the volume of lampricide required and can create unsafe working conditions. Deferrals can be partly attributed to the lack of flexibility in the treatment schedules. When suboptimal flows are encountered, lampricide application teams have three options: wait for flows to change (either by waiting for flows to recede or for rains to increase flows); treat in suboptimal conditions, which leads to increased expense or reduced treatment efficacy; or transfer effort to another stream treatment. Current treatment schedules are fully determined prior to the field season, which limits the opportunity to compensate for either waiting for optimal flows (another stream later in the schedule might remain untreated due to time spent waiting) or treating the stream at a later date. More flexibility in the treatment schedule would increase the likelihood of conducting an effective treatment when suboptimal flows are encountered. Streams deferred for treatment until the following year pose a greater risk of recruiting parasitic animals to the lake, particularly if they contain larvae that would metamorphose during the year of treatment.

Treatments were deferred 28 times on 21 Lake Michigan tributaries during 1987-2010 (Table 8), mainly due to low flow or changes in treatment priority. With two exceptions, low-flow deferrals were in streams in Michigan's Upper Peninsula where lack of groundwater often limits flows. Changes in priority most often occur when a small stream scheduled for treatment is displaced on the schedule by one with a recently discovered larger sea lamprey population that was not originally scheduled for treatment. The reasons for four other deferrals were protection of nontarget-species/spawning Chinook salmon (one time) and the presence of Hungerford's crawling water beetle (three times), which is a federally protected species.

Table 8. Stream-treatment deferrals in Lake Michigan tributaries during 1987-2010. Missing years are years without deferrals. Code definitions are H (excessive volume), L (insufficient volume), F (flood-destroyed larval habitat), P (treatment priority of large stream), S (study stream), N (protected nontarget organisms), C (prohibitive water chemistry), and A (lack of access).

Stream	87	88	89	91	93	95	98	00	02	03	04	06	07	08	Total
Furlong Creek	L														1
Ten Mile Creek	L														1
Brevort River	L	L													2
Cedar River	L										H				2
Beattie Creek	L														1
Manistique River		H													1
Swan Creek		P	L												2
Valentine Creek		P													1
Sunnybrook Creek		P													1
East Branch Whitefish River			S												1
Hudson Creek			L												1
Pentwater River				P											1
Porter Creek					H	F									2
Rapid River							L								1
Carp Lake River									N	N			N	L	4
Boardman River								S							1
Casco Creek												N			1
Grand River (Norris Creek)													P		1
St. Joseph (Paw Paw) River														P	1
Oconto River														C	1
Huntspur Creek (Milakokia River)														A	1
Total	5	5	3	1	1	1	1	1	1	1	1	1	2	4	28

Pollution Abatement

Pollution abatement can lead to improvements in water quality that result in more favorable conditions for sea lamprey infestation (Sullivan et al. 2003), potentially increasing the distribution and reproductive capacity for sea lampreys as well as control program costs. While the GLFC strongly supports efforts to improve water quality, continued coordination between fishery and sea lamprey managers regarding such initiatives, particularly in streams that do not currently harbor sea lampreys, is essential in managing abundances to target levels.

Barrier Removal

The Environmental Objectives Working Group of the Lake Michigan Technical Committee (LMTC) identified the protection and restoration of connectivity and quality tributary spawning and nursery habitats as one of the environmental objectives necessary for the achievement of fish-community objectives, and efforts within the Lake Michigan basin are currently being focused on watershed management and dam removal (Rutherford et al. 2004; Clapp and Horns 2008). Balancing the benefit of enhanced connectivity with the goal of controlling sea lampreys will be a challenge for the future as increased connectivity increases the availability of sea lamprey spawning and nursery areas.

Recruitment from Other Sources

Many aquatic species, including sea lampreys, have benefited from implementation of pollution-abatement measures following the signing of the Great Lakes Water Quality Agreement by Canada and the United States. In particular, clean-up efforts and natural processes have reduced concentrations of toxic metals, chemicals, and pesticides in sediments of the four interconnecting waterways (St. Marys, St. Clair, Detroit, and Niagara Rivers.)

Although none of the four waterways is directly connected to Lake Michigan, tagging studies have demonstrated movement of parasitic and spawning-phase sea lampreys between Lakes Huron and Michigan. Increases in parasitic-phase sea lampreys in northern Lake Michigan since the early 1990s are believed due, in part, to recruitment from the St. Marys River (Lavis et al. 2003). Although the integrated control strategy implemented in the St. Marys River has not resulted in a reduction in lake trout mortality in northern Lake Michigan as of yet, other factors, such as increased sea lamprey production from the Manistique River, may have masked the potential effects of this effort. Ongoing control efforts in the St. Marys River and the current enhanced North Channel treatment strategy should reduce recruitment to Lake Michigan from these areas.

Fish-Community Interactions

Parasitic-phase sea lampreys prey upon multiple fish species, including salmonines, coregonines, catastomids, percids, cyprinids, and burbot (Wells and McClain 1973; Smith 1971). However, changes in sea lamprey feeding behavior in response to changes in prey abundance are poorly understood. Because sea lampreys do not require specific intermediate or terminal hosts, sea lamprey control affects and is affected by the entire fish community. Consequently, the effects of sea lamprey control are difficult to interpret when exclusively evaluated through traditional estimates of spawning-phase sea lamprey abundance and the marking rate on lean lake trout >532 mm. To better determine the effects of sea lamprey control on the fish community, sea lamprey induced mortality should be assessed for a number of sea lamprey prey species and not restricted solely to lean lake trout. Strategies to address better assessment are discussed later in this plan.

Public Use

Lake Michigan tributaries support a wide variety of public use, particularly during warm summer months and on weekends when water-related activities typically peak. Treating during times of high public use can result in negative public perception of the sea lamprey control program. While there are no restrictions on swimming, boating, or fishing during lampricide applications or authority to halt irrigation, the public is informed of applications through news releases and personal contact with user groups to decrease usage during treatments to minimize exposure to lampricides. Treatment supervisors often adjust treatments to minimize times when peak public river use will occur, but it is nearly impossible to account for all activities. Irrigators are requested to cease irrigation during treatments because water withdrawals can reduce discharge and flow times, which complicates the application process.

Fish-Community Objectives

Fish-community objectives (FCOs) developed for Lake Michigan by the management agencies encompass broad ecological concepts that provide a framework for more specific fisheries-management objectives (Eshenroder et al. 1995b). Within this context, the LMC recognized the impact of sea lampreys on the entire fish community and adopted the following FCO for sea lampreys:

> *Suppress the sea lamprey to allow the achievement of other fish-community objectives.*

Among the Lake Michigan fish community, sea lamprey induced mortality likely has the most detrimental impact on salmonines, benthivores, and planktivores. The FCOs for these components of the Lake Michigan fish community are:

> *Establish a diverse salmonine community capable of sustaining an annual harvest of 2.7 to 6.8 million kg (6 to 15 million lb), of which 20-25% is lake trout.*
>
> *Establish self-sustaining lake trout populations.*
>
> *Maintain self-sustaining stocks of lake whitefish, round whitefish, sturgeon, suckers, and burbot. The expected annual yield of lake whitefish should be 1.8-2.7 million kg (4 to 6 million lb).*
>
> *Maintain a diversity of planktivore (prey) species at population levels matched to primary production and to predator demands. Expectations are for a lakewide planktivore biomass of 0.5 to 0.8 billion kg (1.2 to 1.7 billion lb).*

Sea Lamprey Suppression Targets

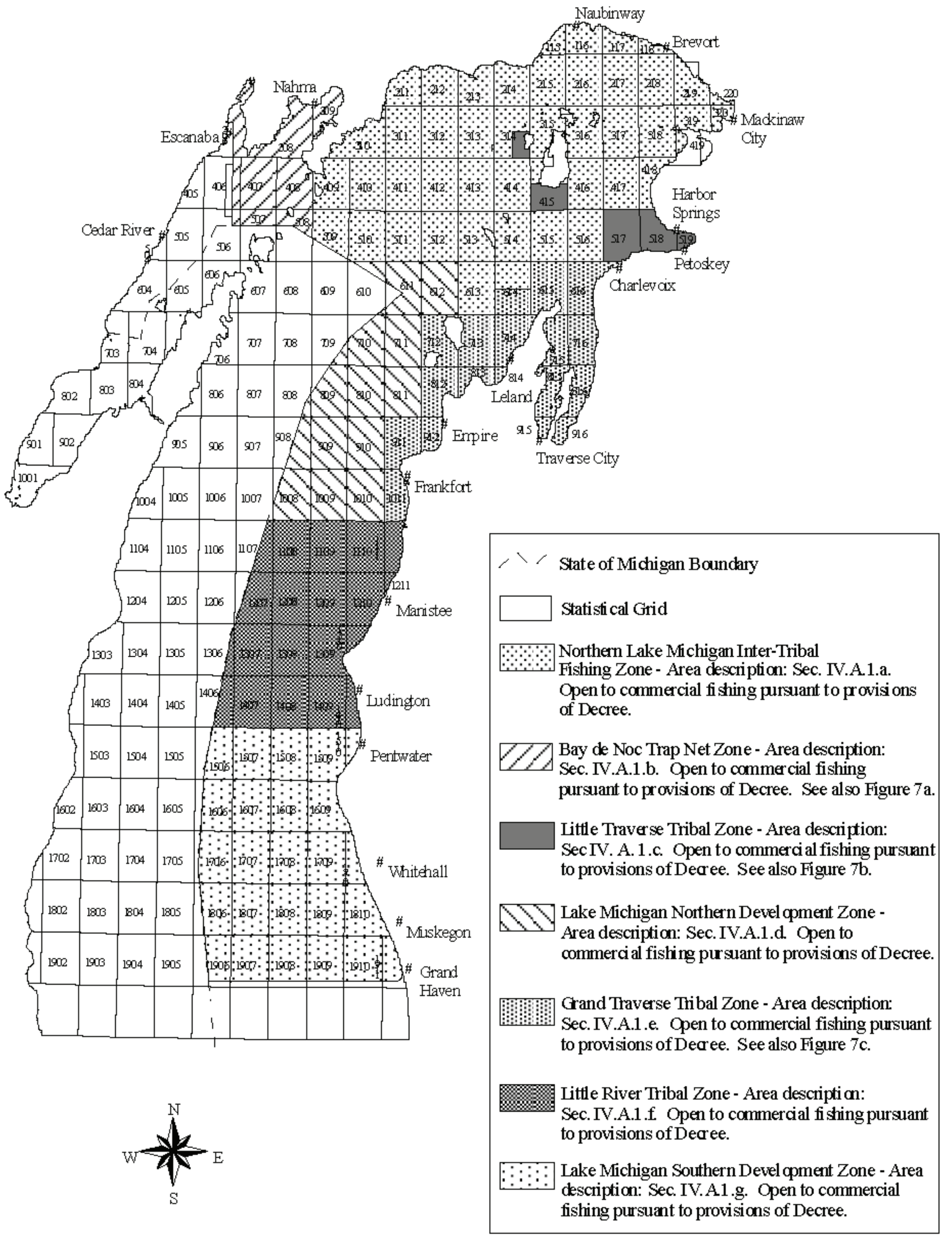
The overall goal for sea lamprey control in this plan is to suppress sea lampreys at least to the extent that target levels for spawning-phase sea lamprey abundance and target levels for fish-community marking rates established by the LMC are achieved and maintained over time.

In 2004, the LMC established 57,000 ± 18,000 as the explicit target level of abundance for spawning-phase sea lampreys (Lake Michigan Committee 2004). This target level was the average annual abundance estimated for 1988-1992 when marking rates were closest to the target level of 5 marks per 100 fish (4.7 Type A, Stages I-III marks per 100 lake trout of total length >532 mm). Marking rates of less than 5 per 100 fish were found to result in a sea lamprey induced mortality rate of less than 5% based on a relationship between marking rates and the probability of surviving a sea lamprey attack.

It has been recommended that total annual lake trout mortality in Lake Michigan should not exceed 40% (Bronte et al. 2008). Mortality is to be controlled through the management of fishery exploitation and continued suppression of sea lampreys (Holey et al. 1995). Sea lamprey induced mortality is considered a major impediment to lake trout rehabilitation in Lake Michigan. Estimates of this mortality in northern Lake Michigan have ranged from 6-22% (Bronte et al. 2008). Sea lamprey marking rates are generally lower than the target in southern Lake Michigan, suggesting that sea lamprey induced mortality may be below 5% in these areas. The LMC developed a lake trout rehabilitation strategy in 2010 based on the recommendations in Bronte et al. (2008). The strategy calls for increased efforts to reduce sea lamprey induced mortality, shifts the focus of stocking to two primary rehabilitation areas, and recommends stocking more of the Seneca Lake lake trout strain, which has demonstrated greater resiliency to sea lamprey attacks (Madenjian et al. 2004; Bronte et al. 2007).

Reduced sea lamprey induced lake trout mortality is also a stipulation in the 2000 Consent Decree (State of Michigan 2000). The decree is a federal court order that specifies how fishery resources are managed and allocated among five tribal governments and the State of Michigan within the Michigan waters of the 1836 Treaty of Washington, an area that extends from Bay de Noc to Grand Haven (Fig. 19). The decree, based on a settlement agreement among the U.S. Department of Interior, five tribal governments, and the State of Michigan embraces the goals of lake trout rehabilitation and requires the effective control of sea lamprey numbers and sea lamprey induced mortality to lake trout. To adopt the goals of lake trout rehabilitation and management within the decree, the parties stipulated that "sea lamprey control efforts will (would) significantly reduce sea lamprey induced lake trout mortality from 1998 levels." Failure to achieve a significant reduction in sea lamprey induced mortality on lake trout within the 1836 Treaty waters in Lake Michigan could result in a party requesting relief from the lake trout rehabilitation goals in the decree.

Fig. 19. Lake Michigan tribal fishing zones within the 1836 Treaty of Washington area as identified in 2000 Consent Decree (State of Michigan 2000).



Maps for general reference only.
refer to text of Consent Decree for specific provisions.

20 0 20 40 Miles

August 3, 2000
Version 3.0

Objectives and Strategies within Program Elements

Lampricide Control

Populations of sea lamprey larvae in streams are generally controlled through application of the TFM lampricide. During 1999-2010, 241 Lake Michigan tributaries were treated with TFM with an average of about 17 treated per year during 1999-2006, and about 26 were treated per year during 2007-2010 (Table 9).

Populations of sea lamprey larvae in lentic areas are controlled through application of the gB bottom-release toxicant. Historically, frequency of treatment of lentic areas has been variable, but the importance of control in these areas has become a higher priority in recent years.

Table 9. Sea lamprey treatment information for Lake Michigan during 1999 to 2010. TFM and Bayluscide are reported as kilograms of active ingredient used.

Year	Number of treatments	TFM (kg)	Stream length (km)	Bayluscide (kg)
1999	15	7,849	593	62
2000	17	11,250	499	116
2001	19	15,680	597	187
2002	14	16,908	727	182
2003	14	11,933	830	205
2004	28	9,953	888	45
2005	12	16,195	816	128
2006	19	19,398	839	236
2007	27	11,359	1,027	110
2008	25	14,723	817	219
2009	25	31,914	1,249	292
2010	26	13,346	854	92

Objective 1: Within five years, increase the proportion of sea lampreys killed by the lampricide control program (stream- and lentic-specific strategies) by 60%.

Strategy: Review treatment history of streams and identify streams where treatment effectiveness may be improved and develop and implement strategies to treat more effectively, such as maintaining concentrations in excess of the MLC for at least nine hours; increasing the duration of application by one-three hours; applying lampricide to backwaters, rivulets, and seepage areas that would otherwise remain untreated during the primary treatment; treating at the optimal time of year to ensure appropriate discharges; and treat in the spring when larval sea lamprey fitness is lowest (Scholefield et al. 2008). Candidate streams include all streams in Table 6.

Cost: Included in the current base program.

Strategy: Review treatment history and annually identify tributaries from the treatment rank list where treatment effectiveness can be increased by inventorying geographic features and increasing effort to conduct secondary lampricide applications. Candidates include the Ford, Whitefish, Sturgeon, Manistique, and Cedar Rivers.

Cost: Included in the current base program.

Strategy: Coordinate with state and tribal management agencies to address challenges to successful treatment, including the communication of risks, goals, and benefits of lampricide control to stakeholders and requirements to protect species at risk while ensuring that entire areas infested with sea lampreys in each stream are treated.

Cost: Included in the current base program.

Strategy: Continue to conduct treatments in lentic areas associated with streams with known lentic populations during or immediately following the stream treatment. Candidates include the Jordan, Boyne, Manistique, and Days Rivers and Horton and Porter Creeks.

Cost: Included in the current base program.

Strategy: Continue annual TFM treatments to the Days River to reduce sea lamprey recruitment to the associated lentic area.

Cost: Included in the current base program.

Strategy: Beginning in 2011, use nets to remove larvae activated in tributaries during treatments in tributaries to larger untreated portions of the system, such as main streams or inclusive lakes. Candidates include the Platte, Carp Lake, Grand, Kalamazoo, and Muskegon Rivers.

Cost: Included in the current base program.

Strategy: Continue coordination with state and tribal agencies to negotiate implementation of the lake sturgeon protocol to accommodate lakewide target levels of sea lamprey suppression on the Cedar, Muskegon, Peshtigo, and Big Manistee Rivers.

Cost: Included in the current base program.

Strategy: When necessary, apply lampricides for 24 hours at lower than normal concentrations to compensate for large pH fluctuations and minimize nontarget mortality. Candidates include the Oconto and Peshtigo Rivers.

Cost: Included in the current base program.

Objective 2: By 2014, modify lakewide stream-treatment strategies to reduce transformer escapement (whole-lake strategies).

Strategy: Beginning in 2012, identify and treat on a shorter rotation (i.e., treat every two years vs. every three years) at least three large sea lamprey producing streams so that fewer transformers escape if a treatment is deferred. Candidates include the Ford, Muskegon, Pere Marquette, Big Manistee, White, and Manistique Rivers.

Cost: Dependent on the streams selected.

Strategy: Beginning in 2012, implement consecutive treatments for two years in the top five or six sea lamprey producing streams with a history of high post-treatment residuals (Ford, Muskegon, Pere Marquette, Big Manistee, White, and Manistique Rivers).

Cost: Dependent on the streams selected.

Strategy: Beginning in 2012, periodically incorporate treatments in two consecutive years into the treatment cycle for streams with a history of significant residual sea lampreys. For example, a stream with a three-year treatment cycle would be treated in years one, two, five, six, nine, and ten. Candidates include the Ford, Muskegon, Pere Marquette, Big Manistee, and White Rivers and Furlong Creek (Millecoquins River).

Cost: Dependent on the streams selected.

Strategy: Treat all streams with a history of annual recruitment on a three- or four-year cycle (i.e., do not rank streams for treatment, just determine lampricide application points and treat).

Cost: Analyses are currently being conducted but are likely to be cost neutral.

Objective 3: By 2012, develop a regional treatment strategy that will not only kill sea lampreys but also reduce the long-term need for continuous treatment based on recolonization strategies.

Strategy By 2012, review current transformer sea lamprey mark-recapture information in the context of recolonization strategies and evaluate how sea lamprey reduction at a regional level might affect and be affected by the regional fish community. Establish regional goals for spawning-phase sea lamprey abundance.

Cost: Cost will depend on the strategy, but, if funding becomes available, it could be applied to the northwest region of Lake Michigan where marking tends to be high. Recolonization could be evaluated over the next three years.

Strategy: Apply results from the Lake Huron North Channel treatment strategy to this objective, investigate the potential to identify a subset of top-producing streams within a region, and treat this subset of streams in two consecutive years.

Cost: Dependent on the streams selected for the strategy.

Larval Assessment

Assessment of the larval sea lamprey life stage is used to prioritize streams for lampricide treatment, determine where lampricides should be applied, evaluate the relative effectiveness of treatments, evaluate the effectiveness of barriers, and detect new infestations. Standard protocols for assessing larvae (Slade et al. 2003) are used in Lake Michigan tributaries, and about 80-100 streams and 10-15 lentic areas are assessed annually.

Objective 1: By 2012, maximize the effectiveness of larval assessments to provide enough among-stream information to better prioritize streams for lampricide application and sufficient within-stream information to more effectively plan a lampricide application.

Strategy: Continue to use expert judgment based on prior knowledge of annual recruitment and treatment history to prioritize streams for treatment. Allocate effort saved to post-treatment assessments within one year of treatment to determine residual abundance and the potential for re-treatment. Candidates include the Cedar, Ford, Manistique, Big Manistee, Pere Marquette, White, and Muskegon Rivers.

Cost: Included in the current base program.

Strategy: Conduct detection surveys for new populations of sea lamprey larvae every five to seven years in streams with suitable spawning and nursery habitats, and conduct evaluation surveys every three years in previously infested streams.

Cost: Need to calculate the cost of additional detection surveys.

Strategy: Determine the upstream and downstream limits of sea lamprey infestation either the year prior to or the year of treatment for each stream scheduled for lampricide application.

Cost: Included in the current base program.

Objective 2: By 2015, prioritize and treat lentic and estuarine areas that regularly recruit larval sea lampreys.

Strategy: Continue to use RoxAnn© mapping to quantify substrates in lentic and estuarine areas.

Cost: Included in the current base program.

Strategy: Continue to assess at least three new potential lentic areas annually until all are accounted for (list and prioritize based on potential).

Cost: Included in the current base program.

Strategy: Reduce the recruitment of larvae to lentic areas by evaluating the feasibility of implementing annual TFM treatments on streams associated with lentic populations >500 larvae/ha.

Cost: Included in the current base program.

Strategy: Re-assess larval sea lamprey densities in known infested lentic areas every two to three years to determine the need for treatment.

Cost: Included in the current base program.

Objective 3: By 2013, implement alternative methods to prioritize streams and lentic areas for lampricide application.

Strategy: Develop additional criteria to prioritize streams for treatment based on historical larval assessment and treatment data or current larval assessment data not typically used to rank streams for treatment.

Cost: Included in the current base program.

Strategy: Consult with the LMTC to prioritize lampricide application by incorporating host abundance in the prioritization method in areas where sea lampreys are more likely to survive and damage fish. Begin with streams tributary to the northern basin of Lake Michigan in 2012. Coordinate this strategy with strategies in Objective 3 in Lampricide Control and Objective 1 in Metrics of Success.

Cost: Additional staff time will be required to work with technical and lake committees in developing improved prioritization models.

Strategy: By 2011, evaluate the potential to treat streams or lentic areas on a fixed cycle from the maximum historical points of infestation, thereby reducing reliance on annual larval assessment.

Cost: Currently being investigated.

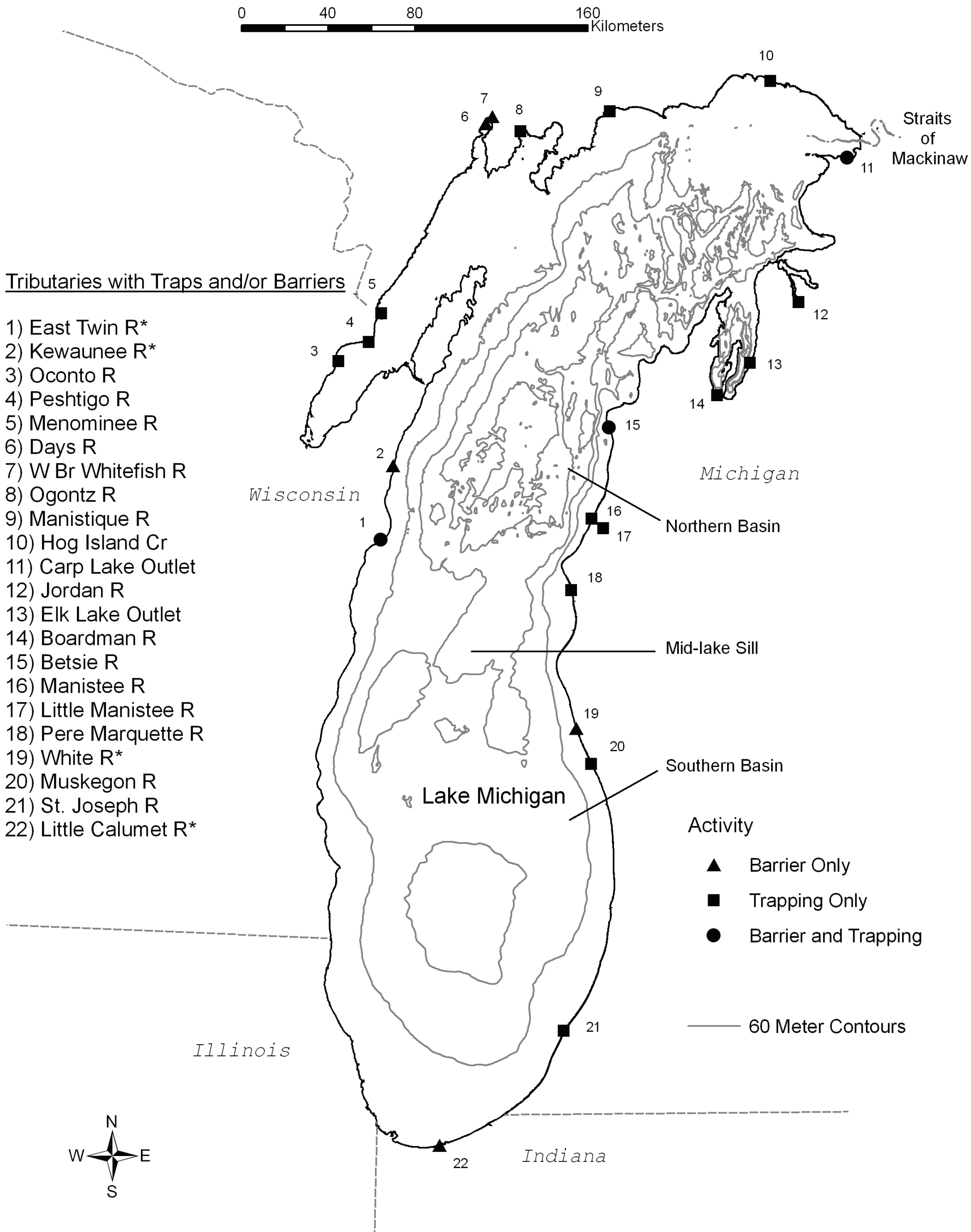
Trapping

Trapping of sea lampreys in the Great Lakes is used for assessment and control and occurs during spawning-phase and metamorphosing life stages. Based on life stage and purpose, trapping activities are described below.

Spawning-Phase Assessment

Spawning-phase sea lampreys are currently trapped in 16 Lake Michigan tributaries (Fig. 20). Total annual catch has averaged 29,693 since 1999. Most of these lampreys have been captured for assessment purposes, but about 10,000/yr are used for the sterile-male release technique (SMRT) program and contribute to control efforts.

Fig. 20. Lake Michigan tributaries with traps and barriers for sea lampreys. Asterisks identify barriers that were built for other purposes but have been modified to block sea lampreys.



A review of the spawning-phase assessment program (Bence et al. 1997) identified a need to expand trapping to more tributaries where large spawning runs are expected. Expanding trapping to more large rivers will improve spawning-phase abundance estimates for runs that are currently estimated by extrapolation using the spawner-discharge model (Mullett et al. 2003), will provide additional control through trapping and removal of spawning-phase sea lamprey, and could provide more sea lampreys for the SMRT program.

Streams trapped for spawning-phase sea lamprey in Lake Michigan represent the best range of stream discharge and spatial distribution among all the Great Lakes. The precision of the estimates of spawning-phase sea lamprey abundance in Lake Michigan is the highest of any of the Great Lakes, averaging about 9% over the past five years. Efforts to identify factors that will improve the accuracy and precision of spawning-phase sea lamprey abundance estimates (Mullet et al. 2003) should lead to improvements in current trapping methodology.

Objective 1: By 2015, determine the optimum level of trapping (suite of streams, size of streams, geographic coverage) needed for accurate estimates of lakewide abundance for each of the Great Lakes with a precision of 20%.

Strategy: By 2012, evaluate factors that will improve the accuracy and precision of annual estimates of spawning-phase sea lamprey abundance. Use this information to determine if improvements are necessary, and, if so, identify and recommend those factors that will improve the desired levels of accuracy and precision.

Cost: Included in the current base program.

Strategy: By 2013, recommend the optimum suite of streams to be trapped to estimate lakewide spawning-phase sea lamprey abundance based on factors identified in the evaluation phase.

Cost: Included in the current base program. Streams will be identified after analyses are complete.

Objective 2: Investigate innovative trap designs and alternative techniques and technologies to obtain spawning-phase abundance estimates, especially in large rivers and streams without barriers, and, if feasible, implement at least one new method by 2015.

Strategy: By 2012, identify potential alternative technologies and techniques evaluation.

Cost: Included in the current base program.

Strategy: By 2012, develop a list of rivers where alternate methods can be evaluated through correlation with mark-recapture estimates of spawning-phase abundance.

Cost: Included in the current base program.

Strategy: By 2014, determine the ability of DIDSON™ camera technology to estimate the spawning-phase sea lamprey run in one or more rivers.

Cost: $80K for DIDSON™ + $20K per stream for operations.

Strategy: By 2014, based on the correlation of spawning-phase abundance with nest counts (Lake Erie data), develop a list of streams where nest counts may be an effective assessment tool and implement in at least one stream by 2015.

Cost: Included in the current base program.

Strategy: By 2015, evaluate the ability of pheromone and eDNA assays to quantify spawning-phase sea lamprey abundance in rivers.

Cost: Included in the current base program.

Metamorphosing Assessment

A lakewide mark-recapture study was conducted in the fall of each year during 2004-2007 using metamorphosing animals marked with coded wire tags and released at streams located throughout Lake Michigan. Spawning-phase adults were recaptured two years after release in assessment traps to estimate abundance of the metamorphosing cohorts that escaped treatment for each release year (Sullivan and Adair 2010). Results of these estimates suggest that mortality in the two years between release and recapture may be as high as 80%. Similar results have been observed in Lakes Huron and Superior. No metamorphosing sea lampreys have been released since 2007, and there are no current plans to continue these studies.

Trapping for Control

Trapping spawning-phase sea lampreys for control is done to some extent in Lake Michigan. Spawning-phase sea lampreys trapped in Lake Michigan tributaries, except those used for mark recapture, are used for the SMRT program or are euthanized and discarded, and these actions may contribute to reducing larval recruitment.

Objective 1: By 2015, increase the proportion of spawning runs captured in traps to 25%.

Strategy: By 2015, increase annual effectiveness of traps to capture at least 25% of the estimated spawning run or capture 20% more than the 2006-2010 average catch in at least two of the 16 Lake Michigan streams currently trapped through trap design improvements and large-scale application of pheromones. Candidates include the Manistique, Carp Lake, Betsie, and Big Manistee Rivers.

Cost: Need to select the streams and determine the cost.

Strategy: By 2020, incorporate permanent or semi-permanent traps into present or planned barriers. Candidates include Trail Creek and the Manistique, Manistee, and Muskegon Rivers.

Cost: Need to select the streams and determine the cost.

Strategy: Investigate and implement novel technologies and techniques to capture more sea lampreys. Candidates include the Pere Marquette, Grand, Kalamazoo, and Manistique Rivers.

Cost: Need to select the streams/techniques and determine the cost.

Objective 2: By 2015, develop and implement trap-control strategies to further reduce spawning-phase sea lamprey populations in locations where they have been reduced through regional or lakewide control efforts or to reduce spawning-phase sea lamprey populations where they are not currently being trapped.

Strategy: Further reduce recruitment of larvae by trapping low-abundance spawning runs with a combination of traditional and novel traps.

Cost: Develop a technical assistance proposal to address where and how to implement this strategy.

Strategy: Use trapnets to capture spawning-phase sea lampreys before they enter the stream. Candidates include locations in Lake Michigan offshore of the Grand, Kalamazoo, and Manistique Rivers.

Cost: Approximately $10K to contract with commercial fisher.

Metamorphosing Control

An alternative application of trapping for control targets the capture of out-migrating, newly metamorphosed sea lampreys in the fall and early spring, which would reduce recruitment of sea lampreys to the parasitic population in the lake. This method has been implemented to capture transformers for mark-recapture studies; provide transformers for research; monitor the effects of sea lamprey control in the St. Marys River; and, more recently, as a method of reducing recruitment from tributaries where large numbers of metamorphosed sea lampreys are likely to be out-migrating.

Trapping metamorphosing sea lampreys has been attempted on Lake Michigan tributaries with variable success. In the fall of 2008 and spring of 2009, over 2,400 metamorphosing sea lampreys were trapped in the Carp Lake River using fykenets and a screw trap. This trapping effort was primarily conducted to mitigate for delayed treatment but demonstrated that these trapping techniques can be effective in reducing recruitment to Lake Michigan. In the fall of 2010, trapping of metamorphosing sea lampreys was conducted on six tributaries to northern Lake Michigan. Although metamorphosing sea lampreys were captured in five of the six streams, only 15 were collected despite considerable effort.

Objective 1: By 2013, reduce recruitment to the lake by trapping newly metamorphosed sea lampreys during their downstream migration.

Strategy: By 2011, develop criteria for stream selection and gear placement to capture out-migrating sea lampreys.

Cost: Included in the base program.

Strategy: By 2012, capture out-migrating sea lampreys from streams where large numbers of metamorphosing-phase sea lampreys are known or suspected. Candidates include the Manistique, Muskegon, Manistee, Ford, Whitefish, and Sturgeon Rivers.

Cost: Purchase ($27K) and operate ($22K) screw traps. Purchase ($10K) and operate ($22K) fykenets.

Alternative Control

Techniques other than traditional lampricide application methods used to control sea lamprey populations are considered alternative control methods. Alternative control methods (in addition to trapping for control) currently being implemented are the SMRT program and barriers. Application of pheromones and the sterile-female-release technique are currently being evaluated via control-scale field applications. Potential alternative controls currently being researched include genetic manipulation, agonists and antagonists for chemical cues, manual destruction of sea lamprey nests, and repellents.

Sterile-Male Release

Since 1997, the SMRT program (Twohey et al. 2003) has been fully implemented in the St. Marys River as a component of the integrated control strategy. Over the past five years, an average of more than 10,000 spawning-phase male sea lampreys have been captured in Lake Michigan tributaries and released in the St. Marys River, accounting for over 36% of the total males collected for this effort. The SMRT program has not been implemented in Lake Michigan tributaries, but the use of males to control sea lamprey populations in the St. Marys River likely provides a direct benefit in terms of reducing sea lamprey inflicted damage to the fish community in northern Lake Michigan.

Objective 1: Reduce larval production through the introduction of sterile males into spawning-phase sea lamprey populations.

Strategy: Implement the SMRT program in two streams within the three upper Great Lakes by 2012.

Pheromones

Pheromones are a promising new technique in the integrated control of sea lampreys (Li et al. 2007). Field trials involving the release of a component (3kPZS) of sea lamprey pheromone to attract migrating sea lampreys to traps were initiated in United States tributaries to the Great Lakes during 2009, including three tributaries to Lake Michigan. Preliminary results indicate that more sea lampreys can be attracted to a pheromone baited trap than an un-baited trap (Johnson and Li 2010). Field trials continued in 2010 and included several Canadian tributaries. A detailed plan to implement pheromones in control applications will be developed once the ability to manipulate lamprey migratory behavior through *in situ* pheromone application is better understood.

Objective 1: By 2013, develop a lakewide integrated pheromone plan.

Strategy: Continue researcher and agent coordination and implementation of pheromone field studies to build expertise in pheromone handling, deployment, and application.

Cost: To be determined.

Strategy: As efficacy of various pheromone compounds is demonstrated, evaluate proposed strategies for integration with other control techniques and implement at least one such strategy by 2013.

Cost: To be determined.

Strategy: Register or secure experimental use permits for pheromone compounds to ensure the ability to implement new pheromone methodologies as they become available.

Cost: To be determined.

Barriers

Spawning-phase sea lamprey migrations are blocked by four barriers (Carp Lake, Betsie, Days, and West Branch Whitefish Rivers; Table 10) purposely designed and built to block sea lampreys and six pre-existing structures built for other purposes but modified to block sea lampreys (East Twin, White, Kewaunee, Fox, Little Manistee, Manistique, and Little Calumet Rivers).

Table 10. Location, date of construction, and distance upstream for purpose-built sea lamprey barriers on Lake Michigan. Stream numbers correspond to those in Fig. 16 and Appendix B.

Stream number	Stream	Date of construction	Distance from stream mouth (km)	Comments
433	Carp River	2005	1.0	Fixed crest low-head barrier
523	Betsie River	1974	18.5	Fixed crest low-head barrier
119	West Branch Whitefish River	1980	37.3	Fixed crest low-head barrier
137	Days River	1983	6.8	Fixed crest low-head barrier

Other barriers not purposely built or modified to block sea lampreys are important in limiting access to prime spawning and nursery habitat. These include barriers on several major watersheds, including the St. Joseph, Grand, Muskegon, Big Manistee, Elk, Escanaba, Cedar, Oconto, Menominee, and Peshtigo Rivers. Efforts are undertaken annually to ensure that blockage of sea lamprey migration occurs at barriers other than those built for sea lamprey control, often referred to as *de facto* barriers. To date, 287 *de facto* barriers in Lake Michigan tributaries have been evaluated for their ability to block sea lamprey migration. These evaluations are used to inform decisions about proposed projects at these sites.

Currently, barriers are planned for construction on Trail Creek, Indiana, and the Manistique River, Michigan. Ongoing plans to repair the dam on the White River in Hesperia, Michigan, and determine the route of escapement at the MIDNR weir on the Little Manistee River and the Union Street Dam on the Boardman River, Michigan, are of high priority.

Objective 1: Maintain the ability of the four purpose-built and six modified, non-purpose-built sea lamprey barriers to block migrating spawning-phase sea lampreys.

Strategy: Conduct larval assessments upstream of barriers consistent with a stream's treatment cycle to ensure that sea lampreys have not breeched the barrier.

Cost: Included in the current base program.

Strategy: Conduct annual inspections and repair or replace worn, broken, or missing parts before they affect barrier performance.

Cost: Variable, depending on the barrier. Monitoring is included in the current base program.

Strategy: Consistent with design objectives, evaluate and fix barriers that fail to block spawning-phase sea lampreys. Candidates include the Days, Boardman, Little Manistee, and White Rivers.

Cost: Currently being estimated.

Objective 2: Annually investigate areas where purpose-built barriers can be constructed consistent with the Barrier Strategy and Implementation Plan.

Strategy: Meet with USACE semi-annually to discuss funding, research, and expertise to design, plan, and fund barriers in the United States.

Cost: Included in the current base program (unless a programmer is needed for GIS or database applications). $2.5 million for the Manistique River.

Strategy: Develop partnerships with state, tribal, and nongovernment organizations to obtain funding and support for barrier projects.

Cost: Included in the current base program.

Strategy: By 2013, develop a new process for selecting and ranking proposed sites for barriers.

Cost: Included in the current base program.

Objective 3: Ensure that spawning-phase sea lampreys remain blocked at important non-purpose-built barriers.

Strategy: By 2012, include non-purpose-built barriers in the barrier database, and, by 2013, develop a ranking method based on their importance to sea lamprey control with condition and future maintenance issues noted.

Cost: Included in the current base program.

Strategy: By 2013, develop a policy and work with partners to preserve the integrity of the furthest downstream barriers that currently block sea lampreys.

Cost: Variable, dependent on the stream.

Strategy: By 2015, use the barrier database to maintain a list of structures that currently do not block sea lampreys but have the potential to be converted to blocking structures. Pursue modification through the ranking process.

Cost: Included in the current base program.

Strategy: By 2012, establish a review process with state, tribal, and conservation authorities to notify sea lamprey control managers of in-stream fish-passage or dam-removal projects before permits are granted.

Cost: Included in the current base program.

Strategy: Update the GLFC website to include a barrier map and/or list of inventoried barriers, contact list for barrier removals, and concurrence request form.

Cost: Included in the current base program.

Strategy: By 2013, develop a ranked list of barrier repair and rebuild projects.

Cost: Included in the current base program.

Objective 4: Integrate barriers with other methods of control to effectively manage sea lampreys.

Strategy: Identify potential sites where barriers in combination with alternative controls (i.e., trapping, manual removal, etc.) can contribute to effective control or suppression. Candidates include the Boardman and Days Rivers.

Cost: Identify alternative controls and estimate the additional cost.

Other Methods of Alternative Control

If proven effective, other methods of alternative control that could be implemented include nest destruction and manual removal of spawning-phase sea lampreys from spawning areas. Both techniques are designed to reduce recruitment. Reduction in larval abundance could extend the time between treatments or result in fewer residual larvae following treatments.

Objective 1: Reduce larval recruitment in streams via alternative control methods.

Strategy: Measure the effectiveness of nest destruction and manual removal of spawning-phase sea lampreys through the development of a technical assistance proposal to the GLFC's Sea Lamprey Research Board, and implement these methods on two tributaries with a history of regular recruitment and treatment. Candidates include Gurney Creek and the Platte River.

Cost: \$20K/stream, includes labor and travel.

Metrics and Measures of Success

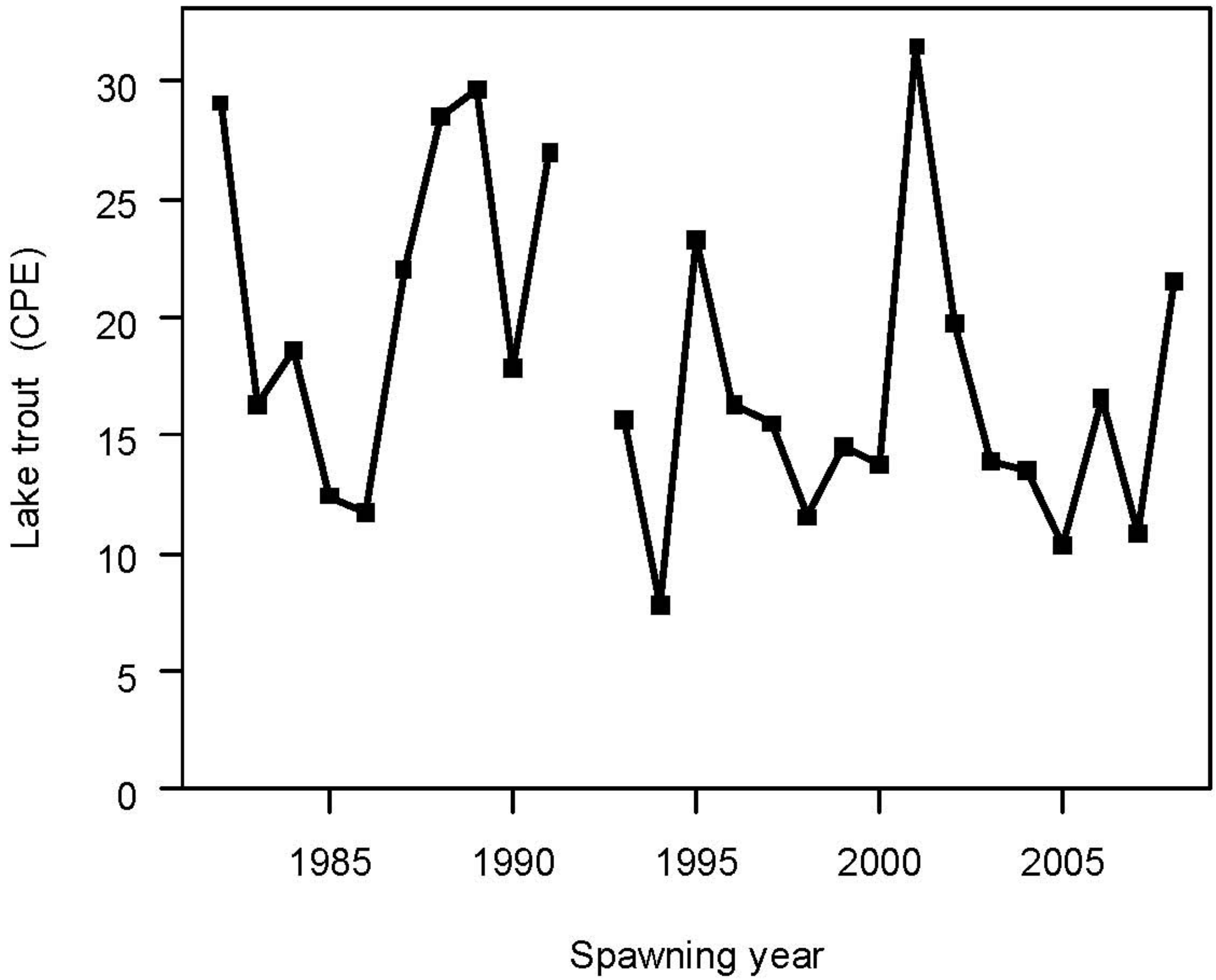
Current metrics for evaluating success of the Five-Year Plan are annual lakewide estimates of spawning-phase sea lamprey abundance and annual estimates of sea lamprey induced mortality rates based on the number of marks on lean lake trout >533 mm. Relationships between the lamprey marking rate, abundance of host species, abundance of sea lampreys causing marks, and control efforts are not as direct as might be expected. Understanding linkages between control efforts and predator-prey dynamics would enable a more complete understanding of the effects of control efforts and may enable these efforts to be targeted to lakes, regions of lakes, or fish stocks to maximize overall benefit.

Increased efforts to reduce sea lamprey induced mortality rates on lake trout to the target level agreed upon by the LMC are imperative for long-term success of lake trout rehabilitation in Lake Michigan (Lake Michigan Committee 2011). The current target and desired marking rates are components of the LMC's plan to restore lake trout in Lake Michigan (Bronte et al. 2008). With the understanding that lake trout marking rates can be influenced by changes in abundance of sea lampreys and lake trout, measures of relative abundance of lake trout are also collected and used to interpret lake trout marking data.

While the standard measures of sea lamprey control are spawning-phase sea lamprey abundance and lake trout marking rates, state and tribal management agencies are concerned about sea lamprey induced damage to the entire fish community. Fish-community marking data are collected for some statistical districts, but there is no current lakewide monitoring.

Efforts to rehabilitate lake trout in Lake Michigan have been ongoing since the 1960s and have consisted primarily of stocking yearling fish and limiting fishing and sea lamprey mortality (Holey et al. 1995; Lavis et al. 2003). Abundance of lean lake trout in Lake Michigan has been relatively stable much of 1993-2008 (Fig. 21). Reproduction from stocked fish has been documented, but substantial recruitment to the adult life stage has yet to occur and standing stocks remain low to moderate lakewide (Bronte et al. 2003b, 2007; Bronte 2008). Suspected impediments to restoration include inadequate numbers of stocked fish, suboptimal stocking practices, excessive mortality from sea lampreys and fishing, and interactions between lake trout and native and non-native species (Bronte et al. 2003b, 2008).

Fig. 21. Estimates of lake trout relative abundance (number of lake trout >532 mm per kilometer of survey gillnet set) in Lake Michigan during 1982-2008.



A guide for the rehabilitation of lake trout in Lake Michigan (Bronte et al. 2008) explicitly identifies controls on lake trout mortality as being a critical component of lake trout restoration in Lake Michigan. Estimates of sea lamprey induced mortality have not been calculated for all statistical districts, but observations from statistical catch-at-age models developed for the 1836 Treaty waters of Lake Michigan suggest that they are generally greater in the northern portion of the lake and have exceeded the 5% target in all statistical districts where they have been estimated (Figs. 22, 23).

Fig. 22. Estimated annual sea lamprey induced mortality on lake trout (average for ages 6-11) in statistical districts in the 1836 Treaty waters of Lake Michigan (Modeling Subcommittee of the Technical Fisheries Committee of the 2000 Consent Decree).

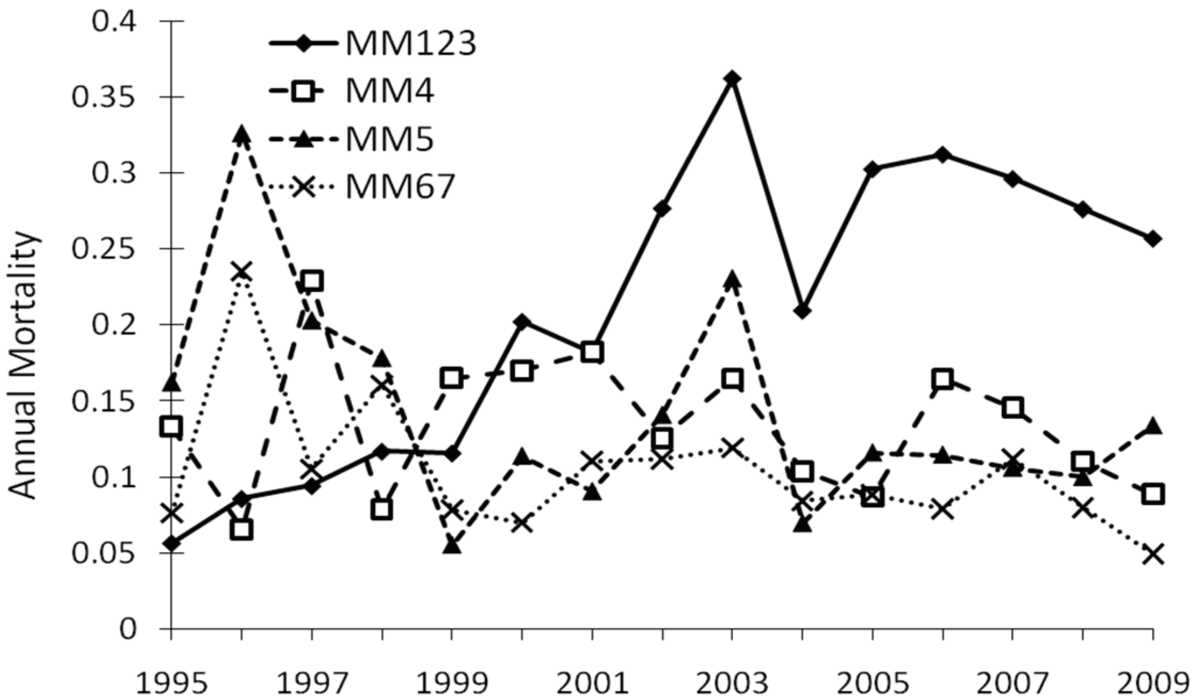
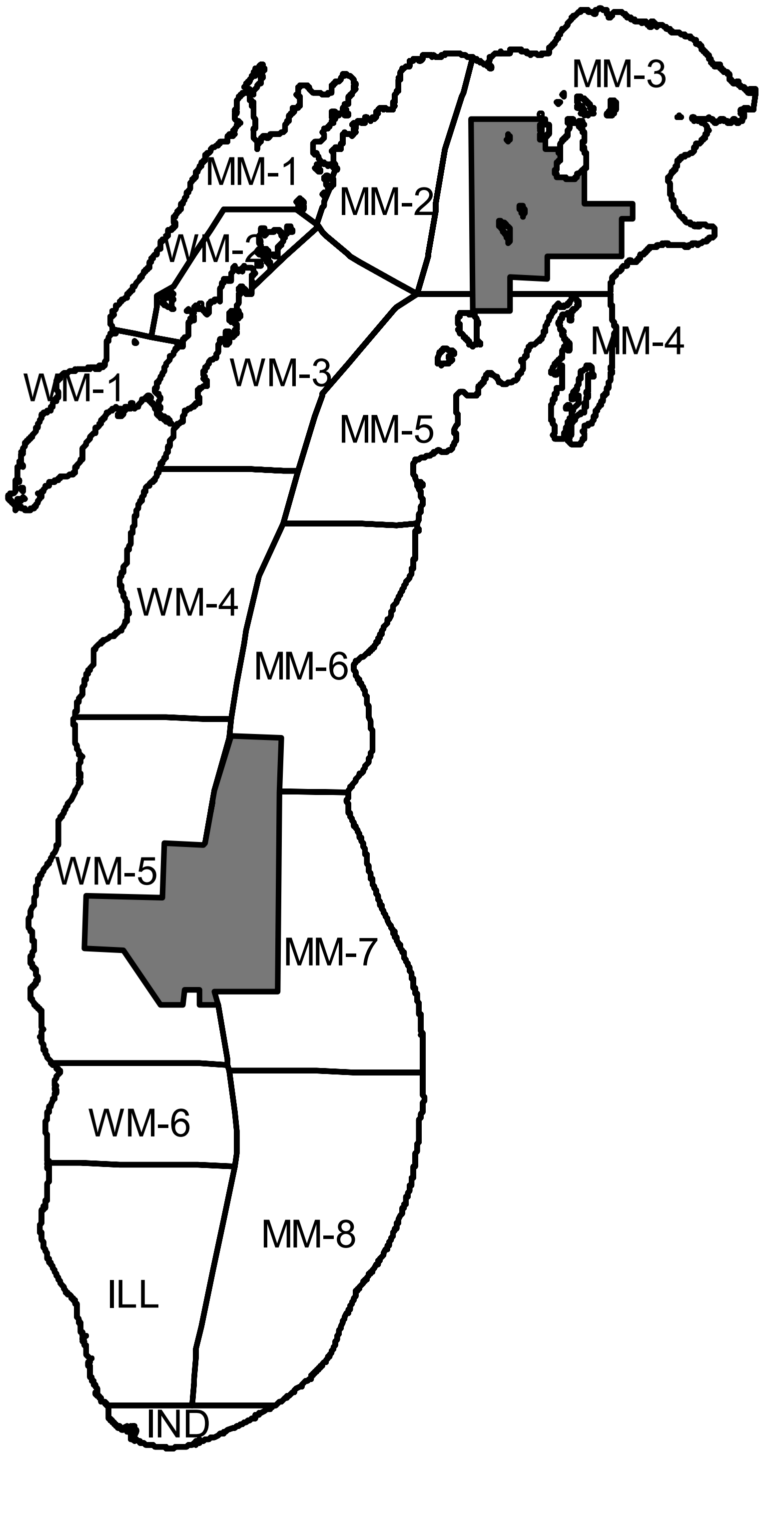


Fig. 23. Statistical districts for Lake Michigan.



Objective 1: By 2014, develop species or fish-community-based marking targets based on sea lamprey induced mortality rates for primary species vulnerable to sea lamprey attack in the Lake Michigan fish community, including lake trout, burbot, lake whitefish (*Coregonus clupeaformis*), and Chinook salmon.

Strategy: By 2015, define the relation between sea lamprey marking rates and host mortality for each primary host species, define acceptable levels of sea lamprey mortality for each primary host species, and develop predator-prey models that link the effects of sea lamprey control to as many species as practical.

Cost: $100K.

Strategy: Maintain the standardization of sea lamprey mark identification through periodic workshops at intervals of no more than five years.

Cost: ~$4K.

Strategy: Use five-year moving average and slope of five-year trend for these metrics for reporting progress towards achieving targets for marking and spawning-phase sea lamprey abundance.

Cost: Included in the current base program.

Objective 2: By 2015, reevaluate the targets for abundance of spawning-phase sea lampreys to determine if fishery managers agree that they are consistent with fish-community objectives. If necessary, develop new targets.

Strategy: By 2015, develop regional targets for sea lamprey abundance based on marking in the entire fish community and the revised objectives proposed in this plan.

Cost: Need to determine these costs.

Strategy: Consider implementation of a transformer mark-recapture study to measure annual recruitment to the lake of newly metamorphosed sea lampreys and better estimate abundance of spawning sea lampreys by 2013.

Cost: Proposal is currently being reviewed.

Strategy: Reevaluate the methods used to determine abundance of spawning-phase sea lampreys with special emphasis on geographic coverage of traps and determine the influence of climate and stream environment, such as temperature and precipitation (flow) on annual variation in spawning-phase sea lamprey catchability in traps.

Cost: To be determined.

Recommended Strategies to Achieve Targets

The Five-Year Plan implements a base program of lampricide control, assessment, and alternative controls designed to support the fish-community objectives for Lake Michigan at an annual cost of about $6,434,377 (based on the fiscal year 2011 budget). Despite these efforts, abundance of spawning-phase sea lampreys, as measured by the current five-year average abundance of spawning-phase sea lampreys (109,741), is nearly double the target level (57,000). Achieving target levels of sea lamprey abundance in Lake Michigan will clearly require the implementation of additional control actions.

Historical lampricide treatment and larval assessment data suggest that the most likely source of parasitic-phase sea lampreys is larvae that survive lampricide applications (residuals) from streams that contain the greatest numbers of larvae. Analyses designed to forecast the effects of various treatment scenarios suggest that lakewide spawning-phase sea lamprey abundance can most reliably be affected through whole-lake selection of streams to treat for residuals. Lakewide spawning-phase abundance was used to measure program success as this is currently the best measure available. In addition, the construction, maintenance, and repair of both purpose-built and *de facto* barriers are direct actions that aim to minimize spawning-phase sea lamprey abundance. Recommended strategies to achieve spawning-phase sea lamprey abundance and fish-community marking targets within the next five years are listed below.

Lampricide Control

Annual effort:	Lake Michigan accounts for 33% of the lampricide control effort expended throughout the Great Lakes basin based on an average of the control expenditures from 2005-2009. Consequently, $3,848,882 will be spent on lampricide control in Lake Michigan in 2011, and this control represents the level required to maintain the long-term average abundance of spawning-phase sea lampreys.
Strategy:	Within the next five years, allocate approximately 1,500 additional staff days of effort to treat the largest sea lamprey producing streams back-to-back. Treatments would be conducted in two consecutive years in the Ford, Muskegon, Pere Marquette, Big Manistee, White, Platte, Manistique, Whitefish, Betsie, and Little Manistee Rivers. This strategy is expected to reduce the residual population by 89% over a two-year period resulting in a commensurate reduction of spawning-phase sea lampreys and marking on lake trout to target levels beginning two years after treatments are completed. This strategy is based on the assumption that the largest source of parasitic-phase sea lampreys in Lake Michigan is larval sea lampreys that survive lampricide applications. In addition, it is also assumed that all sources of sea lamprey production have been accounted for, that production has been quantified correctly in relation to other streams, that lampreys randomly disperse throughout the lake, and that a reduction in the residual larval populations will have a commensurate effect on spawning-phase sea lamprey abundance and lake trout marking.

Additional cost:	~$2,300,000 in year one and $1,600,000 in year two (based on implementation in 2012).

Larval Assessment

Annual effort:	Current assessment supports the among-stream prioritization and within-stream targeting of lampricide control activities, including evaluating treatment effectiveness, assessing the success of barriers, and detecting new infestations of sea lampreys. The average cost of larval assessment to direct the current level of lampricide control in Lake Michigan is $999,535 for 2011.
Strategy:	Ensure upstream and downstream limits of sea lamprey infestation are accurately determined for the Ford, Muskegon, Pere Marquette, Big Manistee, White, Platte, Manistique, Whitefish, Betsie, and Little Manistee Rivers.
Additional cost:	~$80,000 in years one and two to conduct distribution surveys on the additional six streams per year scheduled for treatment.
Strategy:	Increase the frequency of surveys to detect new populations of sea lamprey larvae from once every ten years to once every five years in streams with suitable spawning and nursery habitats.
Additional cost:	~$32,000 each year. Increased assessment is designed to ensure sources of sea lampreys are known.

Alternative Control

Annual effort:	In addition to construction of new barriers, maintenance of the current barrier network (both purpose-built sea lamprey barriers and pre-existing multi-purpose barriers) limits sea lamprey recruitment and spawning-phase sea lamprey abundance. The cost of barrier inspection and maintenance is forecast to be $1,159,997 for barriers in Lake Michigan in 2011.
Strategy:	Construct a barrier in the Manistique River within the next five years to eliminate access to the upper river. This strategy will reduce larval sea lamprey production in the Manistique River by about 90% and reduce future lampricide treatment costs.
Additional cost:	~$2,500,000 for construction.

Strategy:	Evaluate and repair barriers on the Days, Boardman, and Little Manistee Rivers. Spawning-phase sea lampreys have breached these barriers in recent years. Repairing these barriers will block sea lampreys and reduce lampricide treatment costs.
Additional cost:	~$150,000 for construction on the Days River barrier. The cost for the Little Manistee repair is dependent on the determination of route of escapement. Repairs to the Boardman River are estimated at $300,000.

Metrics of Success

Annual effort:	Stream-specific mark-recapture estimates of spawning-phase sea lamprey abundance are the foundation for a model that uses stream discharge, treatment history, and production potential to calculate regional and whole-lake population estimates. The average cost of spawning-phase assessment in Lake Michigan is $425,963 for 2011. Along with marking rates on lake trout (determined by state and tribal fisheries managers), these estimates are used to evaluate performance of the Five-Year Plan. Evaluation of model performance is an ongoing task, and benefits lake-specific estimates across the Great Lakes basin. Alternative methods of estimating sea lamprey induced mortality within the fish community are currently being investigated by the Quantitative Fisheries Center (QFC) at Michigan State University.
Strategy:	Evaluate and refine parameters in the model used to estimate spawning-phase sea lamprey abundance and implement recommended improvements to increase the precision of estimates.
Additional cost:	Dependent on the results of ongoing evaluations.

Strategy:	Continue to work with the QFC and the LMTC to investigate alternative methods of estimating sea lamprey induced mortality based on marking in the entire fish community. This strategy is critical to the development of improved metrics to measure program success and the effects of sea lampreys on the Lake Michigan fish community.
Additional cost:	~$100,000 over a two-year period for research.

Strategy:	Maintain standardization of sea lamprey mark identification through periodic workshops at intervals of no more than five years.
Additional cost:	~$4,000 every five years to sponsor workshops.

Maintaining Targets and the Judicious Use of Lampricides

Advancing alternative control technologies and techniques is critical to achieving targets and applying lampricides in a judicious manner. New strategies, such as using pheromones to improve trap efficiency, are currently being evaluated, while others, such as incorporating traps into planned barriers, are closely associated with current strategies (i.e., barrier construction). Additional strategies, such as increasing trapping effectiveness, reducing recruitment by manual removal of spawning-phase sea lampreys, and developing improved methods to evaluate program success await research designed to evaluate their potential. New alternative controls will help reduce or maintain sea lampreys at target levels throughout the Great Lakes and are not necessarily specific to Lake Michigan. However, the costs for implementing these strategies are not well defined. Estimated costs to advance these technologies and techniques are included in Chapter 7 (Summary) and will require research related to these four general areas: application of pheromones, trapping techniques, methods to reduce recruitment, and sea lamprey/host interactions.

Communication

See Appendix A for information about who to contact about the sea lamprey control program in Lake Michigan.

CHAPTER 4: FIVE-YEAR PLAN FOR LAKE HURON

Lisa Walter[5] and Andrew Treble[6]

Introduction and History

The purpose of this chapter is to build on the general, basinwide discussion of sea lamprey (*Petromyzon marinus*) control outlined in Chapter 1 (Sea Lamprey Control in the Great Lakes Basin). The St. Marys River is the largest single source of parasitic sea lampreys in the Great Lakes, so most sections in this chapter begin with a discussion devoted specifically to sea lamprey control there.

The most recent synthesis of sea lamprey control in Lake Huron (Morse et al. 2003) was published in the Journal of Great Lakes Research in 2007 as a contribution to the Sea Lamprey International Symposium II. This paper is cited often in this plan and is a good document to review for those interested in additional information on sea lamprey control in Lake Huron. The Great Lakes Fishery Commission (GLFC), in collaboration with fisheries managers, has developed this lake-specific Five-Year Plan as an integrated sea lamprey control strategy that focuses on lakewide and locality-specific control tactics to maintain sea lamprey populations at or below target levels.

Sea lamprey control began in Lake Huron in 1945 with the installation of a mechanical weir on the Ocqueoc River (Lavis et al. 2003) and expanded further in 1954 through the use of traps and electrical barriers (Smith et al. 1974). The barrier program eventually included 27 streams in Lake Huron (Morse et al. 2003), but electrical barriers were costly, difficult to maintain under high water conditions, prone to failure, non-selective for sea lampreys, and sometimes unsafe. Based on the success of lampricide control in suppressing sea lamprey abundance, the use of electrical barriers was discontinued on Lake Huron by 1979.

The use of lampricides as a control tool began in 1960. During 1960-1962, 24 streams tributary to Georgian Bay and the North Channel of Lake Huron were successfully treated (Smith and Tibbles 1980). Chemical control was then terminated on Lake Huron to escalate control efforts on Lake Michigan, and sea lampreys rapidly re-established in all treated rivers. Marking on lake

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whitefish (*Coregonus clupeaformis)* and rainbow trout (*Oncorhynchus mykiss*) increased, so sea lamprey control was reinstated on Lake Huron in 1966 (Smith and Tibbles 1980). During 1966-1978, 274 lampricide treatments were conducted on Lake Huron tributaries. The initial effects of these treatments were obvious when fewer sea lampreys were captured during spawning runs and marking rates declined on host species (Smith and Tibbles 1980). However, this success was short-lived due to increased parasitic lamprey production from the St. Marys River in the 1970s (Eshenroder et al. 1995a).

The St. Marys River, the waterway that connects Lake Superior to Lake Huron, is Lake Huron's largest tributary (Schleen et al. 2003). The first sea lamprey was discovered in the St. Marys River in 1962 during dredging operations. However, the species was likely present earlier because sea lampreys had been abundant in Lake Superior since the mid-1940s (Young et al. 1996). Survival would have been difficult as portions of the river were degraded by human activity. Industrial and municipal contaminants limit the distribution, composition, and abundance of the benthic community in the river (Jacques Whitford Environmental Ltd. 2002) and probably likewise affected larval sea lampreys. Another factor that suppressed sea lamprey production until the 1970s was the deterioration of spawning and larval habitat caused by navigational and hydroelectric projects at various points on the river (Young et al. 1996). While parasitic-phase sea lamprey populations responded dramatically and almost immediately to the initiation of lampricide controls in Lake Superior, Lake Huron populations continued to increase even after lakewide chemical control was initiated due to water-quality improvements in the St. Marys River initiated by the Clean Water Act and Canadian Fisheries Act (Ripley et al. 2011). Sea lamprey production in the St. Marys River combined with an increased abundance of bloaters (*Coregonus hoyi*), leading to improved juvenile lamprey survival, was implicated as the major source of parasitic sea lampreys in Lake Huron (Eshenroder et al. 1995a). Eshenroder et al. (1987) estimated that 6.8 million larvae and 50,000 transformers were produced in the river during 1986. By 1995, sea lamprey predation, largely attributable to uncontrolled production from the St. Marys River, became so high that management agencies suspended lake trout (*Salvelinus namaycush*) rehabilitation efforts in the northern waters of Lake Huron until sea lamprey control was successful on the St. Marys River (Schleen et al. 2003). In 1997, the GLFC developed a five-year (1998-2002) control strategy to reduce sea lamprey production in the St. Marys River. The strategy focused on reducing reproductive success of sea lampreys and killing existing larvae (Adams et al. 2003). Sea lamprey reproductive success in the St. Marys River was reduced by trapping spawning-phase sea lampreys as they ascended the river to spawn and releasing sterilized males back into the remaining population. Larval abundance was reduced in 1998, 1999, and 2001 through applications of granular Bayluscide (gB) to selected areas of the river where densities of larvae were particularly high. The 1998 lampricide treatment was a pilot study targeting 82 ha to work out the logistics of gB application. A much larger area (759 ha) was treated in 1999 with help from the State of Michigan, which contributed $3 million. An additional 42 ha was treated in 2001. These lampricide treatments killed an estimated 55% of the sea lamprey population in the river (Fodale et al. 2003; Schleen et al. 2003).

The combination of all sea lamprey control activities resulted in a dramatic decline in sea lamprey abundance from the historical maximum by limiting recruitment of parasitic sea lampreys to the lake population. An increasing trend of sea lamprey abundance was noted during

2005-2008, but abundance dropped dramatically in 2009 (Fig. 24). While sea lamprey abundance in Lake Huron has never been within target values (most likely due to difficulties controlling populations in the St. Marys River), the 1999 large-scale gB treatment of the St. Marys River correlates with a noticeable reduction in sea lamprey spawner abundance and lake trout marking rates (Figs. 24, 25). Sea lamprey induced instantaneous mortality on lake trout dropped almost 40% in some areas of the lake between 1958 and 1988-1998. Lake trout marking continues to exceed the target rate of 5 Type A, Stages I-III marks per 100 lake trout of total length >533 mm but remains much lower than the rate observed prior to the large-scale St. Marys River treatment and subsequent integrated control strategy (Fig. 25).

Fig. 24. Annual lakewide estimates of sea lamprey abundance with 95% confidence intervals (CI) in Lake Huron during 1977-2010. The solid horizontal line represents the abundance target of 73,000 spawning-phase sea lampreys. The dashed horizontal lines are the 95% CI for the target.

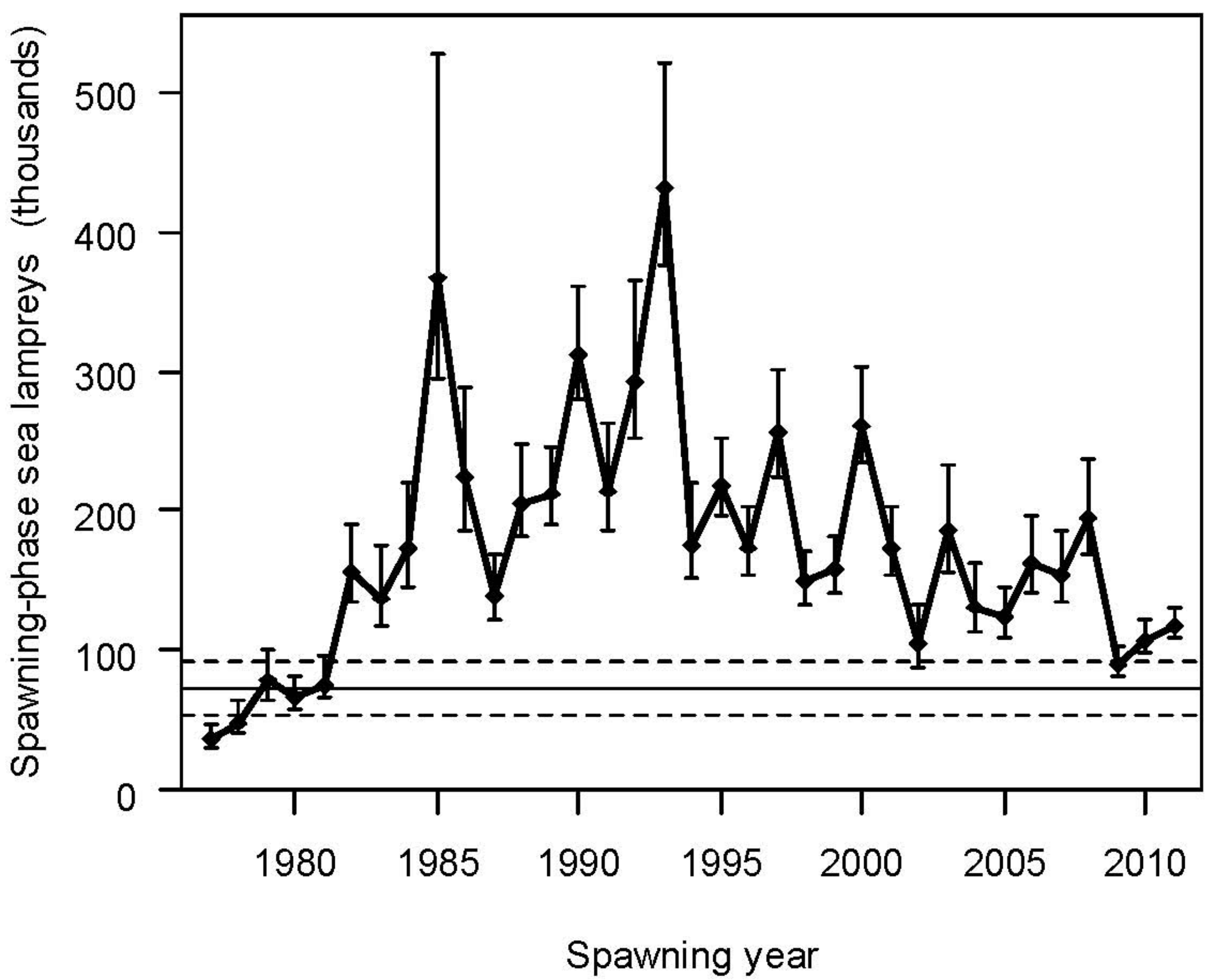
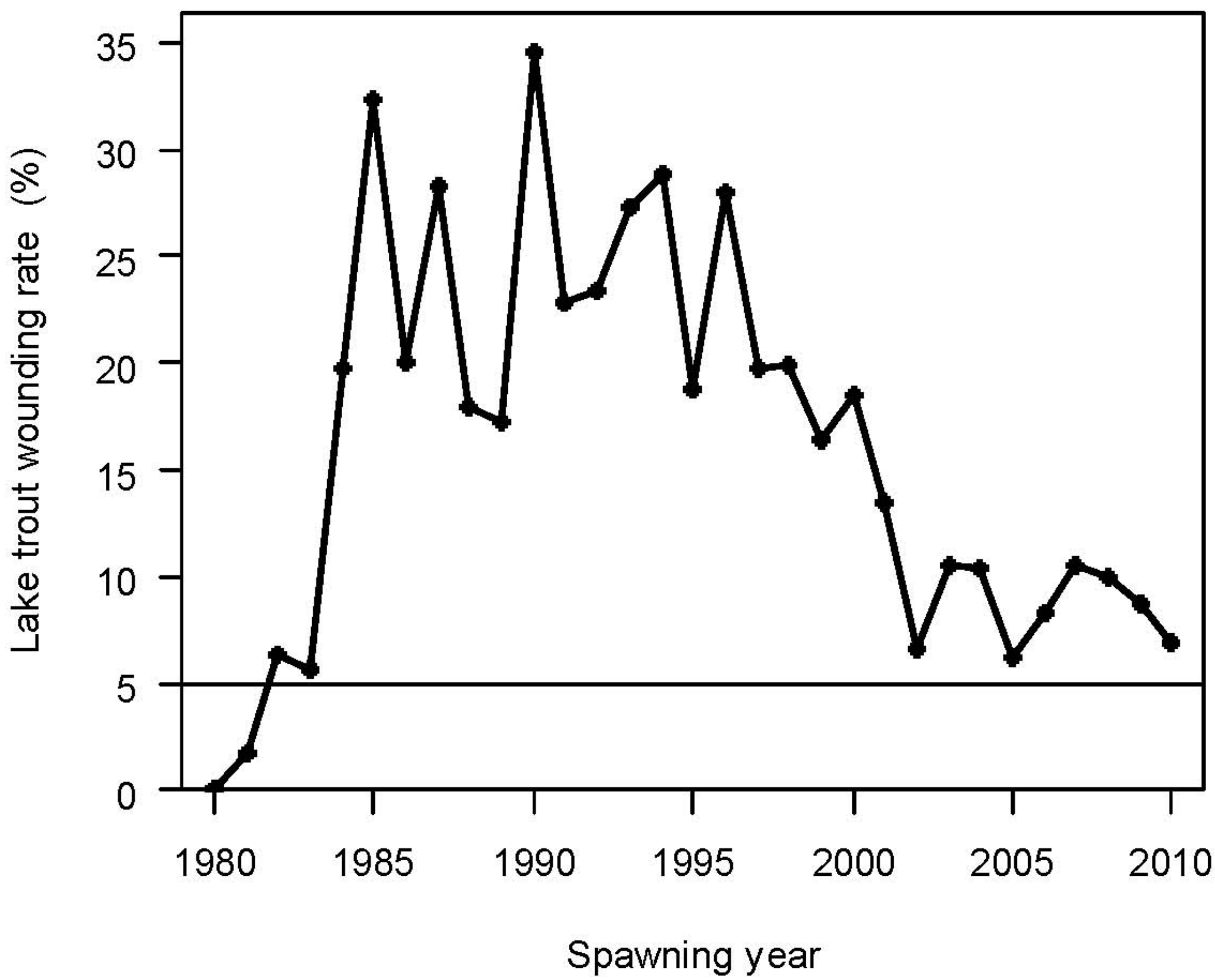


Fig. 25. Annual lakewide estimates of sea lamprey marking rates on lake trout ≥533 mm in Lake Huron during 1984-2009.



Features of the Lake

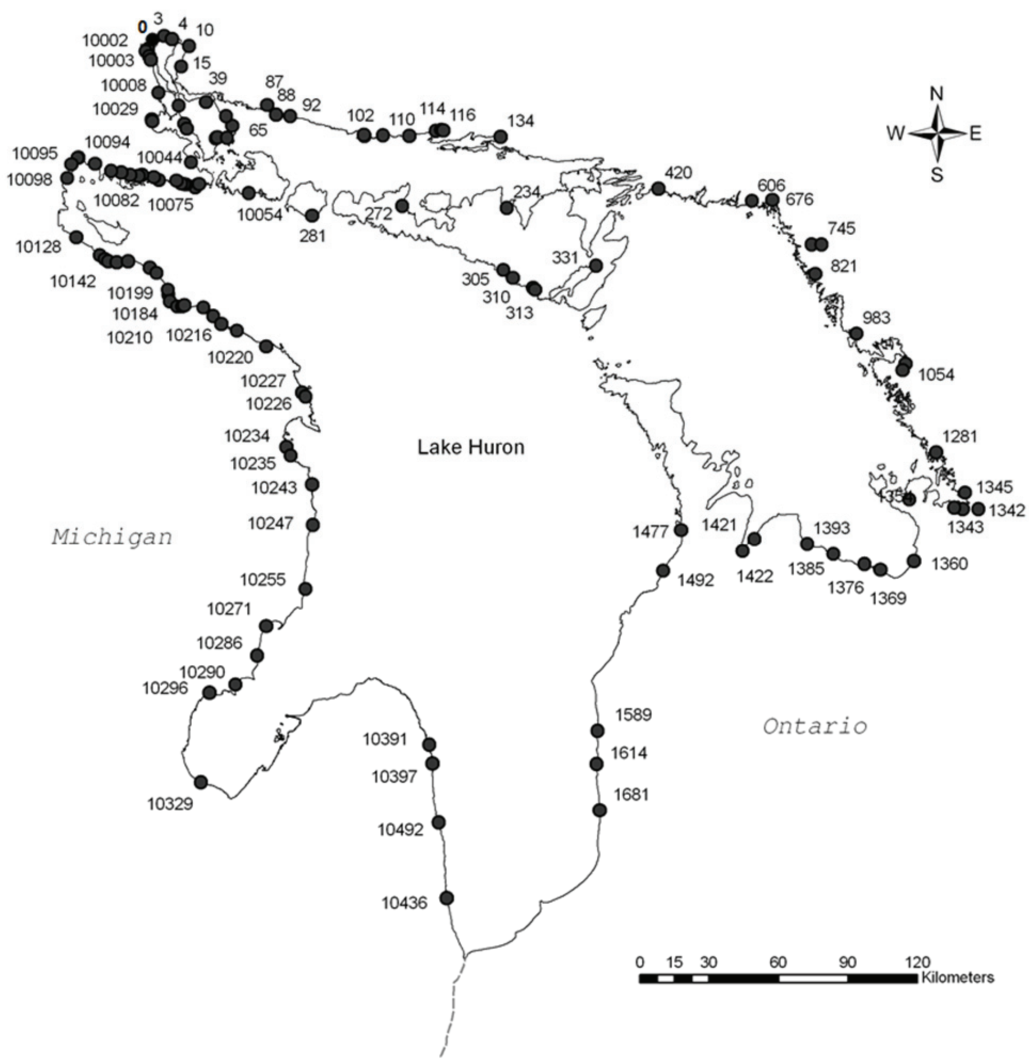
Lake Huron is the world's second largest freshwater lake by area (59,596 km^2) and third largest by volume (3,540 km^3) (Ebener 1995). The Bruce Peninsula and Manitoulin Island divide Lake Huron into three distinct basins: Georgian Bay, the North Channel, and the main basin. The main body of Lake Huron has an average depth of 59 m and a maximum depth of 229 m but also includes the shallow embayment of Saginaw Bay.

Lake Huron receives the bulk of its water from Lake Superior through the St. Marys River (~2,100 m^3/s), but Lake Michigan also contributes water (~15.56 m^3/s) through the Straits of Mackinaw (Berst and Spangler 1973). The rest of Lake Huron's inflow comes from 1,761 tributaries (427 United States, 1,334 Canada) that line the 6,157-km shoreline (Morse et al. 2003). Lake Huron is classified as oligotrophic (Rawson 1952; Ryder 1965) and capable of producing an average of 1.6 kg/ha of fish (Berst and Spangler 1973).

The St. Marys River is the largest single source of sea lamprey production in the Great Lakes. Although 90% of the available spawning habitat is located at the St. Marys rapids (Young et al. 1996), over 885 ha of suitable larval habitat are scattered throughout the 112 km of river between the compensating gates in Sault Ste. Marie to the outflow into Lake Huron (Shen et al. 2003). The St. Marys River has an average annual discharge of 2,100 m^3/s, 20 times more than the discharge of the next largest stream currently treated with lampricide (Nipigon River, 108 m^3/s). Budgetary and technological constraints prevent conventional 3-trifluoromethyl-4-nitrophenol (TFM) treatment of the St. Marys River (Eshenroder et al. 1987).

The distribution of sea lamprey producing tributaries is not uniform around Lake Huron (Fig. 26). The bulk of streams harboring sea lamprey larvae are found in the northern half of the lake around the Straits of Mackinaw and the North Channel, but a few large, dendritic rivers that are highly productive feed Saginaw Bay (Fig. 26). Marking rates on commercial and recreational fish species suggest that the North Channel has an abundant parasitic sea lamprey population, likely due to production from the St. Marys River (Fig. 26). Georgian Bay also has the potential to contribute parasitic sea lampreys to the lake with 22 nursery streams located on the eastern shore and southern part of the bay. In general, very few sea lamprey producing streams exist in the southern half of the lake. On the southeastern side, the Saugeen River was once an important producer that supported a commercial sea lamprey fishery in the 1950s, but reconstruction of Denny's Dam in 1970 has all but eliminated sea lamprey production from this river. Infested streams on the southwestern shore are few in number but possess large, dendritic watersheds that have the potential to produce large larval sea lamprey populations. Five of the six infested rivers in this area can produce between 240,000 and 1 million larvae if not treated consistently.

Fig. 26. Location and stream number of Lake Huron tributaries with records of larval sea lamprey infestation. Stream numbers correspond to those in Appendix B.



Unique Issues

Lake Huron has 1,762 tributaries, of which 117 have records of larval sea lamprey production (Fig. 26). Stream-specific estimates of larval sea lamprey abundance vary widely among streams (Fig. 27) and generally correspond to stream-specific estimates of spawning-phase sea lamprey abundance (Fig. 28). For example, the St. Marys River has the largest estimates of both spawning-phase abundance and larval sea lamprey production in Lake Huron.

Fig. 27. Maximum estimated larval-phase sea lamprey abundance in Lake Huron tributaries during 1996-2010. Streams with the highest estimates, combining for more than half the Lake Huron total, are identified by name. For reference, the maximum estimate of larval-phase sea lamprey abundance for the Garden River is 3.6 million. Estimates for all streams are listed in Appendix B.

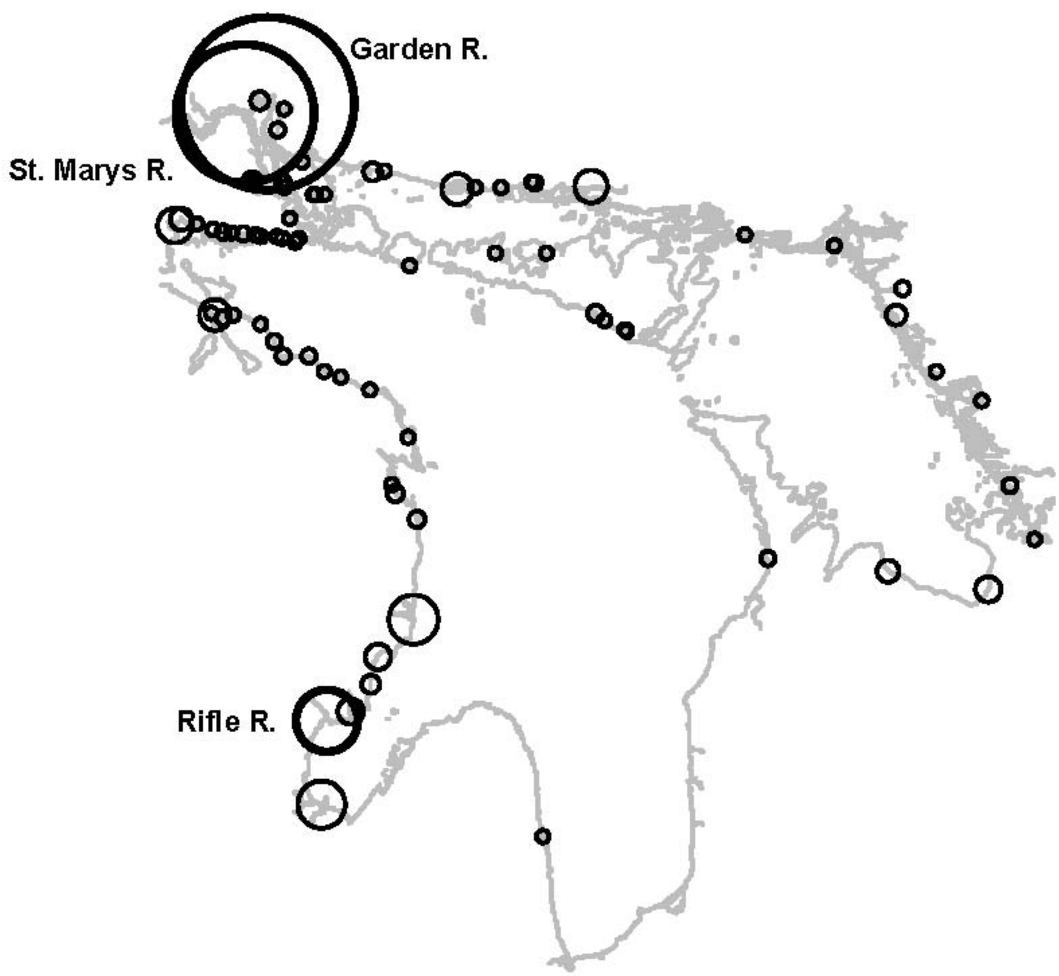
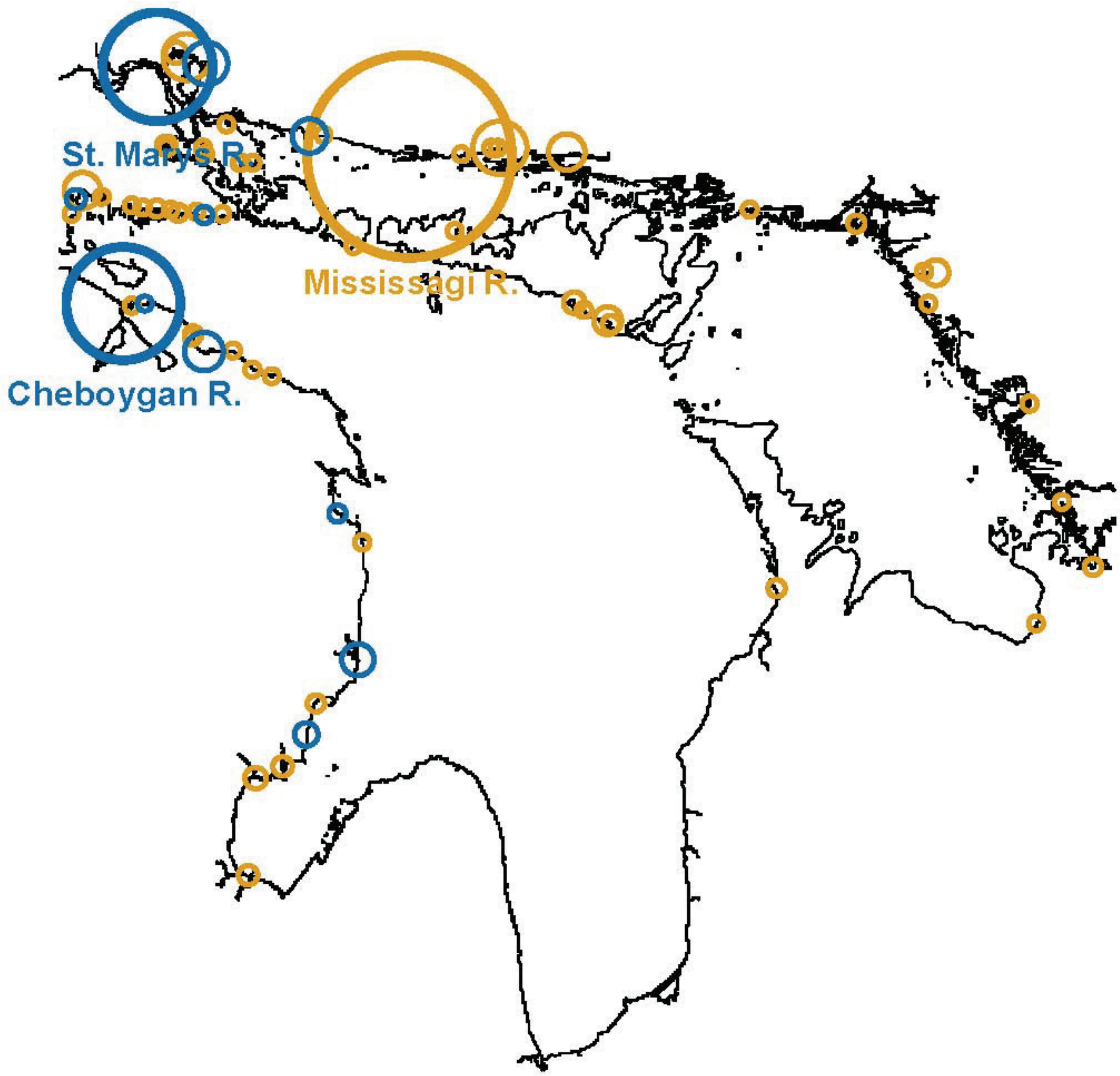


Fig. 28. Five-year average spawning-phase sea lamprey abundance estimates for Lake Huron tributaries during 2006–2010. Streams with the highest five-year average, combining for more than half the Lake Huron total, are identified by name. Colors indicate whether the source of most (at least three of the five) of the annual estimates were from mark-recapture (blue) or not (orange). For reference, the five-year average of spawning-phase sea lamprey abundance for the Mississagi River is 38K. Estimates for all streams are listed in Appendix B.



Specific streams that produce large numbers of sea lampreys and provide unique treatment challenges are listed in Table 11 and briefly discussed below.

Table 11. Summary of challenges to effective sea lamprey control in Lake Huron. Sensitive species and variable discharge limits the period available for treatment.

Stream	Treatment window	Dendritic	Secondaries*	Lentic	Access	Beaver	pH
Root River			X		X	X	
Garden River			X		X	X	
Mississagi River	Hydro						
Spanish River	Hydro						
French River	Hydro						
Magnetewan River				X	X		
Naiscoot-Harris River			X		X	X	
Bighead River		X					
Saginaw River	Flow	X	X				X
Rifle River	Salmonids	X	X			X	
Au Sable River	Hydro, salmonids		X				
Cheboygan (Pigeon) River	Hydro						
Au Gres River	Flow, salmonids				X		
Pine River	Flow	X				X	
Carp River		X		X	X	X	

*Secondary lampricide treatments focus chemical application in areas of potential refuge such as backwaters, oxbows, or beaver dams. Treatment of these areas is labor intensive but improves treatment effectiveness.

- St. Marys River: This river produces more sea lamprey larvae than any other infested tributary in the Great Lakes basin, yet conventional treatments with TFM are not possible due to the river's large volume and flow characteristics (Schleen et al. 2003; Shen et al. 2003). Sea lamprey control in this river consists of an integrated pest-management strategy that targets multiple life stages. The control strategy reduces reproduction by trapping spawning-phase sea lampreys, releasing sterilized males during spawning, and spot-treating areas of high larval density using gB. On average, 92.4 ha of the St. Marys River are treated annually with gB (2001-2009). Estimates of larval production are obtained annually after gB treatments via deepwater electrofishing surveys using a stratified systematic sampling technique. The 2009 St. Marys River larval sea lamprey abundance estimate of 3.3 million larvae was not significantly lower than the 1999 pre-treatment estimate. In response to increasing abundance estimates, the GLFC implemented a large-scale gB treatment during 2010 when 875 ha of the St. Marys River were treated using new, purpose-built gB application boats that reduced application effort by 46%. Similar treatment effort is planned for 2011 as part of the North Channel large-scale treatment initiative.
- The Spanish River is a major tributary to the North Channel that is difficult to assess due to large areas of uniform habitat. The stream has the potential to harbor a large larval population but is rarely cost effective to treat. Although the entire stream rarely ranks for treatment, several of its tributaries do. The Spanish River can be prone to treatment deferral during periods of significant rainfall or drought, because flow is dependent on delivery of controlled flow from Vale Inco's hydroelectric generating station.
- The Mississagi River is a large tributary to the North Channel that is difficult to assess due to large amounts of uniform larval habitat. Like the Spanish River, the Mississagi River has the potential to harbor large populations of larval sea lampreys, and, while it tends to rank for treatment more consistently, it is also prone to deferral because treatment is dependent on delivery of controlled flows from the Red Rock Falls Generating Station (owned and operated by Ontario Power Generation).
- Embayments on St. Joseph and Manitoulin Islands, off the mouth of Lauzon Creek, as well as lentic sections of the French, Musquash, and Magnetawan Rivers harbor low densities of ammocoetes that contribute parasitic-phase sea lampreys to the lake. These populations need to be monitored on a regular basis to ensure that they do not expand.
- The Bighead River is a large dendritic system with more than seven tributaries that regularly recruit larval sea lamprey populations. Aside from difficulties of coordinating treatments on numerous tributaries, several landowners possess wells adjacent to the stream that are used as a source of potable water. Extra effort needs to be devoted to monitoring these wells, both during and after lampricide treatment, to ensure that no lampricide infiltrates these wells. If lampricide does contaminate the wells, then drinking water and continual monitoring has to be provided until the lampricide has dispersed.
- The Saugeen River is a large, dendritic system where most larval sea lamprey habitat is blocked by Denny's Dam. Engineering surveys and structural investigations completed in 2006 indicated that the dam is only marginally stable, is at risk of sliding, and the concrete has deteriorated in places. Reconstruction was originally planned to begin in 2009, but the barrier currently ranks third in the Ontario Ministry of Natural Resources (OMNR) dam rehabilitation project list. The GLFC has committed $800,000 to the project, but lack of

provisional funding is expected to delay reconstruction until 2013. Failure of this dam could subject an additional 105 km of river to sea lamprey infestation and thereby increase the cost of treatment.

- The Saginaw River is a large, dendritic system, and, although the main stream is not infested, at least four major tributaries are infested (Chippewa, Big Salt, Cass, and Shiawassee Rivers). Saginaw River tributaries include over 413 km of stream. Several dams in the watershed limit sea lamprey colonization, including those on the Chippewa, Cass, Tittabawasse, and Shiawassee Rivers. In 2009, the Chessaning Dam on the Shiawassee River washed out as a result of excessively high water. Spawning-phase sea lampreys occasionally breached the dam prior to the wash-out, but increased production is now expected with unimpeded access to upstream habitat. The Saginaw River watershed drains a large, predominantly agricultural area, and large diel fluctuations in pH are common.
- The Rifle River is a large, dendritic tributary estimated to produce over 1 million sea lamprey larvae. Typical lampricide applications occur every three years and cover more than 96 km of main stream and over 80 km of tributaries. Treatment of the Rifle River can be complicated by the stream's dendritic nature, Pacific salmon (*Oncorhynchus* sp.) runs, presence of resident trout, abundant larval refuge areas, and beaver dams.
- The Au Sable River requires dam operators to provide controlled discharge at the Foote Dam (main stream) and a dam on Van Etten Creek. Several oxbows and backwaters create areas of refuge that often harbor residuals.
- The Pigeon River, a tributary of the Cheboygan River, is upstream of a dam, but migration of spawning-phase sea lampreys exists because of an open lock system. The tributary hosts runs of Pacific salmon and resident brown trout (*Salmo trutta*) and brook trout (*Salvelinus fontinalis*), and flows from an automatically controlled dam at the Song of the Morning Ranch fluctuate dramatically. The Cheboygan River main stream below the dam is typically treated through routine application of gB because of high discharge and limited larval habitat. Lake sturgeon (*Acipenser fulvescens*) presence narrows the application window for gB (after July 1), consistent with an agreement between the Michigan Department of Natural Resources and U.S. Fish and Wildlife Service (USFWS).
- The Carp River is a large, dendritic system with limited access on the upper end. A large lentic population spread over more than 9 ha in St. Martin's Bay is treated regularly with gB, but control here remains difficult.

Sources of Parasitic-Phase Sea Lampreys

Potential sources of parasitic-phase sea lamprey production include larvae that escape a lethal dose of lampricide during treatment (residuals), untreated populations (e.g., low-density populations, deferred treatments), undetected populations, and those that migrate from other lakes.

Residuals are likely the most significant source of parasitic sea lampreys in Lake Huron (Morse et al. 2003). In streams with large larval sea lamprey populations, even a small percentage of residuals can contribute to a high abundance of transformers before the next treatment occurs. This is especially true for lentic areas treated with gB, because treatment effectiveness is lower (estimated 75% kill compared to ~95% for an in-stream TFM treatment (Jeff Slade, USFWS, unpublished data)). Strategies to address both deferred treatments and residuals in large streams are addressed later in this plan.

Streams with undetected larval populations are also a potential source of sea lamprey production. All known streams and lentic areas with the potential to produce sea lampreys are monitored every three to five years. However, former sea lamprey producing streams or lentic areas where populations have not re-established and areas with suitable spawning and nursery habitat that have never produced sea lampreys may not be checked as frequently. Those streams where recruitment goes undetected between assessments could contribute parasitic sea lampreys to the lake. Since 2000, new infestations have been identified in five small tributaries, including the Whitefish Channel (St. Marys River), Marcellus Creek and two unnamed tributaries in Ontario, as well as Nagels Creek in Michigan. The Whitefish Channel, Marcellus Creek, and both of the unnamed tributaries (H-114, H-267) have been treated since 2008, while the low-density population in Nagels Creek continues to be monitored.

Infested lentic areas can contribute significantly to parasitic-phase recruitment to Lake Huron. Lentic areas of Lake Huron were regularly treated with gB during the 1970s and 1980s, but applications were sporadic during the 1990s as a result of a programwide reduction in lampricide use and treatment staff (Brege et al. 2003). Control effort has increased since the mid-2000s due to a renewed focus on lampricide use and a commensurate increase in treatment staff. A recognition that lentic populations can contribute significantly to parasitic-phase recruitment has resulted in renewed emphasis on gB treatments as a component of integrated control. With assessments conducted in support of these efforts came the discovery of previously unknown lentic populations off the mouths of Lauzon, Caribou, Beavertail, and Martineau Creeks, as well as outflows of the Trent-Severn Waterway in Georgian Bay and the Hammond Bay Biological Station. Using gB to regularly assess these small populations keeps their larval abundance low. In addition, new technologies have allowed for more effective applications in areas with the greatest potential for parasitic-phase production. RoxAnn© sonar is used to map substrate in lentic areas suspected of harboring larval lamprey populations, and state-of-the-art navigational and product delivery systems are being used to more accurately and efficiently conduct gB treatments in large lentic areas.

On the St. Marys River, areas capable of harboring larval populations have been delineated based on historical distributions. Each area is evaluated annually using specialized deepwater electrofishing gear. On average, annual gB spot treatments target 140 ha, or 46% of the larvae in the river. Treatments conducted using gB are generally 75% effective, and survival can be greater in treated plots if treatment occurs during periods when abundant macrophyte cover inhibits granules from sinking to the bottom. Areas with suitable larval habitat downstream of the region traditionally treated in the St. Marys River also have the potential to support low densities of larvae and need to be continuously monitored to ensure that these populations do not expand.

Special Concerns

Protected Species

The status of species federally or provincially designated as "Species at Risk" does not currently affect sea lamprey control in Canada, but the sea lamprey control program is adjusted to protect federal- and state-listed species in some Lake Huron streams on the United States side. Most listed species whose distribution in the Great Lakes overlaps with sea lampreys are either unaffected by Sea Lamprey Control Program actions or protected through spatial or temporal avoidance. A few species, however, have the potential to be affected, and adverse effects must be minimized (Table 12).

Table 12. Protected species that may require alteration of field schedules to avoid certain areas and time periods in Lake Huron. Formal federal, state, and provincial designations of species are denoted as E (endangered), T (threatened), and SC (special concern).

	Federal		**State/Provincial**	
Species	**U.S.**	**Canada**	**MI**	**ON**
Lake sturgeon			T	T
Northern brook lamprey		SC		SC
Piping plover (*Charadrius melodus*)	E	E	E	E
Snuffbox mussel (*Epioblasma triquetra*)	*		E	E

*Species proposed for federal listing.

Lake Sturgeon

A protocol for application of lampricides to streams with populations of young-of-the-year (YOY) lake sturgeon (*Acipenser fulvescens*) has been implemented for treatment of lake sturgeon spawning streams in the United States and prescribes restrictions to the timing of treatments and the concentrations of lampricides applied to provide additional protection to YOY lake sturgeon (<100 mm). The protocol has since been modified to exclude the restrictions to concentration because of increased sea lamprey survival as a result of adherence to the protocol. Michigan streams that have been treated under the modified protocol include the Cheboygan, Au Sable, Rifle, and Saginaw Rivers. The placement of barriers to sea lamprey migration may also impede lake sturgeon reproduction, however, few sea lamprey barriers exist on large rivers that have historically supported or currently support the largest lake sturgeon spawning migrations. Sea lamprey barriers have been built on 6 of 33 historic lake sturgeon spawning streams, including Echo, Still, Sturgeon, Manitou, Saugeen, and Rifle (West Branch) Rivers.

Northern Brook Lamprey

In Canada, the northern brook lamprey (*Ichthyomyzon fossor*) is federally listed under the Species at Risk Act as a “Species of Special Concern.” This species is indistinguishable in appearance from the silver lamprey (*Ichthyomyzon unicuspis*) during its larval phase, and an elevation in status to “Endangered” or “Threatened” for either species could negatively impact sea lamprey control in Lake Huron. To date, *Ichthyomyzon* sp. have been documented in 71 (37 in Canada and 34 in the United States) streams in the Lake Huron drainage. Of these, 58 streams (29 in Canada and 29 in the United States) also have a history of sea lamprey infestation. Several *Ichthyomyzon* sp. populations are protected by barriers that serve to block sea lampreys, thus eliminating their exposure to lampricide. For example, an assessment of the northern brook lamprey population upstream of Denny’s Dam on the Saugeen River was conducted in 2007 and yielded an estimate of over 203,000 northern brook lamprey larvae distributed over 105 km of stream (Fisheries and Oceans Canada, Sea Lamprey Control Centre, unpublished data).

Freshwater Mussels

In Canada, 12 freshwater mussel species that inhabit the Great Lakes-St. Lawrence Region are listed as “Endangered.” Many of the species are found in the southern Lake Huron drainage (Metcalfe-Smith et al. 2003; Staton et al. 2003), but, at this time, no listed mussels have been found in known sea lamprey producing streams in the Lake Huron basin.

In the United States, the snuffbox mussel (*Epioblasma triquetra*) was proposed for federal listing in 2010. The species is found in the Saginaw River and, once listed, requires formal consultation with the USFWS’s Ecological Services (ES) branch prior to subsequent treatments of the river. Formal consultation involves drafting a biological assessment by the USFWS and a biological opinion by ES that serve as legal documentation of the review process and evaluate the proposed action and its effect on the endangered species. During consultation, conservation measures are developed to avoid and protect the species and habitat that are critical to its survival.

Studies are being conducted to determine the toxicity of TFM to all life stages of the snuffbox mussel (glochidia, juvenile, and adult), as well as toxicity to the primary host fish, the logperch (*Percina caprodes*). This information will be used in the biological assessment to evaluate the effects of TFM treatments and negotiate treatment options with ES.

Timing and Discharge Restrictions

Permits issued by the State of Michigan prescribe protection for Pacific salmon, brown trout, and brook trout during their spring and fall spawning periods and require that activities affecting these species be scheduled between June 1 and either September 15 or October 1, depending on the stream. These restrictions are requested for most streams that have moderate to heavy fishing pressure and support spawning migrations of Pacific salmon or spawning populations of brook or brown trout. Streams affected by restrictions include the Rifle, Cheboygan, Au Gres, and Sable Rivers.

Lampricide applications in some large Lake Huron tributaries must be coordinated with hydroelectric companies or other dam operators to ensure that a consistent and manageable discharge is provided during treatment, including the Au Sable, Cheboygan, Thessalon (OMNR controlled), Mississagi, Spanish, and Wanapitei Rivers.

Stream-Treatment Deferrals

Most stream-treatment deferrals on Lake Huron since 1987 were caused by either too much or too little water (Table 13). Treatments of deferred streams were often completed in the following year, but some streams have not been treated within two or more years of the deferral (e.g., Spanish River in 1986-1987, Devils River in 1989-1990). At times, treatments are deferred so that sea lamprey research can be conducted, as was the case in the Black Mallard River during 1995-2000.

Table 13. Stream-treatment deferrals in Lake Huron during 1986-2010 (years without deferrals are excluded). Code definitions are H (excessive volume), I (insufficient numbers of larvae), L (insufficient volume), N (protect nontarget organisms), P (treatment priority of large stream), R (Ontario Ministry of Natural Resources request), S (research stream), T (time constraints), and U (unfavorable water chemistry).

River	86	87	88	89	90	91	92	95	96	97	98	99	00	01	05	06	07	08	09	10	Total
Spanish River	H	R			L													H	H		5
Cheboygan River		L																			1
Saginaw River		L						L						U		L					4
Pine River			L																		1
Charlotte River			L																		1
Chikanishing River			L																		1
Timber Bay Creek			L														L				2
Au Gres River				L																	1
Devils River				L	S							L									3
Black River				L																	1
Watson Creek				L																	1
Au Sable River					I																1
Black Mallard River					I	L		S	S	S	S	S	L				S	L			10
Nottawasaga River					L														H	L	3
Thessalon River					L																1
Pentwater River						P															1
Root River						I															1
Trout River							L														1
Naiscoot River							L			L	L										3
Browns Creek										L											1
Magnetawan River											L				L					L	3
Grand Lake Outlet												L									1
Shebeshekong River												L	L								2
Serpent River												L									1
Albany Creek													T								1
H-267														T							1
Sand Creek															T						1
Bighead River																H					1
Caribou Creek																	L				1
Grace Creek																		L			1
Mill Creek																		N	N		2
Sauble River																		H			1
Garden River																				L	1
French River																				L	1
Total	1	3	4	4	6	3	2	2	1	3	3	5	3	2	2	2	3	4	3	4	60

Recent deferrals can be partly attributed to the lack of flexibility in treatment schedules. When suboptimal flows are encountered, treatment crews have two options: wait for flows to change (either by waiting out a flood crest or for rains to increase flows) or transfer effort to another stream treatment. However, the treatment schedule is fully determined prior to the field season. This limits the opportunity to compensate for either waiting for optimal flows (another stream later in the schedule might remain untreated due to time spent waiting) or to return to the stream at a later date to effect treatment. Increased flexibility in the treatment schedule would increase the likelihood of conducting an effective treatment on a stream when suboptimal flows are encountered.

Pollution Abatement

While generally recognized as good stewardship and a positive step forward for remediation, pollution-abatement initiatives can have a negative impact on the Five-Year Plan because improved water and habitat quality increase the potential for new infestations and subsequently increase program costs. The Saginaw and St. Marys Rivers are two such examples in the Lake Huron watershed. These systems are consistently infested with sea lampreys, but a reduction in pollutants has allowed the infestation to spread to areas that were once uninhabitable, increasing assessment and treatment costs and possibly resulting in higher larval abundance and increased residual production.

Barrier Removal

Balancing the benefit of enhancing connectivity of tributaries to Lake Huron with goals of managing sea lampreys is a clear challenge for the future. The increased spawning and nursery habitat for native fishes resulting from improved fish passage or barrier removal can also lead to increased sea lamprey recruitment and survival. Management of these structures needs to be of benefit to the entire fish community, not just the needs of one species or management agency.

Public Use

Public use activities, such as swimming, boating, or fishing, are not restricted during lampricide applications, although irrigators are required to cease operations for a 24-hour period during treatment. Water withdrawn by irrigators can lead to decreased discharge and flow times, which complicates the treatment process. The public is advised to minimize unnecessary exposure to lampricides through news releases and personal contact with user groups. Treatment supervisors may adjust treatment timing to exclude periods of peak use by the public, but it is nearly impossible to accommodate all activities. Treating during times of high public use requires additional planning and effort to ensure that the public is well informed so that negative perceptions can be minimized.

Recruitment from Other Sources

Given the geographic position of Lake Huron, the contribution of sea lampreys from other sources is the movement of spawning-phase sea lampreys from Lake Superior via the St. Marys River, from Lake Michigan via the Straits of Mackinac, or from Lake St. Clair and Lake Erie via the Detroit and St. Clair Rivers. The contribution of these lampreys to the spawning-phase population and recruitment of larvae is likely small, but it has not been quantified. Sea lampreys are also known to move back and forth between Lakes Huron and Michigan (Applegate 1950). Parasitic-phase sea lampreys are also known to travel through Lake Huron while attached to lake freighters, but the increase in predation from these migrants is unknown.

Fish-Community Interactions

The structure and composition of the fish community in Lake Huron may have an important influence on sea lamprey abundance and control of their populations. Young et al. (1996) found a direct correlation between bloater abundance in northern Lake Huron and subsequent increases in abundance of sea lampreys and postulated that recovering bloater populations provided a critical food source for recently metamorphosed sea lampreys that helped increase their in-lake survival and subsequent spawning-phase abundance. When large lake trout were present in the population of northern Lake Huron, they were the preferred host for sea lampreys, but, as their abundance declined, sea lampreys began to prey more on Chinook salmon (*Oncorhynchus tshawytscha*) (Morse et al. 2003; Fig. 29). Initiation of regular treatment in the St. Marys River has resulted in declines in marking rates and associated sea lamprey induced mortality on lake trout in northern Lake Huron. This reduced sea lamprey mortality, in combination with reduced fishing effort, has led to increases in lake trout abundance, age-class structure, and the size of individuals in northern Lake Huron since about 2002 (Madenjian et al. 2004). Although lake trout mortality has declined, sea lamprey induced mortality of lake whitefish has increased substantially in northern Lake Huron since the late 1980s, and sea lamprey induced mortality on large lake whitefish has exceeded 25% or more (Ebener et al. 2010; Fig. 29). In 2009, sea lamprey marking on fish <610 mm was greater on ciscoes (*Coregonus* spp.) and lake whitefish than on lake trout (Fig. 30). These shifts in sea lamprey predation within the fish community of northern Lake Huron suggest that metrics to assess efficacy of the sea lamprey control program should be broad-based across the entire fish community and not confined solely to lake trout.

Fig. 29. Estimates of sea lamprey induced mortality of age 4 and older lake whitefish in northern Lake Huron during 1980-2009. Mortality was calculated following the methods of Dobiesz et al. (2005).

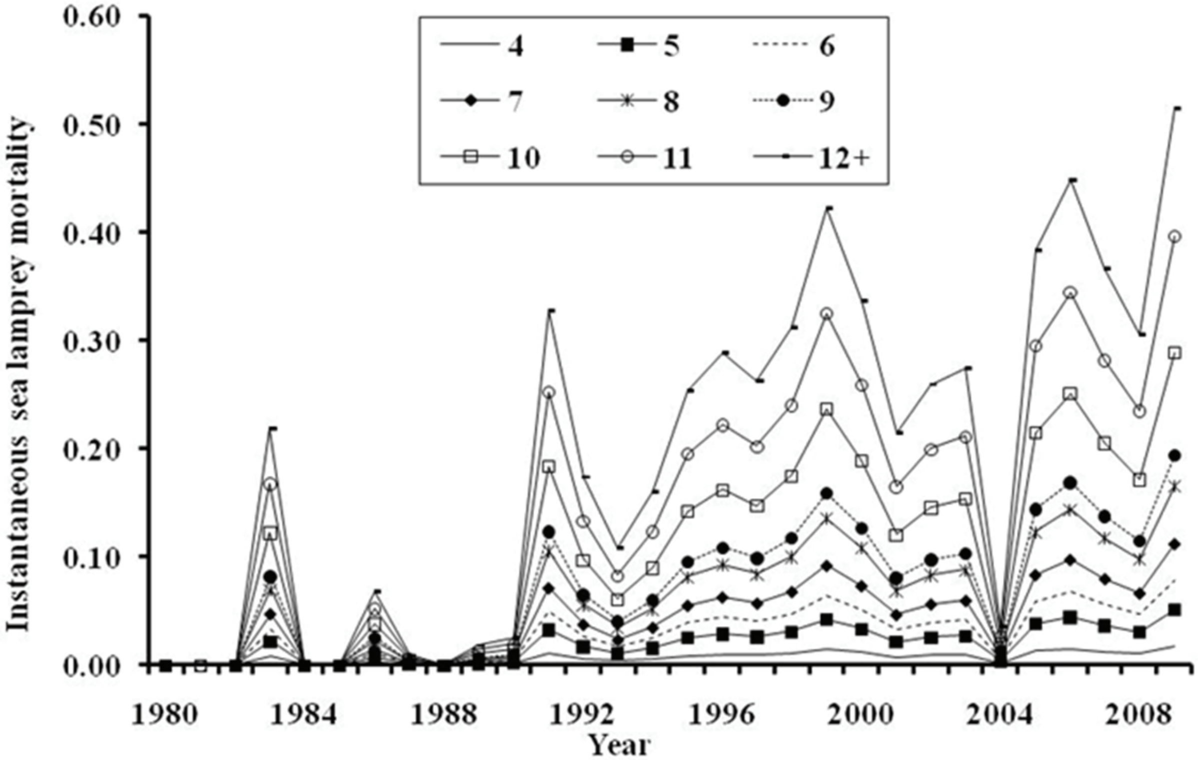
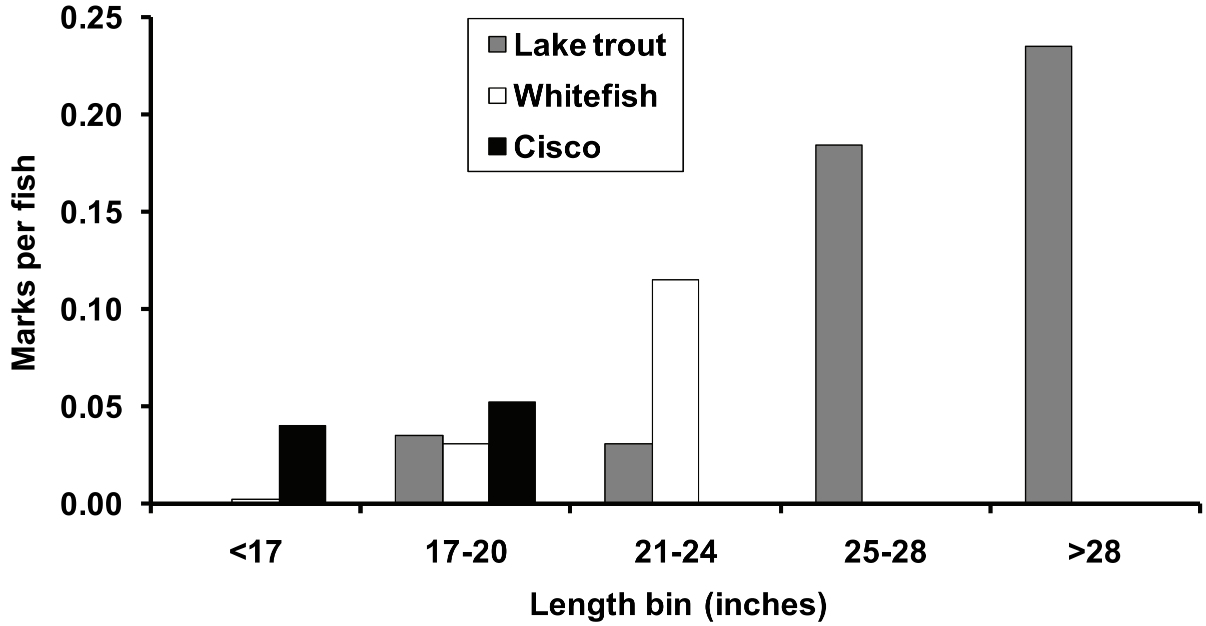


Fig. 30. Sea lamprey marking rates (Type A, Stages I, II, and III marks per fish) on five size-classes of lake trout, whitefish, and ciscoes captured during graded-mesh gillnet surveys in northern Lake Huron during July-October 2009 (M. Ebener, unpublished data).



Fish-Community Objectives

Fish-community objectives (FCOs) for Lake Huron are used by agencies to manage fisheries in their jurisdiction under the framework described in the document (DesJardine et al. 1995). The FCO for sea lampreys in Lake Huron is:

> *Reduce sea lamprey abundance to allow the achievement of other fish community objectives. Obtain a 75% reduction in parasitic-phase sea lamprey by the year 2000 and a 90% reduction by the year 2010 from present levels.*

These sea lamprey objectives support the other FCOs, specifically, the salmonine and coregonine objectives:

> *Establish a diverse salmonine community that can sustain an annual harvest of 2.4 million kg, with lake trout the dominant species and anadromous (stream-spawning) species also having a prominent place.*
>
> *Maintain the present diversity of coregonines; manage lake whitefish and ciscoes at levels capable of sustaining annual harvests of 3.8 million kg; restore cicso to a significant level, and protect, where possible, rare deepwater ciscoes.*

Sea Lamprey Suppression Targets

The overall goal for sea lamprey control in this plan is:

> *Reduce sea lamprey abundance to target levels.*

The Lake Huron Committee (LHC) has agreed that an annual target abundance of 73,000 ± 28,000 spawning-phase sea lampreys should lead to the target of 5 marks per 100 lake trout and achievement of the sea lamprey FCO. The target abundance and range was the average number of adult sea lampreys estimated for the five-year period of 1994-1998.

Reduction in sea lamprey induced lake trout mortality is also an important stipulation in the 2000 Consent Decree (State of Michigan 2000). The decree is a federal court order that specifies how fishery resources are managed and allocated among five tribal governments and the State of Michigan within the Lake Huron waters of the 1836 Treaty, an area that extends within United States waters from the Straits of Mackinaw to Alpena (Fig. 31). The decree embraces the goals of lake trout rehabilitation and requires the effective control of sea lamprey numbers and the mortality they cause to lake trout. To adopt the goals of lake trout rehabilitation and management within the decree, the parties stipulated that "sea lamprey control efforts will (would) significantly reduce sea lamprey induced lake trout mortality from 1998 levels." Failure to achieve a reduction in sea lamprey induced mortality on lake trout within the 1836 Treaty waters in Lake Huron could result in a party requesting relief from the lake trout rehabilitation goals contained within the decree.

Fig. 31. Tribal fishing zones in Lake Huron, as defined in the 1836 Treaty and 2000 Consent Decree.

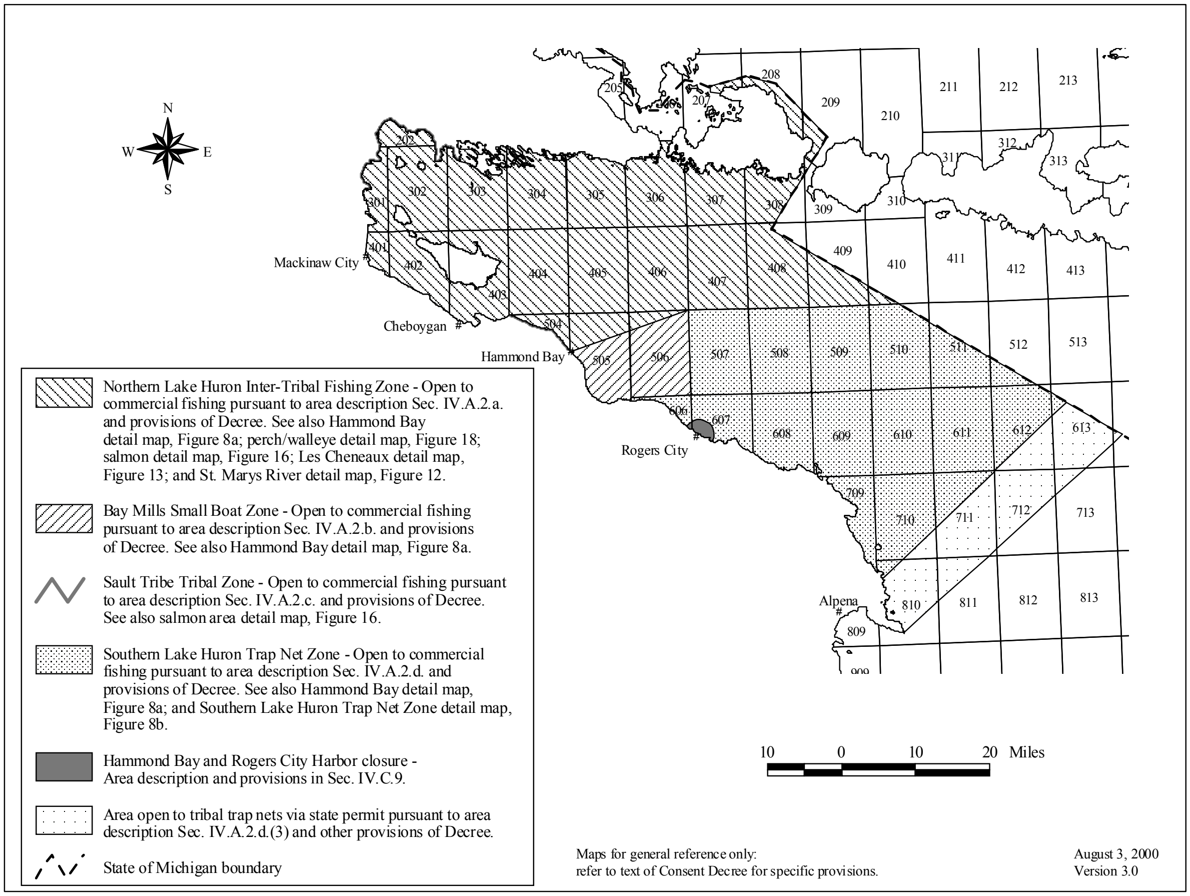


Figure 8. Lake Huron Tribal Fishing Zones (Sec. IV.A.2.).

Objectives and Strategies within Program Components

Lampricide Control

Concerns regarding the effects of lampricides on nontarget organisms, the use of pesticides in the environment, and the increasing cost to produce TFM resulted in a desire to reduce dependency on chemical lampricides during the 1990s (Brege et al. 2003). These concerns led to a reduction in the amount of TFM applied to Lake Huron tributaries. However, because of an increase of spawning-phase sea lampreys in Lake Huron beginning in the mid-1990s, the amount of lampricide applied to tributaries was increased beginning in 2001.

During 2010 and 2011, the GLFC approved additional treatment effort focused on the North Channel of Lake Huron in response to local declines in lake trout populations and increasing larval sea lamprey abundance estimates in the St. Marys River. This additional effort targeted the largest larval producers in the North Channel west of the Spanish River through the Detour Passage area (Fig. 32), and 875 ha of larval habitat in the St. Marys River (Fig. 33). Treatments are to be conducted in successive years to first remove the majority of the larval population and then to remove residual larvae and any year-classes that have re-established between treatments. Through this concerted effort and assuming that all sources of sea lamprey production in the North Channel have been identified and treated with at least 90% efficacy, parasitic and spawning-phase populations in the North Channel area, and possibly throughout Lake Huron and northern Lake Michigan, are expected to show marked decreases in abundance with concomitant decreases in marking rates on the fish community. An analysis of the hypotheses and assumptions regarding the North Channel treatment initiative is currently being completed by the Sea Lamprey Integration Committee and the Assessment Task Force. This analysis will be used to evaluate the outcome of the strategy through comparison of a number of metrics, including spawning-phase sea lamprey trap catch, larval recruitment, St. Marys River transformer catch, and marking rates on fish stocks in the Drummond Island refuge and throughout Lake Huron.

Fig. 32. Distribution of streams being treated with lampricide under the North Channel large-scale treatment strategy during 2010-2011. Name of stream can be cross referenced in Appendix B. Including the St. Marys River, this effort represents a total expenditure of 1,520 staff days above the base control effort.

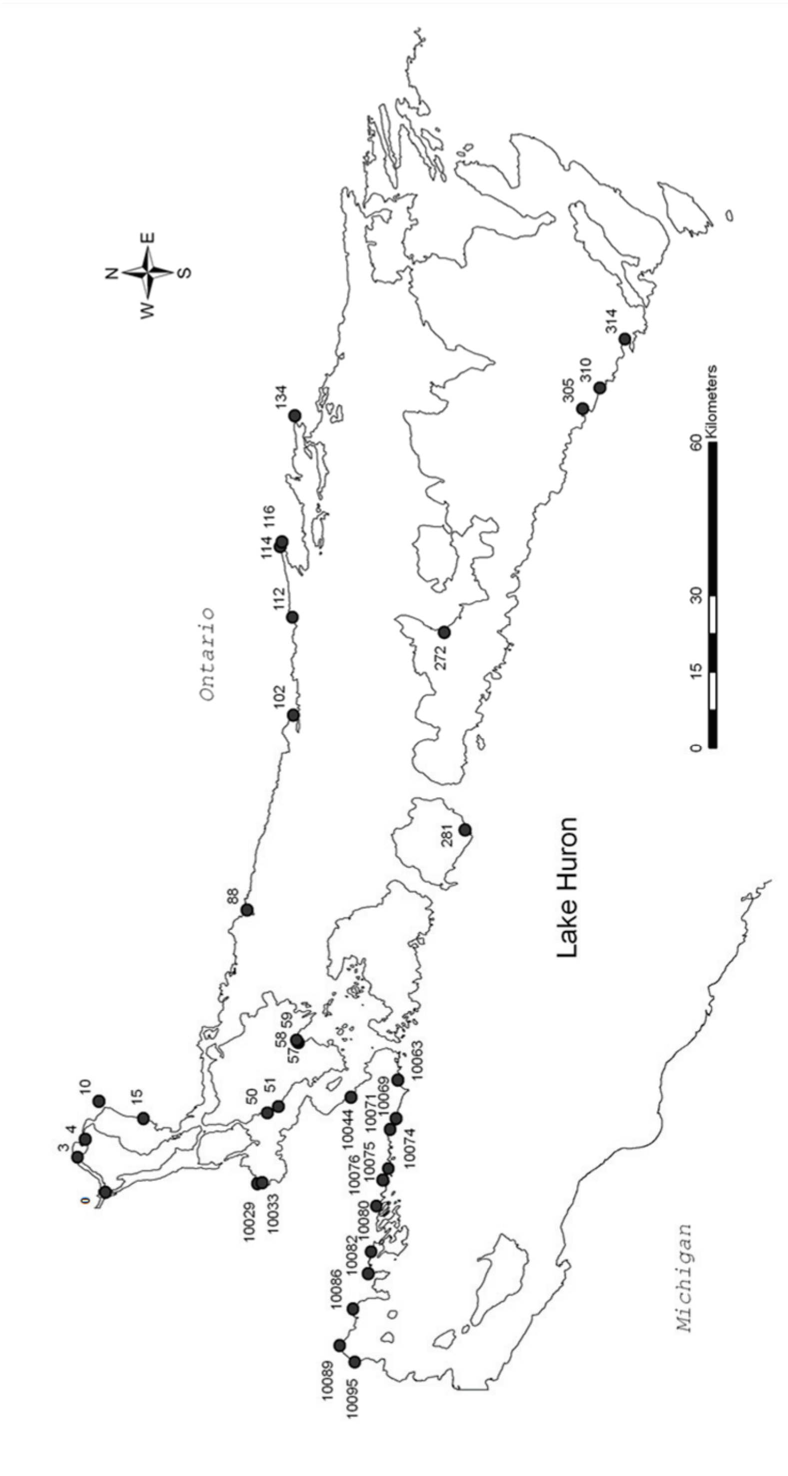
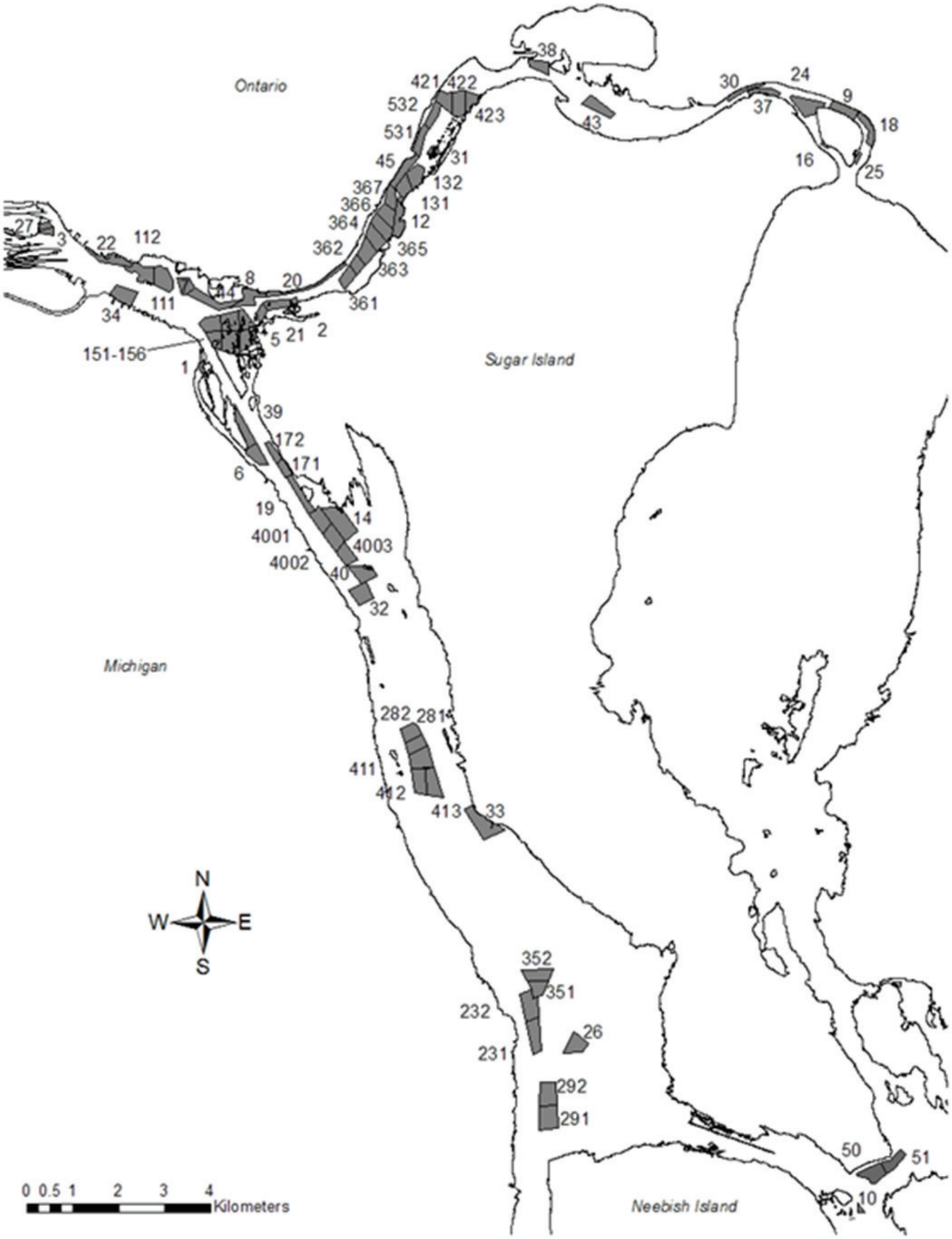


Fig. 33. Location of the 71 granular Bayluscide plots that make up the 875 ha of larval habitat treated in the St. Marys River as part of the North Channel large-scale treatment scenario during 2010-2011.



During 1999-2010, 71 Lake Huron tributaries have been treated with an average of 27.5 tributaries being treated each year since 2006 (Table 14). An average of 16.5 tributaries was treated annually between 1999 and 2006.

Table 14. Lampricide treatment information for Lake Huron during 1999-2010. TFM and Bayluscide are reported as kilograms of active ingredient used.

Year	Number of treatments	TFM (kg)	Stream length (km)	Bayluscide (kg)	Bayluscide area (ha)
1999	14	7,177	292	4,256	760
2000	16	10,750	475	53	9
2001	19	4,251	234	242	43
2002	12	17,645	527	85	15
2003	19	15,505	572	532	95
2004	19	7,715	280	548	98
2005	19	8,461	495	739	132
2006	14	5,786	387	543	97
2007	23	18,302	535	698	125
2008	24	14,967	540	926	165
2009	19	12,856	728	498	89
2010	44	24,671	1,003	5,161	912

Objective 1: By 2012, reduce the abundance of larvae to less than 1 million on the St. Marys River by using gB in conjunction with alternative control methods.

Strategy: Complete St. Marys River substrate mapping using RoxAnn© sonar technology, and use this information to fine tune spatial definitions of infested areas.

Cost: Cost is dependent on the level of detail sought. At 20-m resolution, approximately 40 staff days to map ~1000 ha (25 ha/day).

Strategy: Coordinate the use of both USFWS and Fisheries and Oceans Canada gB spray boats to maximize the total annual area treated. This strategy includes organizing the logistics of gB transport and loading, which are processes that currently interfere with potential gains in efficiency.

Cost: Mostly base funding, although the processes may require the purchase of equipment for transport and loading of gB.

Strategy: Treat plots with larval densities >2,000 larvae/ha twice each year to reduce residual survival. Candidates include Plots 5, 111, 112, and 363, but additional included plots are dependent on population estimates.

Cost: The treatment cost of the four candidate plots is approximately $255K. Treating all plots with densities >2,000 larvae/ha could be as much as $1.1M in a year, depending on population estimates.

Strategy: Identify St. Marys River plots that are prone to heavy weed growth, and treat these plots as early in the season as possible.

Cost: Included in the base program.

Strategy: Evaluate the feasibility of removing St. Marys River plots from the rank list and treating them at a consistent level dependent on larval population estimates.

Cost: Dependent on the larval population estimate and plot area. The 2011 cost of gB application in the St. Marys River is $3,970/ha.

Strategy: Use the results from the Quantitative Fisheries Center's (QFC) updated St. Marys River decision analysis and results from the large-scale North Channel treatment initiative to evaluate the contribution of trapping, sterile-male release technique (SMRT) program, and lampricide treatment to the integrated pest-management strategy in the St. Marys River.

Cost: Dependent on the chosen integrated pest-management strategy, as determined by the decision analysis.

Objective 2: By 2014, increase the proportion of sea lampreys killed during lampricide treatments by developing and implementing strategies for optimal success in all tributaries.

Strategy: Identify streams where treatment effectiveness may be improved and develop and implement strategies to treat more effectively, such as maintaining concentrations in excess of the minimum lethal concentration for at least nine hours; increasing the duration of application by one-three hours; applying lampricide to backwaters, rivulets, and seepage areas that would otherwise remain untreated during the primary treatment; treating at the optimal time of the year to ensure the appropriate discharges; and treat when larval sea lamprey fitness is lowest. Candidate streams include the Saginaw, Au Sable, Cheboygan, Au Gres, and Pine Rivers.

Cost: Included in the base program. However the overall cost of treating the candidate streams would increase due to increased staff and lampricide costs.

Strategy: Identify tributaries from the stream-treatment rank list where treatment effectiveness can be increased by inventorying geographic features and increasing effort to conduct secondary lampricide applications. Candidates include the Black and Cheboygan Rivers and their associated tributaries.

Cost: Included in the base program. However, the overall cost of treating the candidate streams would increase due to increased staff and lampricide costs.

Strategy: Coordinate with state, provincial, and tribal management agencies to address challenges to successful treatment, including the communication of risks, goals, and benefits on lampricide control to stakeholders; requirements to protect species at risk through formal biological assessments, evaluations and opinions; and ensure that the entire infested area of a stream is treated.

Cost: Included in the base program.

Strategy: Continue to conduct lentic treatments during or immediately following the stream treatment on streams with known lentic populations. Candidates include the Carp River; McKay, Caribou, Trout, Garden, Manitou, and Lauzon Creeks; Tenby Bay (Browns, Watson, and Gordon Creeks); and Whitefish Channel (St. Marys River).

Cost: Included in the base program, but the required gB would increase the treatment cost of candidate streams.

Strategy: Continue to coordinate with United States states and tribes to negotiate implementation of the sturgeon protocol with respect to lakewide target levels of suppression when necessary.

Cost: Included in the base program.

Strategy: Beginning in 2011, use nets to capture and remove larvae activated during treatments of tributaries to larger untreated systems or tributaries that enter a lake when sea lamprey larvae have been observed in the associated estuarine area. Candidates include the Carp and Munuscong Rivers; Caribou, Albany, and McKay Creeks in Michigan. Also included are the Elm, Bar, and Iron Creeks of the Echo River; West Root River; Cannon Creek of the Root River; Grassey Creek of the Serpent River, Watsons Creek; and the Lauzon River all in Ontario.

Cost: Base program plus additional fykenets.

Strategy: When necessary, apply lampricides for 24 hours at lower than normal concentrations to minimize nontarget mortality due to large pH. The candidate includes the Saginaw River.

Cost: Included in the base program. However, increased lampricide costs for candidate streams may mean lower ranked streams are treated less frequently.

Objective 3:	Beginning in 2012, reduce the number of residuals that are allowed to escape to the lakes from regularly treated streams.
Strategy:	Identify and treat on a shorter rotation at least three large sea lamprey producing streams that are prone to deferral so fewer transformers escape if a treatment is deferred. Candidates include the Saginaw, Au Sable, Au Gres, Rifle, Cheboygan, Pine, Carp, Garden, Thessalon, Mississagi, Magnetawan, and Pine (Nottawasaga) Rivers.
Cost:	Included in the base program. However, streams near the bottom of the rank list will be treated less frequently.
Strategy:	Reduce the largest estimated residual populations by implementing consecutive treatments on the top five sea lamprey producing streams exclusive of the St. Marys River, which are the Garden, Rifle, Spanish, Mississagi, and Au Sable Rivers.
Cost:	Included in the base program, but the lower-ranked streams would be treated less often.
Strategy:	Periodically implement treatments in two consecutive years in streams with a history of significant residual sea lampreys. For example, a stream with a three-year treatment cycle would be treated in years one, two, five, six, nine, and ten. Candidates include the Carp, Rifle, Au Sable, Saginaw, Root, Garden, and Little Munuscong Rivers, as well as Browns, Watsons, and Albany Creeks (upstream of the barrier, as necessary).
Cost:	Included in the base program, but the lower-ranked streams would be treated less often.
Strategy:	Treat all streams with regular annual recruitment on a three- or four-year cycle (i.e., just set application points and treat).
Cost:	Cost analyses currently being conducted. Assessment resources would be reallocated among program elements.
Strategy:	Reduce the contribution of sea lampreys from lentic areas and estuaries by treating any predefined plots in lentic areas containing larvae >100 mm with gB.
Cost:	Included in the base program, but the lower-ranked streams would be treated less often.

Objective 4: By 2015, determine how the North Channel treatment strategy affected lakewide spawning-phase abundance and frequency of lampricide treatments on major sea lamprey producing tributaries.

Strategy: Following completion of the treatment strategy in 2012, review mark-recapture information on recently metamorphosed sea lampreys in the context of recolonization strategies and evaluate how sea lamprey reduction at a regional level might affect and be affected by the regional fish community. Establish regional goals for spawning-phase sea lamprey abundance.

Cost: Included in the base program.

Strategy: By 2015, determine the effectiveness of the North Channel treatment strategy by comparing pre- and post-treatment estimates of lakewide spawning-phase abundance, larval abundance in the St. Marys River, and marking rates on the entire northern Lake Huron fish community.

Cost: Included in the base program.

Larval Assessment

Larval assessment uses standardized protocols to determine the presence, abundance, size structure, and distribution of sea lamprey larvae within streams and lentic areas of Lake Huron. The assessment information is used to prioritize treatment effort among streams, lentic areas, and St. Marys River plots throughout the Great Lakes by using a basinwide ranking procedure based on the cost of lampricide treatment necessary to kill larvae >100 mm in length, generally assumed to be 99% of the larval population. Larval assessment is also used to assess treatment success.

Objective 1: By 2012, use ongoing research and new technology to optimize the balance between larval assessment and lampricide treatment on the St. Marys River.

Strategy: Use results from Wilberg et al. (2008) and other studies to determine the optimal method for prioritizing infested areas of the St. Marys River for treatment.

Cost: Included in the base program.

Strategy: Use results from the QFC's updated decision analysis for the St. Marys River to optimize the balance between assessment, lampricide treatment, trapping, and the SMRT program.

Cost: Dependent on the selected integrated pest-management strategy, but the cost will be described in the decision analysis. It is expected to be cost neutral or a cost savings.

Objective 2: By 2012, maximize the effectiveness of the larval assessment program so that it provides enough among-stream information to prioritize streams for lampricide application and sufficient within-stream information to effectively plan a lampricide application.

Strategy: Continue to use expert judgment (EJ) criteria to prioritize streams with multiple years of recruitment for treatment and to allocate effort saved to post-treatment assessments within one year of treatment to determine residual abundance and the potential for re-treatment. EJ criteria include a history of consistent recruitment and treatment on a particular stream. In Michigan, EJ streams include the Pine, Carp, Cheboygan, Black Mallard, Ocqueoc, Trout, Devils, Au Sable, East Au Gres, Au Gres, and Rifle Rivers; Greene and Elliot Creeks; and Tawas Lake Outlet. In Ontario, EJ streams include the Root, Garden, Thessalon (Lower), Mississagi, Mindemoya, Wanapitei (French River), Magnetawan, Naiscoot, Boyne, Sturgeon, Pine (Nottawasaga River), and Bighead Rivers; and Grassy (Serpent River), Watson, Timber Bay, and Blue Jay Creeks.

Cost: Included in the base program.

Strategy: Ensure that detection surveys for new populations of sea lamprey larvae are conducted every five to seven years in streams with suitable spawning and nursery habitats, and evaluation surveys are conducted every three years in previously infested streams.

Cost: Increased cost to conduct detection surveys. Evaluation surveys are included in the base program.

Strategy: Ensure that upstream and downstream limits of sea lamprey infestation are accurately determined either the year prior to or the year of treatment for each stream scheduled for lampricide application.

Cost: Included in the base program.

Objective 3: By 2015, prioritize and treat all lentic and estuarine areas that regularly recruit larval sea lampreys.

Strategy: Continue to use RoxAnn© mapping to quantify substrates in lentic and estuarine areas.

Cost: Funded through priority additions and dependent on the location and total area to be surveyed. Recent mapping projects have been able to map ~100 ha/day. With travel, setup. and ground-truthing, the cost is approximately 1 staff day/25 ha.

Strategy: Continue to assess at least three new potential lentic areas annually until all are accounted for.

Cost: Included in the base program.

Strategy: Evaluate the feasibility of implementing annual TFM treatments on streams with lentic populations >500 larvae/ha with the goal of preventing recruitment to the lentic area.

Cost: Included in the base program.

Strategy: Revisit known infested lentic areas every two to three years to determine the need for treatment.

Cost: Included in the base program.

Objective 4: By 2013, maximize the implementation of alternative methods to prioritize streams and lentic areas for lampricide application

Strategy: Develop additional criteria to prioritize streams for treatment based on expanded EJ criteria or other non-ranking survey data in hand. Candidates include the Saginaw, Rifle, Au Gres, Au Sable, Pine, Carp, Lauzon, Aux Sables (Spanish), and Bighead Rivers and Blue Jay Creek.

Cost: Included in the base program. Prioritization will free up resources from assessment that can be put towards control.

Strategy: Consult with lake technical committees to prioritize lampricide application based on where sea lampreys are more likely to survive and damage fish by incorporating host abundance or marking rate in the prioritization method. Begin with the North Channel streams in 2012.

Cost: Possible additional integrated management of sea lamprey program support or cooperation with the Lake Huron Technical Committee (LHTC) and/or the Modeling Subcommittee.

Strategy: By 2011, have the Assessment Task Force evaluate treating streams or lentic areas on a fixed cycle from the maximum historical points of infestation.

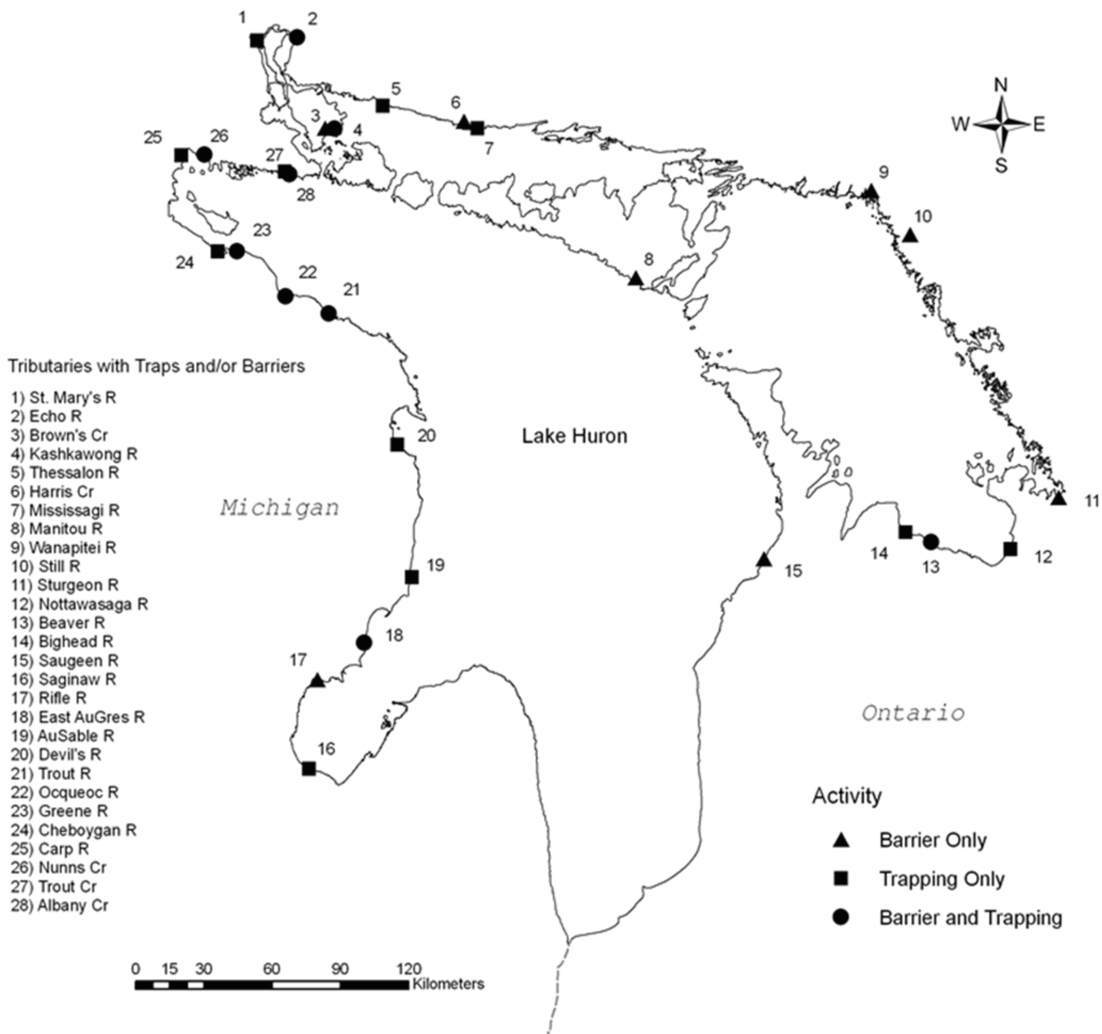
Cost: Analysis is in progress. Savings to be reallocated to other program elements.

Trapping

Trapping of spawning-phase sea lampreys during migration serves three purposes: assessing spawning-phase sea lamprey abundance; removing sea lampreys from the spawning population; and providing male sea lampreys for the SMRT program used in the St. Marys River. The SMRT program is discussed further in Alternative Control.

Spawning-phase sea lampreys are currently trapped in 20 tributaries to Lake Huron (Fig. 34). Total catch has averaged 32,617 since 1999 with most of the captured animals being used for assessment purposes and an average of ~14,000 being put towards the SMRT program.

Fig. 34. Location of Lake Huron tributaries with traps and barriers to sea lamprey spawning migrations.



Spawning-Phase Assessment

Lakewide spawning-phase sea lamprey abundance is estimated from a combination of mark-recapture estimates conducted at trap sites; historical estimates of trapping efficiency at sites where mark-recapture is not conducted; and modeling of expected spawning runs based on tributary-specific values for drainage area, geographic region, larval sea lamprey production, timing of the last lampricide application, and year (Mullett et al. 2003).

Objective 1: By 2015, determine the optimum level (suite of streams, size of streams, geographic coverage) of trapping spawning-phase sea lampreys needed to obtain accurate estimates of lakewide abundance with a precision of ±20%.

Strategy: By 2012, evaluate factors that will improve the accuracy and precision of annual estimates of abundance. Utilize this information to determine if improvements are necessary and to identify and recommend which factors will improve accuracy and precision to the desired level.

Cost: Included in the base program.

Strategy: By 2013, based on previous analyses, recommend the suite of streams and optimum level of trapping to precisely estimate (±20%) lakewide spawning-phase sea lamprey abundance. Candidates include the Mississagi, Spanish, French, and Saginaw Rivers.

Cost: Included in the base program. Streams will be identified after analyses are complete.

Objective 2: Investigate innovative trap designs and other techniques and technologies to improve spawning-phase abundance estimates, especially in large streams without barriers and, if feasible, implement at least one new method by 2015.

Strategy: By 2012, develop a list of rivers where alternate methods can be evaluated and correlated with mark-recapture estimates of spawning-phase abundance. Candidates include the Cheboygan and Ocqueoc Rivers where the coefficient of mark-recapture estimates is lowest.

Cost: Included in the base program.

Strategy: By 2014, determine the ability of DIDSON™ camera technology to estimate the spawning-phase sea lampreys run in one or more rivers.

Cost: \$80K for DIDSON™ + \$20K per stream for operations.

Strategy: By 2014, based on data analyses correlating spawning-phase abundance with nest counts (Lake Erie data), develop a list of streams where nest counts may be an effective assessment tool and test this method in at least one stream by 2015.

Cost: Implementation of nest-count surveys would incur additional cost to the base program.

Strategy: By 2015, evaluate the ability of pheromone and eDNA assays to quantify spawning-phase sea lamprey abundance in rivers.

Cost: Covered in research funding.

Trapping for Control

Trapping for control is primarily used on the St. Marys River to limit larval sea lamprey recruitment through the removal of spawning-phase sea lampreys. In other streams where trapping is employed, the portion of the catch that is not directed towards mark-recapture or to supply the SMRT program is removed from the system, likely reducing recruitment in these rivers.

Trapping out-migrating, newly metamorphosed sea lampreys in the fall and early spring is an alternative method for limiting the recruitment of sea lampreys to the parasitic population in the lake. This method has also been implemented to capture transformers for mark-recapture studies, provide transformers for research, and monitor parasitic-phase production in the St. Marys River.

Objective 1: Increase the proportion of the spawning run that is captured in the St. Marys River. Spawning-phase sea lampreys trapped on the St. Marys River are used for both assessment and control purposes (removal and the SMRT program), so improvements in trap efficiency will have added benefits to the overall program.

Strategy: Continue to use video observations of lamprey behavior at specific trap sites to fine-tune the effectiveness of individual traps.

Cost: Included in the base program.

Strategy: By 2013, use the results of acoustic telemetry studies to increase the number of spawning-phase sea lampreys caught in traps and increase the percentage of the entire run that is vulnerable to trapping.

Cost: Dependent on research findings.

Strategy: By 2012, evaluate the applicability of the Great Lake Restoration Initiative funded project that explores the effects of different flow regimes at the Great Lakes Power electrical generating facility on trap catch and efficiency.

Cost: Dependent on research findings and the ability to negotiate with Great Lakes Power.

Strategy: Investigate the feasibility of trapping at the St. Marys River compensating gates.

Cost: Not currently included in the base program, but work would likely require a technical assistance proposal, including an explanation of costs.

Objective 2: Increase the proportion of the spawning run that is captured in all other traps by 20%.

Strategy: By 2015, increase annual effectiveness of traps to at least 25% of the estimated spawning run or 20% more than the 2006-2010 average catch in at least two of the 17 Lake Huron streams currently trapped via improvements in trap design and management-scale application of pheromones. Candidates include the Ocqueoc, East Au Gres, Echo, Thessalon, Mississagi, Bighead, and St. Marys Rivers.

Cost: Funding for mechanical modifications, if required. Pheromone application costs are dependent upon the streams selected (e.g., operated by control agents from headquarters, requirement for travel, and hiring of a contractor).

Strategy: By 2020, incorporate permanent or semi-permanent traps into present or planned barriers. Candidates include the Sturgeon, Bighead, Pine (Nottawasaga), and Rifle Rivers.

Cost: Construction cost will vary among rivers and barriers.

Strategy: Investigate and implement novel technologies and techniques to capture more sea lampreys as they become available.

Cost: Cost dependent upon technology and technique selected, hardware and staff requirements, and opportunity to partner.

Objective 3: By 2015, develop a trapping-for-control strategy to trap spawning-phase sea lampreys where populations have been reduced through regional or lakewide control efforts.

Strategy: Evaluate the ability to affect low recruitment to the larval-phase by trapping reduced spawning runs with a combination of traps that provide refuge (tube or bucket traps) and barrier-integrated traps.

Cost: Cost will depend upon the stream(s) selected, novel technologies implemented, and construction and deployment of traps.

Objective 4: By 2013, reduce recruitment by trapping newly metamorphosed sea lampreys during their downstream migration to the lake.

Strategy: By 2011, develop criteria for stream selection and trap placement to capture out-migrating sea lampreys.

Cost: Included in the base program as part of planning.

Strategy: By 2012, capture out-migrating sea lampreys from streams where large numbers of metamorphosing-phase sea lampreys are known or suspected.

Cost: Increased cost of purchasing/manufacturing and operating traps. Stream dependent.

Alternative Control

Sterile-Male Release

Lake Superior was the initial site for an experimental application of the SMRT program during 1991-1996 (Twohey et al. 2003). In 1997, all sterile males were reallocated to the St. Marys River except for 1,500 released into the Bad River (Lake Superior) at the request of the Bad River Band of Lake Superior Chippewa Indians for an additional year of releases. During 1998-2011, all available sterile-male sea lampreys were released into the St. Marys River. Future re-allocation of sterile males could be considered in a stream with low spawner densities and effective trapping.

Objective 1: Reduce larval production in the St. Marys River through the introduction of sterile-male spawning-phase sea lampreys.

Strategy: Reinstate use of the SMRT program in the St. Marys River.

Cost: $753K.

Pheromones

Pheromones offer promise as a new methodology for the integrated control of sea lampreys (Li et al. 2007). While pheromones have been envisioned in a variety of suppression techniques, their first use will likely be to enhance trapping. Field trials using the pheromone 3kPZS to attract migrating sea lampreys to traps were initiated in the East Au Gres and St. Marys Rivers (United States tributaries) in 2009 and expanded to the Echo, Thessalon, and Little Thessalon Rivers (Canadian tributaries) in 2010. Preliminary results indicate that more sea lampreys were attracted to the pheromone baited traps than the un-baited traps. Additional pheromone components are being investigated for exploitable behavior responses. A detailed plan to implement pheromones in control applications will be developed after the ability to manipulate lamprey migratory behavior through *in situ* pheromone application is better understood.

Objective 1:	By 2013, develop a lakewide integrated plan for using pheromones to manipulate sea lamprey migratory behavior.
Strategy:	Continue coordinated implementation of pheromone field studies to develop expertise in pheromone handling, deployment, and application.
Cost:	One to two staff to oversee pheromone deployment during sea lamprey spawning runs. $10-20K.
Strategy:	As efficacy of various pheromone compounds is demonstrated, evaluate proposed strategies for integration with other control techniques and implement at least one such strategy by 2013.
Cost:	To be determined. Potential technical assistance or research proposal.
Strategy:	Register (or secure experimental use permits for) pheromone compounds to ensure their availability for use in new pheromone methodologies.
Cost:	Approximately $40K.

Barriers

Currently, barriers to sea lamprey migration exist on 17 sea lamprey producing tributaries, of which 13 were constructed for sea lamprey control (purpose-built) (Fig. 34; Table 15). Construction of new barriers typically takes three to six years and requires several steps, including negotiations with land owners, consultation with stakeholders, design, environmental assessments, and partnering agreements during construction.

Four pre-existing non-purpose-built barriers (built for purposes other than a sea lamprey barrier) have been modified to block sea lampreys. Structural inspections are conducted annually to ensure that blockage of sea lamprey migration occurs at these four barriers. In addition, 217 other pre-existing non-purpose-built barriers in Michigan were evaluated between 2007 and 2009 for their ability to block sea lamprey migration in Lake Huron, and these records are used to inform decisions about future projects at these sites.

Table 15. Location, date of construction, and distance upstream for barriers on Lake Huron tributaries purposely built for sea lamprey control (purpose-built). Stream numbers correspond to those in Fig. 34.

Stream number	Stream	Date of construction	Distance from stream mouth (km)	Comments
2	Echo River	1986	17.0	Low-head dam with integrated trap
3	Browns Creek	1998	0.5	Low-head sheetpile dam
4	Koshkawong River	1980	1.0	Low-head dam with integrated trap
6	Harris Creek (Mississagi River)	1958	14.0	Stop log barrier
8	Manitou River	1983	1.0	Improved natural falls
10	Still River	1986	5.0	Rebuilt in 2010 with integrated trap
11	Sturgeon River	1979	1.9	Low-head sheetpile dam
15	Saugeen River	1970	4.2	Built-in fishway
17	West Branch (Rifle River)	1997	89.6	Fixed-crest low-head dam with fishway
18	East Branch Au Gres River	1983	22.5	Fixed-crest low-head dam
22	Ocqueoc River	1999	5.8	Fixed-crest, low-head, and gradient field dam with integrated trap
23	Greene Creek	2003	0.4	Adjustable-crest barrier with integrated trap
26	Nunns Creek	1997	1.4	
28	Albany River	1985	1.0	Adjustable-crest barrier

Objective 1: Assess and maintain the ability of the 13 purpose-built sea lamprey barriers and the 4 modified non-purpose-built sea lamprey barriers to block spawning-phase sea lampreys.

Strategy: Conduct larval assessments above barriers in conjunction with the treatment cycle below the barrier to ensure that sea lampreys have not breached the barrier.

Cost: Included in the base program.

Strategy: Conduct annual inspections of the structure, banks, stream bed, portages, and safety signage and implement repairs before barrier performance is affected.

Cost: Inspections included in the base program. Cost of repairs will be barrier specific.

Strategy: Evaluate and repair barriers that fail to block spawning-phase sea lampreys consistent with their design objectives.

Cost: Specific to the barrier in need of repair.

Objective 2:	Beginning in 2011, annually investigate areas where purpose-built sea lamprey barriers can be constructed consistent with the Barrier Strategy and Implementation Plan.
Strategy:	Meet with the U.S. Army Corps of Engineers and Great Lakes Fishery and Ecosystem Restoration Program semi-annually to discuss funding, research, and expertise to design, plan, and fund barriers in the United States.
Cost:	Included in the base program as part of annual planning.
Strategy:	Develop partnerships with state, tribal, and nongovernment organizations to obtain funding and support for barrier projects.
Cost:	Included in the base program as part of annual planning.
Strategy:	By 2013, develop a decision-analysis tool in combination with a barriers database to provide an objective means to integrate and rank feasible barrier construction and dam refurbishment projects across the basin.
Cost:	Included in the base program.
Strategy:	By 2014, determine the feasibility of constructing new barriers on the Root, Pine, and Bighead Rivers.
Cost:	Additional funds will be required. Amount will be stream specific.
Objective 3:	Ensure spawning-phase sea lampreys remain blocked at important non-purpose-built pre-existing barriers.
Strategy:	By 2012, include non-purpose-built pre-existing barriers in the barrier database, and, by 2013, develop a ranking method based on their importance to sea lamprey control with condition and future maintenance issues noted.
Cost:	Included in the base program.
Strategy:	By 2013, develop a policy and work with partners to preserve the integrity of the furthest downstream barriers that currently block sea lampreys.
Cost:	Included in the base program. May require GLFC participation/negotiation.
Strategy:	By 2013, use the barrier database to maintain a list of structures that currently do not block sea lampreys but have the potential to be converted to blocking structures and pursue modification through a ranking process.
Cost:	Included in the base program.

Strategy: By 2012, establish with state, provincial, tribal, and conservation authorities and First Nations regulators the means for notification and participation of sea lamprey control managers in the review process of in-stream fish passage or dam removal projects before permits are granted.

Cost: Included in the base program as part of planning activities.

Strategy: Update the GLFC website to include a barrier map and/or list of inventoried barriers, contact list for barrier removals, and concurrence request form.

Cost: Included in the base program.

Strategy: By 2013, develop a ranked list of barrier repair and rebuild projects.

Cost: Included in the base program as part of planning activities.

Strategy: By 2013, reconstruct Denny's Dam on the Saugeen River in partnership with the OMNR.

Cost: The GLFC contribution to the Denny's Dam reconstruction is $800K.

Objective 4: Integrate barriers with other methods of control to achieve more effective sea lamprey control.

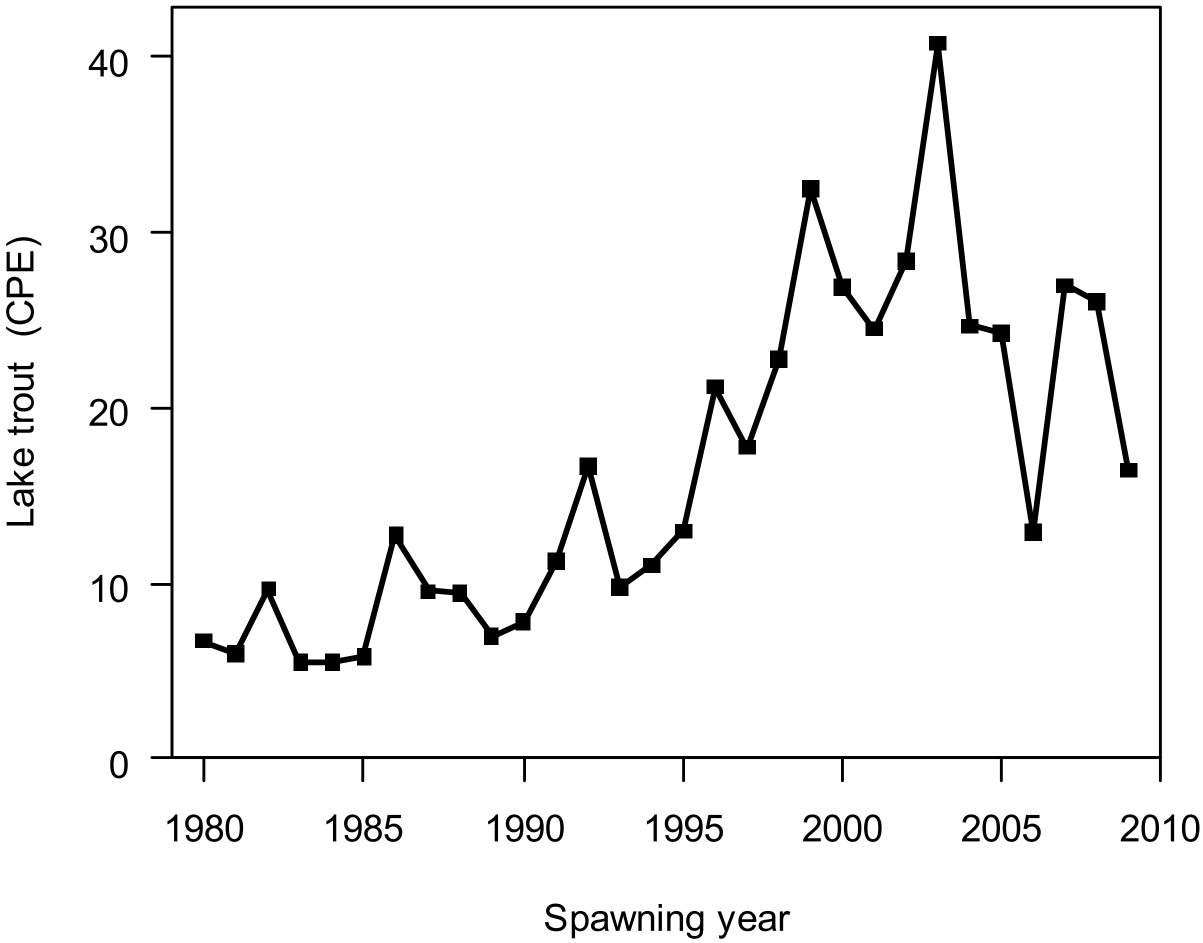
Strategy: By 2011, identify potential sites where barriers, in combination with alternative controls, can contribute to more effective control or suppression.

Cost: Investigations will require additional funds. Dependent on system and alternative controls used.

Metrics and Measures of Success

Current metrics for evaluating the success of the sea lamprey program are annual lakewide estimates of spawning-phase sea lamprey abundance and counts of sea lamprey marks on lean lake trout >533 mm (Fig. 35). Relationships between the sea lamprey marking rate, abundance of host species, abundance of sea lampreys causing marks, and control efforts are not as direct as might be expected. Understanding the linkages between control efforts and predator-prey dynamics would enable a more complete understanding of the effects of sea lamprey control efforts and may enable these efforts to be targeted to lakes, regions of lakes, or fish stocks to maximize overall benefit.

Fig. 35. Annual estimates of lake trout relative abundance. Catch per effort (number of lake trout >532 mm per kilometer of survey gillnet set) in Lake Huron during 1980-2009.



While the sea lamprey control program and other fishery-management agencies currently focus on lean lake trout marking as a primary metric for determining the effects of parasitic sea lampreys, additional species have historically been impacted by sea lamprey marking. These species include white suckers (*Catostomus commersoni*), channel catfish (*Ictalurus punctatus*), and Chinook salmon in northern Lake Huron near the St. Marys River (Schleen et al. 2003), as well as rainbow trout, splake (*Salvelinus namaycush x S. fontinalis*), and deepwater coregonines (Spangler et al. 1980). Lake whitefish inhabiting waters near the St. Marys River exhibit high marking rates associated with parasitic-phase sea lampreys emigrating from the St. Marys River (Ebener et al. 2010). Because of the breadth of species impacted by sea lamprey predation, importance should be placed on assessing damage measurements of the entire fish community, rather than just lean lake trout.

Objective 1: By 2012, use sea lamprey marking rates to develop sea lamprey abundance targets based on all species vulnerable to sea lamprey attack in the Lake Huron fish community starting with lake trout, whitefish, cisco, and Pacific salmon.

Strategy: By 2013, provide data and advice to Ted Treska, USFWS, Green Bay Fishery Resource Office, to help develop predator-prey models that link the effects of sea lamprey control to sea lamprey marking for as many species as practical.

Cost: Included in the base program.

Strategy: Maintain standardization of sea lamprey mark identification through periodic workshops at intervals of no more than five years.

Cost: Approximately $4K. Workshops could be in conjunction with LHTC meetings.

Strategy: By 2012, develop regional spawning-phase sea lamprey abundance and fish-community marking targets for the North Channel, Georgian Bay, and the main lake.

Cost: Included in the base program. Requires consultation with the LHC and LHTC.

Strategy: By 2013, evaluate present sea lamprey marking and abundance targets (5 marks per 100 lake trout, 73,000 spawning-phase sea lampreys) to determine if fishery managers agree that fish-community objectives are obtainable, even if targets are not being met.

Cost: Included in the base program. Requires consultation with the LHC.

Strategy: By 2014, analyze time-series data to evaluate if there are effects due to climate change on sea lamprey survival, length, weight, growth, feeding duration, fecundity, and host mortality.

Cost: Research the topic. Data provision and agent support are included in the base program.

Objective 2: By 2012, reevaluate targets for abundance of spawning-phase sea lampreys and, if necessary, develop new targets.

Strategy: Develop regional targets for sea lamprey abundance based on marking in the entire fish community and the revised objectives proposed in this plan.

Cost: Specific costs are unknown. Requires consultation with lake fishery-management agencies.

Strategy: Reevaluate methods used to determine the abundance of spawning-phase sea lampreys, and measure the influence of climatic factors, such as temperature and precipitation (flow), on annual variation in trap efficiency. Coordinate with Objective 1 in Spawning-Phase Assessment.

Cost: In progress.

Recommended Strategies to Achieve Targets

The Five-Year Plan implements a base program of lampricide control, assessment, and alternative controls designed to support the fish-community objectives for Lake Huron at an annual cost of about $8.6M (based on the fiscal year 2011 budget). Despite control efforts, abundance of spawning-phase sea lampreys, as measured by the current five-year average abundance of spawning-phase sea lampreys (154,000), continues to exceed the target (73,000). To achieve the target levels for sea lamprey abundance and marking on the fish community will clearly require the implementation of additional control actions.

Historical lampricide treatment and larval assessment data suggest that the most likely source of parasitic-phase sea lampreys in Lake Huron is the St. Marys River, but larvae surviving lampricide applications (residuals) in other streams also contribute to the problem. Analyses designed to forecast the effects of various treatment scenarios suggest that lakewide spawning-phase sea lamprey abundance can most reliably be affected through whole-lake selection of streams to treat for residuals, with heavy emphasis on the St. Marys River. These analyses have already been put into action in Lake Huron in the form of the large-scale North Channel treatment scenario that the GLFC committed to fund during 2010-2011. The level of success of this somewhat experimental treatment scenario will be analyzed using a variety of metrics, including lakewide spawning-phase abundance, larval and spawning-phase abundance estimates in the St. Marys River, and marking on fish in the North Channel. Other high-priority efforts to minimize spawning-phase sea lamprey abundance include the construction, maintenance, and repair of constructed sea lamprey barriers, maintenance of pre-existing barriers, and increased efficiency of sea lamprey trapping in the St. Marys River. Recommended strategies to reach targets within the next five years are listed below.

St. Marys River

Annual effort:	Treatment of the St. Marys River accounts for 6% of the lampricide control effort expended throughout the Great Lakes basin based on the average control expenditure during 2005-2009. In a typical year, $690K is spent on gB application in the St. Marys River, and $61K is spent to estimate the post-treatment larval population in the river and prioritize specific plots for treatment the following year. Additional control is achieved through trapping and the SMRT program. Trapping provides a mark-recapture estimate of spawning-phase sea lamprey abundance, male sea lampreys used in the SMRT program, and a modest amount of control by removing spawning-phase sea lampreys from the river prior to spawning. The annual cost to operate traps in the St. Marys River is $119K, and SMRT program-related sterilization and re-release of about 25,000 males costs $491K.
Strategy:	During 2010-2011, allocate 365 staff days to treat all known infested areas in the St. Marys River for two consecutive years. This effort is in association with increased lampricide control targeting sea lamprey producing streams in Lake Huron's North Channel. The total effort of 1,520 additional staff days targeting Huron's North Channel is projected to reduce sea lamprey spawners by an estimated 116,000 animals lakewide.
Additional cost:	~$2.1M to purchase gB in excess of the annual effort. The remainder of the treatment cost is absorbed by reallocation of staff from treatments elsewhere.
Strategy:	Use results from the QFC's updated St. Marys River decision analysis and results from the large-scale North Channel treatment initiative to evaluate the contribution of trapping, the SMRT program, and lampricide treatment to the integrated pest-management strategy in the St. Marys River.
Additional cost:	Dependent on the outcome of the decision analysis.

Lampricide Control

Annual effort:	Excluding the St. Marys River, Lake Huron accounts for 21% of the lampricide control effort expended throughout the Great Lakes basin based on the average control expenditure during 2005-2009. A base level of $3.1M will be spent on lampricide control in Lake Huron in 2011, excluding streams scheduled for treatment as part of the North Channel treatment strategy.
Strategy:	Beginning in 2010, allocate approximately 1,155 additional staff days of effort to treat infested streams in Lake Huron's North Channel. The large-scale treatment strategy includes all streams from the Spanish River west to the St. Marys River; streams on Manitoulin, Cockburn, and Drummond Islands; and tributaries in the western St. Marys River, Detour Passage, and St. Martin's Bay areas. All stream and gB plot treatments will be conducted in two consecutive years. Treatment effort in 2010 includes 80 gB plots and 35 liquid TFM stream treatments. A comparable level of effort is planned for 2011. This strategy is projected to reduce the residual population by 152% over a two-year period.
Additional cost:	Costs determined at the time this strategy was pursued included ~$1.7M and 1,155 staff days to conduct the treatments outside of the St. Marys River. These costs have been included in the base budget for fiscal year 2011.

This recommendation is based on the assumption that spawning-phase sea lampreys are a single population within Lake Huron, and this population derives from larval sea lampreys that survive lampricide applications, metamorphose, and migrate into the lake. It is also assumed that all sources of sea lamprey production have been accounted for, that production has been quantified correctly in relation to other streams, that sea lampreys randomly disperse throughout the lake, and that a reduction in the residual larval populations will have a commensurate effect on spawning-phase sea lamprey abundance and marking on lake trout and other important species in the fish community.

Larval Assessment

Annual effort:	Current assessment supports the among-stream prioritization and within-stream targeting of lampricide control activities, including evaluating treatment effectiveness, assessing the success of barriers, and detecting new infestations of sea lampreys. The average cost of larval assessment to support the current level of lampricide control in Lake Huron is $782K for 2011.
Strategy:	Ensure upstream and downstream limits of sea lamprey infestation are accurately determined for all streams included in the North Channel treatment strategy.
Additional cost:	Assessment in support of consecutive treatments on all North Channel streams will require ~$26K for additional distribution surveys.

Strategy:	Increase the frequency of surveys to detect new populations of sea lamprey larvae from once every ten years to once every five years in streams with suitable spawning and nursery habitats.
Additional cost:	~$32K each year. Increased assessment is designed to ensure that all sources of sea lampreys are known.

Adult Assessment

Annual effort:	Sea lampreys are currently trapped in 22 tributaries to Lake Huron. This effort provides mark-recapture estimates of spawning-phase sea lamprey abundance, male sea lampreys to the SMRT program, and a modest amount of control by removing spawning-phase sea lampreys from rivers prior to being able to spawn. The annual cost to operate all traps on Lake Huron tributaries (with the exception of the St. Marys River) and provide males from these streams to the SMRT program is $502K.
Strategy:	Increased trapping on Lake Huron tributaries exclusive of the St. Marys River is not expected to result in sufficient reduction in recruitment to impact lakewide spawning-phase sea lamprey abundance. Expenditures on increased lampricide control are more cost effective and result in more immediate reductions in the recruitment of parasitic-phase sea lampreys to Lake Huron.
Additional cost:	None at present.

Alternative Control—Barriers

Annual effort:	Maintenance of the current barrier network, both purpose-built sea lamprey barriers and pre-existing barriers, limits sea lamprey recruitment and helps to maintain current spawning-phase sea lamprey abundance. The cost of barrier inspection and maintenance is forecast to be $476K for Lake Huron in 2011.
Strategy:	By 2013, to maintain current control, in partnership with the OMNR, reconstruct Denny's Dam on the Saugeen River.
Additional cost:	The GLFC contribution to the Denny's Dam refurbishment is $800K.

Metrics of Success

Annual effort:	Stream-specific mark-recapture estimates of spawning-phase sea lamprey abundance are the foundation for a model that uses stream discharge, treatment history, and production potential to calculate regional and whole-lake population estimates. Along with marking rates on lake trout collected and assembled by state and tribal fisheries managers, these estimates are used to evaluate performance of the Five-Year Plan. Evaluation of model performance is an ongoing task that benefits lake-specific estimates across the Great Lakes basin. Alternative methods of estimating sea lamprey induced mortality are currently being investigated by the QFC at Michigan State University.
Strategy:	Re-assess and develop regional targets for spawning-phase sea lamprey abundance and integrate with a metric based on marking in the entire fish community. This strategy will result in a more precise estimation of spawning-phase sea lamprey abundance and, coupled with localized effects of host species abundance, enable better interpretation of lamprey control efforts at a scale smaller than the lake basin.
Additional cost:	$30K annually.
Strategy:	Maintain standardization of sea lamprey mark identification through periodic workshops at intervals of no more than five years.
Additional cost:	$4K every five years to sponsor workshops.

Maintaining Target Levels and the Judicious Use of Lampricides

Advancing alternative control technologies and techniques is critical to maintaining targets and applying lampricides in a judicious manner. Strategies, such as the application of pheromones to improve trap efficiency, are currently being evaluated, while others, such as incorporating traps into planned barriers, are closely associated with strategies yet to be implemented (i.e., barrier construction). Additional strategies, such as increasing trapping effectiveness, manual removal of spawning-phase sea lampreys, and development of improved methods to evaluate program success, rely on research designed to evaluate their potential. New alternative controls will help maintain the effect of sea lampreys at or below target levels throughout the Great Lakes. Estimated costs to advance these technologies and techniques are included in Chapter 7 (Summary), but actual costs will be determined by research related to these four general areas: application of pheromones, trapping techniques, methods to reduce recruitment, and sea lamprey/host interactions.

Research and Assessment Needs

Increased understanding of linkages between sea lamprey abundance, the control program, and fish-community responses requires input from other lake management agencies.

Further research into the stock-recruitment relationship in sea lampreys is also required. The correlation between larval sea lamprey abundance and spawning-phase sea lamprey abundance within a river is positive, but a comparison among Figs. 27 and 28 shows that there may also be some stream-specific effects that could account for variability in sea lamprey stock-recruitment models. Information regarding enhanced survival on specific streams could help direct the construction of new barriers and affect the methods used to prioritize streams for larval sea lamprey assessment and lampricide control.

Communication

See Appendix A for information about who to contact about the sea lamprey control program in Lake Huron.

CHAPTER 5: FIVE-YEAR PLAN FOR LAKE ERIE

Jeff Slade[7]

Introduction and History

The purpose of this chapter is to build on the general, basinwide discussion of sea lamprey (*Petromyzon marinus*) control outlined in Chapter 1 (Sea Lamprey Control in the Great Lakes Basin). The most recent synthesis of sea lamprey control in Lake Erie (Sullivan et al. 2003) was published in the Journal of Great Lakes Research in 2007 as a contribution to the Sea Lamprey International Symposium II. This paper is cited often in this plan and is a good document to review for those interested in additional information on sea lamprey control in Lake Erie. The Great Lakes Fishery Commission (GLFC), in collaboration with fisheries managers, has developed this lake-specific Five-Year Plan as an integrated sea lamprey control strategy that focuses on lakewide and locality-specific control tactics to maintain sea lamprey populations at or below target levels.

Sea lampreys have been present in Lake Erie since the early 1920s (Dymond 1922), but they were not considered a serious threat to the fish community until the late 1970s (Pearce et al. 1980). Limited prey and spawning and nursery habitat, along with unfavorable water quality due to pollution, combined to suppress abundance of sea lampreys. Environmental legislation (Ferreri et al. 1995) led to improvements in water quality and, together with stream habitat improvement and enhanced salmonid stocking (Pearce et al. 1980), conditions for expansion of sea lampreys improved rapidly.

Larval sea lamprey surveys during 1980-1986 revealed an expanding population (Johnson 1987) that was sufficiently large to inhibit lake trout (*Salvelinus namaycush*) restoration. As a result, a plan to control sea lampreys in Lake Erie was implemented in 1986. During 1986-1987, lampricides were applied to all tributaries to the lake with larval sea lamprey populations. Control efforts were enhanced by the construction or modification of low-head barriers on seven streams, eliminating the need for periodic treatments in Normandale, Forestville, and Clear Creeks, and, during most treatments, reducing the distance treated in Venison (tributary to Big Creek), Little Otter (tributary to Big Otter Creek), and Young's Creeks. Success of the

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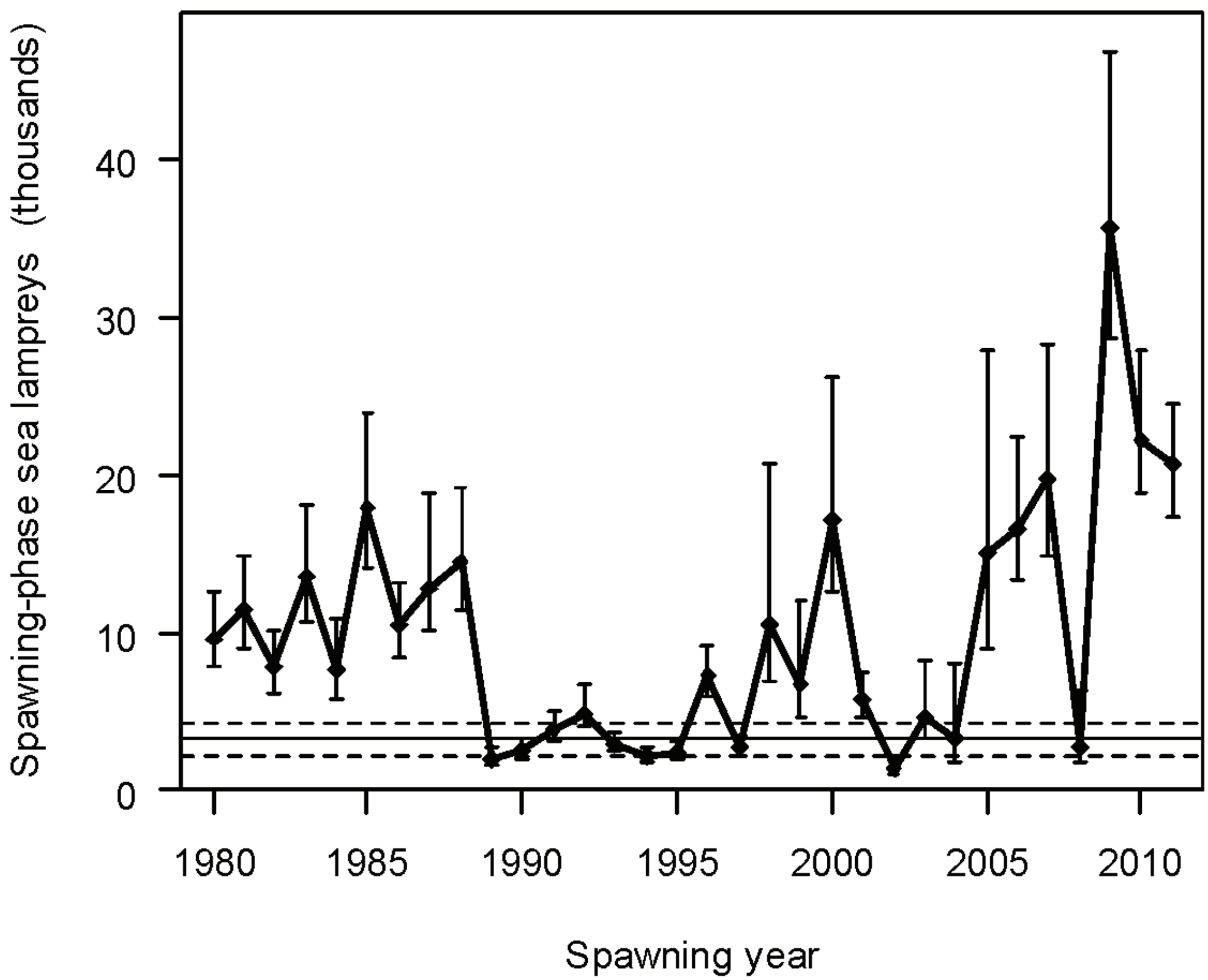
experimental barrier on Big Creek, which employs a series of seasonally operated, pneumatic crest gates, has been elusive because of technical problems that have plagued the barrier since its construction.

Following the first round of treatments during 1986-1987, sharp declines occurred in all indices of Lake Erie's sea lamprey population and, by the early 1990s, most of the objectives pertaining to reductions in sea lamprey abundance and lake trout mortality were achieved (Great Lakes Fishery Commission 1986; Fig. 36).

Fig. 36. Annual lakewide estimates of sea lamprey abundance (±95% confidence intervals) in Lake Erie during 1980-2010. The solid horizontal line represents the abundance target of 3,000 spawning-phase sea lampreys, and the dashed horizontal lines are the 95% confidence interval for the target.

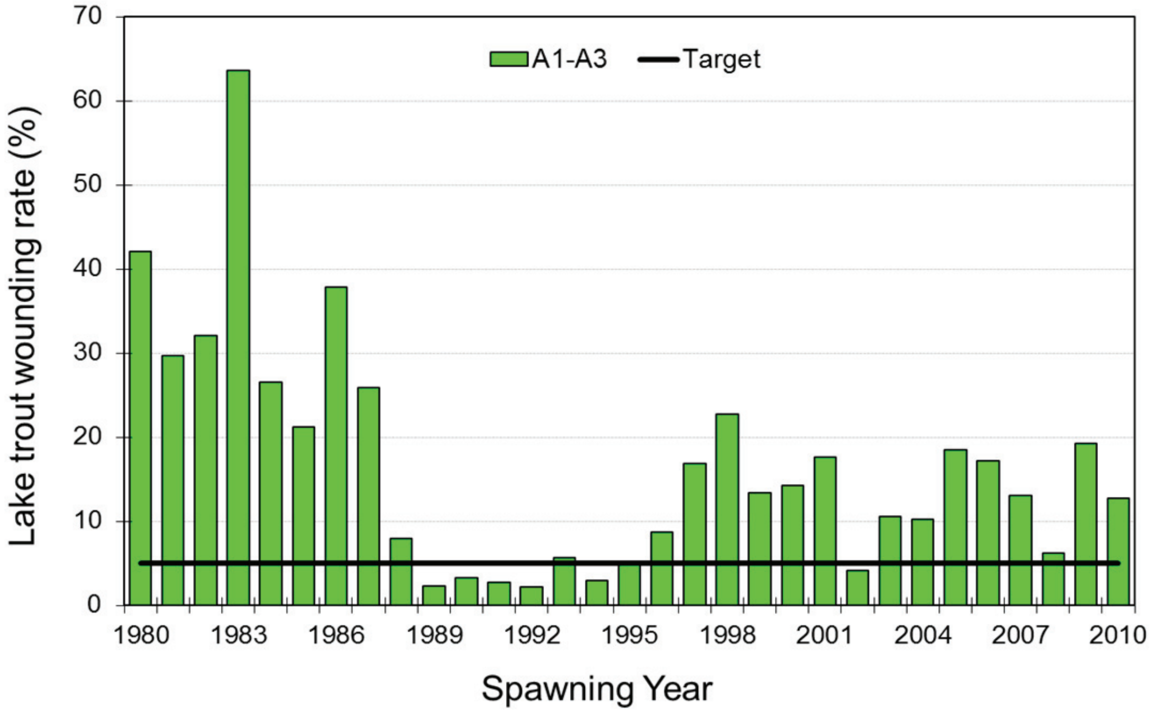


Beginning in 1998, spawning-phase sea lamprey abundance increased in Lake Erie, reaching pre-control levels by 2000 (Fig. 37). The increase in spawning-phase sea lamprey abundance was accompanied by an increase in lake trout marking rates (Fig. 37), sea lamprey nests in streams, number of infested streams, and, in some cases, in-stream distribution of larval sea lampreys. Reduced efficacy of the control program was likely due to a combination of factors, including new lampricide application techniques, implementation of new criteria for selecting streams for treatment, concerns about nontarget species, reduced number of post-treatment assessments and changes in the Lake Erie fish community (Sullivan et al. 2003). These factors combined with intentional efforts to reduce lampricide use (Brege et al. 2003) likely contributed to a greater number of residuals (sea lampreys that survive treatment) in the lake.

An increase in the number of streams treated during 1999-2002 was followed by a decline in spawning-phase sea lamprey abundance and lake trout marking. By 2005, however, spawning-phase sea lamprey abundance returned to pre-control levels and remained at these levels through 2007 (Fig. 36). Most major sea lamprey producing streams were treated during 2005-2006, and in 2008, abundance of spawning-phase sea lampreys declined sharply, likely because of the 2005-2006 treatments.

Concerned that residual sea lamprey populations jeopardized efforts to restore lake trout, the GLFC developed a large-scale treatment strategy specifically for Lake Erie. This strategy involved treating all sea lamprey producing tributaries in spring 2008 and fall 2009. The first round of treatments, conducted in the spring of 2008, included all nine tributaries to the main basin of Lake Erie known to contain larval sea lampreys. The second round of treatments, conducted in the fall of 2009, included the same tributaries and South Otter Creek, a stream found to contain larval sea lampreys in 2009. South Otter Creek was treated for a second time in 2010. The abundance of spawning-phase sea lampreys was the highest on record in 2009, and, although abundance declined in 2010, it was the second highest ever recorded (Fig. 36). The results of this large-scale treatment strategy are currently being evaluated and will not be complete until 2011 or later.

Fig. 37. Number of Type A, Stages I-III marks per 100 lake trout of total length 533 mm or larger caught during standardized assessments conducted on Lake Erie in August 1979-2009. Marks are plotted offset by one year. The horizontal line represents the target marking rate of 5 marks per 100 lake trout.



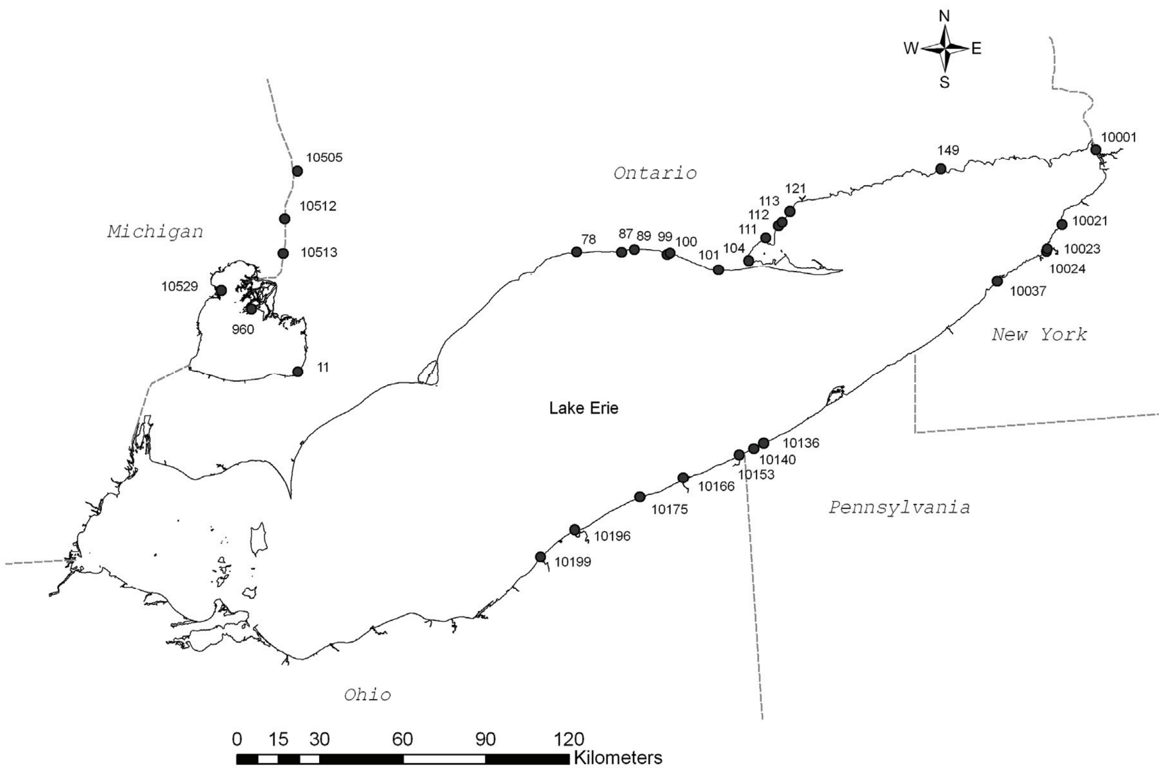
Features of the Lake

Lake Erie is the shallowest and southernmost Great Lake (Hartman 1972). The surface area of the lake is 25,690 km^2 (10,035 mi^2), which is the second smallest of the Great Lakes. Lake Erie has three basins: a western basin with a mean depth of 7.4 m (24.1 ft), a central basin with a mean depth of 18.5 m (60.1 ft), and an eastern basin with a mean depth of 24.4 m (79.3 ft) (Ryan et al. 2003). Lake Erie's primary source of water is from the upper Great Lakes by way of the Detroit River. The lake discharges into Lake Ontario through the Niagara River. In comparison to the upper Great Lakes, the area with cold, hypolimnetic water is relatively small, and, thus, cold-water fishes, such as lake trout, are particularly susceptible to increases in sea lamprey abundance.

Streams with a history of sea lamprey production are distributed primarily in Lake Erie's central and eastern basins and in the St. Clair River watershed (Fig. 38; Appendix B). Sullivan et al. (2003) reported that gradients in sea lamprey producing tributaries on the south shore of Lake Eire exceed those on the north shore by an average of 162% (range 22-426%). Differences in gradient influence water velocity and substrate particle size, which is demonstrated by the prevalence of bedrock, rubble, and gravel in south-shore streams and lack of good larval habitat. Lack of larval habitat in south-shore streams limits sea lamprey production (Morman et al. 1980). In contrast, substrates in north-shore streams are primarily sand, silt, and clay (Thomas

1963; Sullivan et al. 2003) with spawning gravel in the upper reaches (Morman et al. 1980). Quantitative measures of larval sea lamprey habitat (Slade et al. 2003) in three south-shore streams (Conneaut and Cattaraugus Creeks and the Grand River) revealed that the proportion of substrate suitable for larval burrowing averaged less than 21%. In contrast, the proportion of suitable substrate in two north-shore streams (Big and Big Otter Creeks) is 64%. The higher gradient and prevalence of bedrock in south-shore streams leads to rapid increases in discharge during rain events, creating challenges for successful lampricide application. Summer flows are often unfavorable for a successful treatment, which reduces the number of days a stream can be treated (i.e., treatment window).

Fig. 38. Geographic location and stream number for tributaries with records of larval sea lamprey infestation. Names of streams can be cross-referenced in Appendix B.



Excessive stream temperatures in summer and dams likely preclude recruitment of sea lampreys from many western basin tributaries (Sullivan et al. 2003). Although spawning-phase sea lampreys have been observed in several of these tributaries (Goodyear et al. 1982), larval sea lampreys are rare or have not been detected despite numerous surveys. The combined influence of stream temperature on spawning stream selection (Morman et al. 1980), hatching success (Piavis 1961), and survival of larvae (Potter and Beamish 1975) are likely the factors limiting recruitment from western-basin tributaries.

Lake temperature, particularly in the summer months, likely limits the distribution of parasitic sea lampreys and their primary salmonid hosts (Swink 1993; Coutant 1977) to Lake Erie's eastern basin and the eastern half of the central basin (Morman et al. 1980). Therefore, prior to spawning, most parasitic sea lampreys are feeding on hosts in the eastern half of the lake in relatively close proximity to preferred spawning and nursery streams (Fig. 38).

Although not unique to Lake Erie streams, some of the primary sea lamprey producing streams on the south shore have relatively low pH. In contrast, streams on the north shore, which mainly flow through agricultural land of low gradient, have relatively high pH, typically exceeding 8.0. As pH, conductivity, and alkalinity of water increase, greater concentrations of the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) are required to kill sea lamprey larvae (Bills et al. 2003). Therefore, in terms of the amount of TFM required to treat a given discharge, some Lake Erie streams on the south shore are less expensive to treat than streams on the north shore.

Unique Issues

Of the 842 tributaries to Lake Erie, only 22 have historical records of larval sea lamprey production, and 19 streams (11 in Canada and 8 in the United States) have larval populations that warranted lampricide application. From 1995-2007, estimates of larval sea lamprey numbers were generated for most sea lamprey infested Lake Erie tributaries by use of standardized techniques (Slade et al. 2003). These estimates were the product of the amount of larval habitat and larval density (Slade et al. 2003). The maximum estimated larval population in the streams ranges from <1,000 larvae to >200,000 larvae (Fig. 39; Appendix B). Sea lamprey spawning runs have been reported in 8 additional tributaries (Goodyear et al. 1982; Sullivan et al. 2003), but surveys found no evidence of larval production in these streams. Stream-specific estimates of maximum larval sea lamprey production do not always correspond to stream-specific estimates of spawning-phase sea lamprey abundance (Figs. 39, 40). The lack of correlation is likely influenced by the presence of barriers that block access to spawning and larval habitat on some streams and the fact that a small to moderate number of spawners can produce a large number of recruits (Jones et al. 2003).

Fig. 39. Maximum estimates of larval-phase sea lamprey abundance in Lake Erie tributaries during 1996-2008. Streams with the highest estimates that combine for more than half the Lake Erie total are identified by name. For reference, the maximum estimate of larval-phase sea lamprey abundance for Big Creek is 213,000. Estimates for all streams are listed in Appendix B.

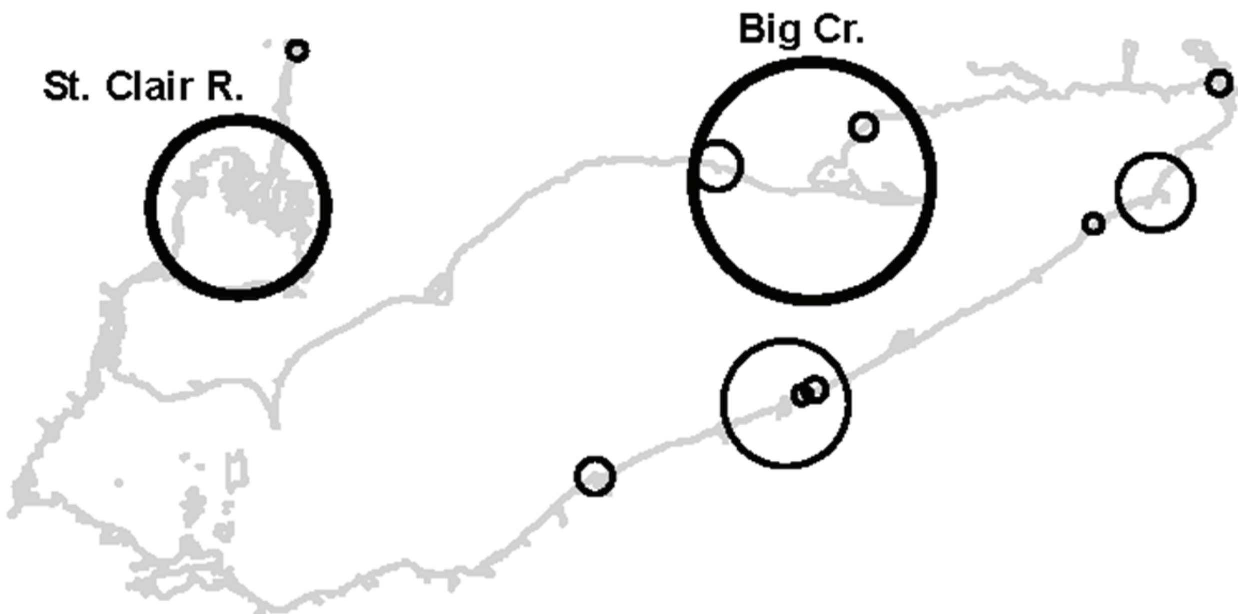
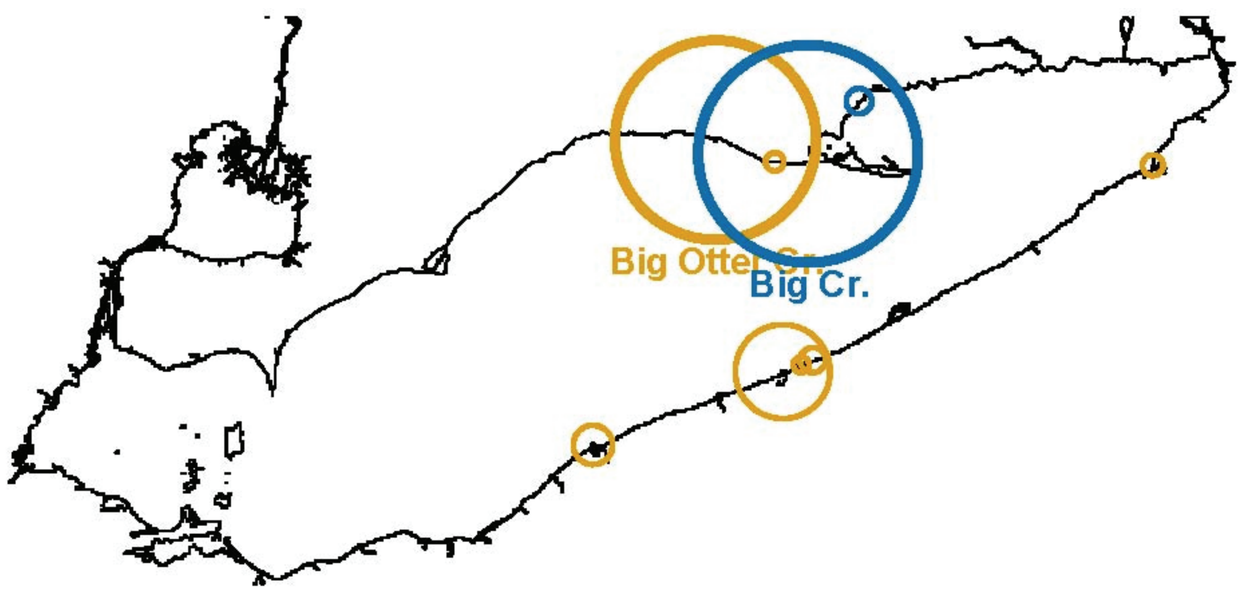


Fig. 40. Five-year-average stream-spawning-phase abundance estimates in Lake Erie during 2005-2009. Streams with the highest five-year average that combine for more than half the Lake Erie total are identified by name. Colors indicate whether the source of annual estimates was from mark-recapture (blue) or not (orange). For reference, the five-year average of spawning-phase sea lamprey abundance for Big Creek is 5,000. Estimates for all streams are listed in Appendix B.



Only three lentic areas have historical records of larval sea lamprey production (Grand River and, Conneaut Creek, Ohio and Cattaraugus Creek, New York), but, because of the low numbers of larvae collected, the populations in these areas are considered of little significance. Therefore, none of the lentic areas have been treated with lampricide. All three historically positive lentic areas were surveyed with granular Bayluscide (gB) during 2009, and only four larval sea lampreys were found off the mouth of Cattaraugus Creek, which indicates that this lentic area, although positive for sea lampreys, likely is a small contributor to the parasitic population.

Sea lamprey producing streams that are especially challenging to treat effectively with lampricides are listed in Table 16. Complicating factors that create challenges to effective control are the presence of sensitive species, high discharge from rain events, or low discharge in midsummer that reduce the treatment window; numerous refuge areas in backwaters, beaver impoundments, oxbows, and rivulets that require secondary lampricide applications (secondaries); and the dendritic and complex nature of some streams. Objectives and strategies to address these challenges are discussed later in this document. In addition, several streams have unique challenges. These streams and their specific challenges include:

- Big Creek: Despite relatively low densities of larval sea lampreys, the large amount of larval habitat in the main river is capable of holding a large number of larvae. Assessment of this stream is often difficult due to intense agricultural activities and a clay-based substrate that induces stream turbidity. The Quance Dam and Fishway in Delhi, Ontario, has effectively blocked spawning-phase sea lampreys since its reconstruction in the 1990s. The dam had been breached in the past, however, resulting in recruitment upstream to the Teeterville Dam and in a 40-km length of stream requiring treatment.
- Cattaraugus Creek: Portions of the main stream and the majority of Clear Creek flow through the Cattaraugus Indian Reservation and require tribal concurrence for treatment. Treatment of Clear Creek is often complicated by the presence of numerous beaver dams. Midsummer flows are often inadequate for successful treatment, and the gradient and geology in this watershed are such that rapid increases and decreases in discharge occur during rain events. The dam in Springville, New York, is currently an important barrier to sea lamprey migration.
- Conneaut Creek: Presence of the northern brook lamprey (*Ichthyomyzon fossor*), currently identified as endangered by the State of Pennsylvania, has precluded treatment of stream segments infested with sea lampreys. Midsummer flows are often inadequate for successful treatment, and the gradient and geology in this watershed are such that rapid increases and decreases in discharge occur during rain events.

Table 16. Summary of challenges to effective treatment in Lake Erie. Sensitive species and variable discharge limit the time period available for treatment.

Stream	Sensitive species	Discharge	Secondaries*	Dendritic	Access	Beaver dams	pH
Big Creek	Steelhead (*Oncorhynchus mykiss*)		X				
Cattaraugus Creek	Stonecat (*Noturus flavus*)	Low flow	X	X	X	X	X
	Steelhead						
Crooked Creek	Steelhead	Low flow				X	
Raccoon Creek	Steelhead	Low flow				X	
Conneaut Creek	Northern brook lamprey	Low flow	X	X			
	Mudpuppy (*Necturis maculosus*)						
	Stonecat						
	Walleye (*Sander vitreus*)						
Grand River	Mudpuppy	Low flow					
	Stonecat						
	Steelhead						

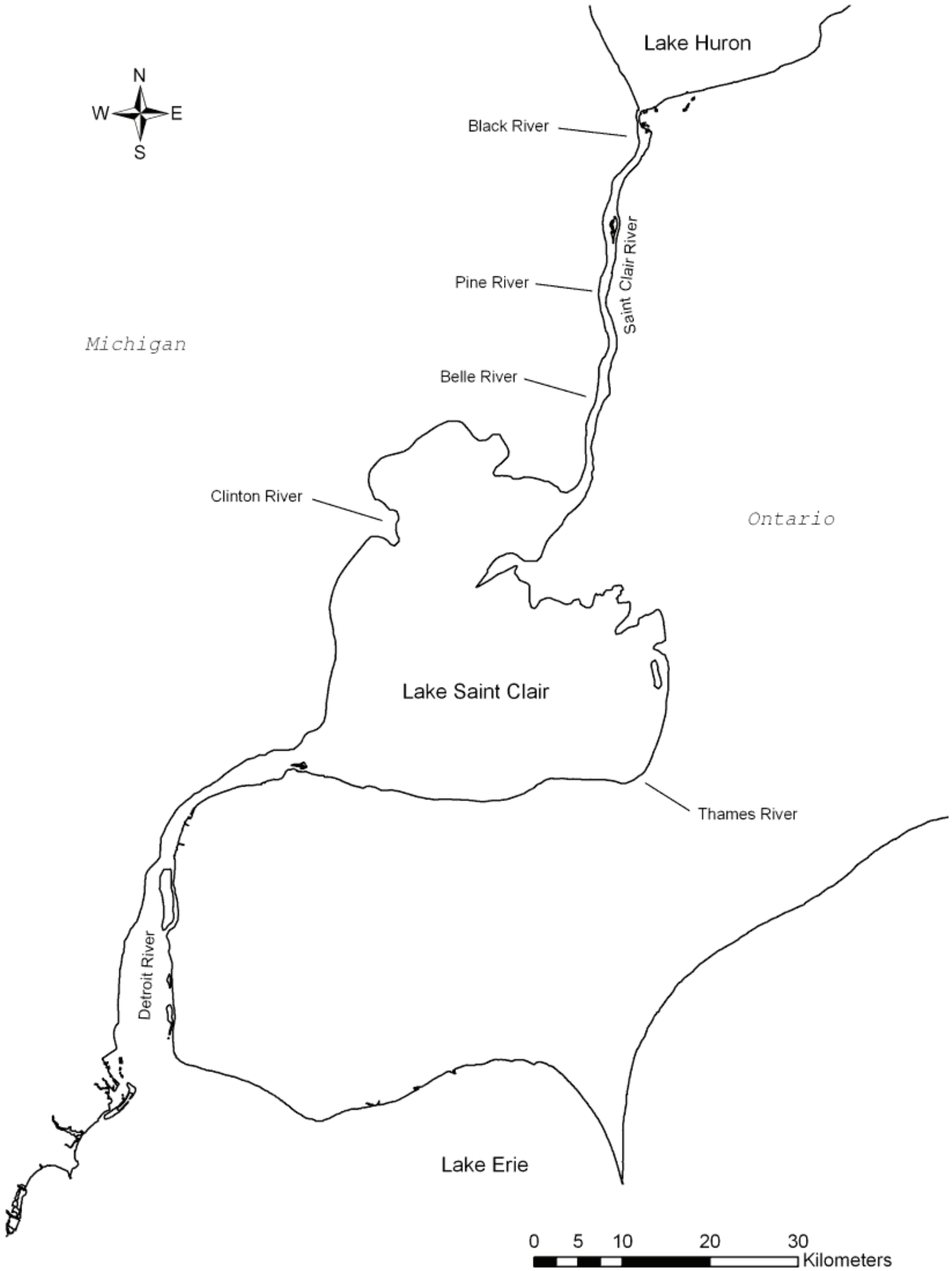
*Secondary lampricide treatments focus chemical application in areas of potential refuge such as backwaters, oxbows, or beaver dams. Treatment of these areas is labor intensive but improves treatment effectiveness.

Potential Sources of Parasitic-Phase Sea Lampreys

Parasitic sea lampreys in Lake Erie are animals that escaped a lethal dose of lampricide during treatment (residuals) and those from untreated or undetected populations. Sullivan et al. (2003) identified untreated streams or stream reaches and larvae residual to lampricide applications as large contributors to increases in spawning-phase abundance in the mid-to-late 1990s. These same factors were likely responsible for increases in spawning-phase abundance during 2004-2007. In streams with large larval populations, even a small percentage of residuals can contribute to a high abundance of transformers before the next treatment occurs in two or three years. Strategies to address both deferred treatments and residuals in productive streams are addressed later in this plan. Since 2000, efforts to identify new areas of sea lamprey production were intensified, and many tributaries known to be negative for sea lampreys were re-assessed. Despite these enhanced efforts, no new sea lamprey producing tributaries have been identified.

The St. Clair River, three of its tributaries (the Black, Pine, and Belle Rivers), and two tributaries to Lake St. Clair (the Clinton and Thames Rivers) have been positive for sea lampreys (Fig. 41; Appendix B). Except for the St. Clair River, recruitment of larval sea lampreys to these tributaries is intermittent and production is limited. Contribution of sea lampreys to Lake Erie from the St. Clair River, its tributaries, and tributaries to Lake St. Clair is unknown, but sea lamprey parasitism on host fish in Lake St. Clair has not been observed. Pollution and predation from teleost fishes in Lake St. Clair and the western basin of Lake Erie were hypothesized to impair survival of larval and parasitic-phase sea lampreys (Sullivan et al. 2003). However, for the first time since 1916, lake whitefish (*Coregonus clupeaformis)* reproduction has been documented in the Detroit River (Roseman et al. 2007), an indication of improved ecosystem health. Thus, contribution of parasitic sea lampreys to Lake Erie from the St. Clair and Detroit Rivers remains a concern.

Fig. 41. Location of tributaries to the St. Clair River and Lake St. Clair with records of sea lamprey infestation.


Lake Huron
N
W
E
S
Black River
Saint Clair River
Pine River
Michigan
Belle River
Clinton River
Ontario
Lake Saint Clair
Thames River
Detroit River
Lake Erie
0 5 10 20 30
Kilometers

Emigration from Lake Ontario through the Welland Canal is likely a minor contributor to the parasitic and spawning populations of sea lampreys in Lake Erie, and contributions from Lake Huron may have been about 4% of the mean annual lakewide abundance of spawning-phase sea lampreys from 1998-2001 (Sullivan et al. 2003). The assumption that immigration is only a minor factor is supported by surveys conducted at spawning-phase trapping sites on Big and Young's Creeks in 2009-2010. Beginning in 2005, thousands of sea lamprey larvae marked with coded wire tags were released into the Pine (tributary to the Nottawasaga River) and East Au Gres Rivers. These two Lake Huron tributaries were part of a larger study on the contribution of residual larvae to parasitic-phase populations (B. Swink, unpublished data). Recaptures were monitored in spawning-phase traps through 2010, and movement of sea lampreys between Lakes Michigan and Huron was demonstrated. However, an examination of 7,572 spawning-phase sea lampreys (3,883 in 2009 and 3,689 in 2010) captured in traps at Big and Young's Creeks produced no tagged animals.

Special Concerns

Protected Species

The Endangered Species Act and the National Environmental Policy Act require United States federal agencies to review the effects of their proposed actions and take steps to comply with laws governing endangered species and environmental protection. This requirement involves coordination with many state, tribal, and federal agencies and working with others to minimize risk to nontarget organisms. Protected species that may be affected by sea lamprey control activities are listed in Table 17, including their formal federal, state, or provincial designation.

Table 17. Protected species that may require sea lamprey control personnel to avoid certain areas and periods in Lake Erie. Formal federal, state, and provincial designations of species are denoted as E (endangered), T (threatened), and SC (special concern).

	Federal		**State/provincial**				
Species	**U.S.**	**Canada**	**MI**	**OH**	**PA**	**NY**	**ON**
Lake sturgeon (*Acipenser fulvescens*)			T	E	E	T	T
Northern madtom (*Noturus stigmosus*)		E					E
Northern brook lamprey		SC		E	E		SC
Rayed bean mussel (*Villosa fabalis*)	E	E	E	E	E	E	E
Snuffbox mussel (*Epioblasma triquetra*)*		E	E	E	E		E

*Species expected to be proposed for federal listing in the United States during 2010.

Protecting listed species during lampricide applications is a constant challenge to reaching target abundance of sea lampreys in Lake Erie. Reducing concentrations of lampricides increases the risk of larvae surviving, and failure to treat the entire infested area of a stream leaves larvae to recruit to the parasitic population. Both of these approaches have been used to protect sensitive species, and both approaches have likely been responsible for increases in parasitic populations (Sullivan et al. 2003).

Lake Sturgeon

Lake sturgeon (*Acipenser fulvescens*) are endangered in Ohio and Pennsylvania and threatened in Michigan, New York, and Ontario. Protective measures have not been recommended or implemented during lampricide applications. However, in United States waters of the St. Clair River, locations located immediately downstream from known lake sturgeon spawning areas have been removed from the sites historically sampled with gB for assessment purposes.

Northern Madtom

The northern madtom (*Noturus stigmosus*) is endangered in Canada and is present in the Thames, Detroit, and St. Clair Rivers. The three rivers have not been treated with lampricides, so no measures to protect this species have been recommended or implemented.

Brindled Madtom

The brindled madtom (*Noturus miurus*) is listed as threatened in Pennsylvania and is present in Conneaut Creek. Protective measures have not been recommended or implemented during lampricide applications.

Northern Brook Lamprey

The northern brook lamprey is endangered in Ohio and Pennsylvania, and efforts to avoid areas where they exist and still conduct effective lampricide treatments is an ongoing challenge. The northern brook lamprey has been listed in Canada under the federal Species at Risk Act as a species of special concern and is currently being considered for listing in the United States under the Superfund Amendments and Reauthorization Act. Larvae of northern brook lamprey are indistinguishable from larvae of silver lamprey (*Ichthyomyzon unicuspis*), which makes it difficult to document the distribution of northern brook lamprey and thus protect the species during lampricide applications.

Freshwater Mussels

Streams with larval-phase sea lampreys and the rayed bean mussel (*Villosa fabalis*) include the Thames, Black, Pine, Belle, and Clinton Rivers. The snuffbox mussel (*Epioblasma triquetra*) is also found in the Thames, Pine, and Grand Rivers (Fig. 38; Appendix B). Prior to treating these streams with lampricides, formal consultation with the U.S. Fish and Wildlife Service's (USFWS) Ecological Services branch is required. This involves the USFWS drafting of a biological assessment and biological opinion that serve as legal documentation of the review process for the proposed action (treatments) and its effect on the snuffbox mussel. During consultation, conservation measures are developed to avoid and protect the species and critical habitat.

Species of Special Interest

In addition to restrictions to protect formally listed species, permit stipulations in United States waters of Lake Erie have also included protection for the purple wartyback mussel (*Cyclonaias tuberculata*), mudpuppy (*Necturus maculosus*), and steelhead (*Oncorhynchus mykiss*). The purple wartyback mussel is not a protected species, but it is considered rare in Michigan (Detroit River). Permits require that activities affecting this species be planned for October or later to avoid the breeding season. The mudpuppy is not a state-listed species, but it is a species of special interest to the State of Ohio and is sensitive to TFM. Treatments in the Grand and Conneaut Rivers require coordination with personnel from the Ohio Department of Natural Resources Division of Wildlife and Division of Natural Areas and Preserves, Lake County Metro Parks, and the Cleveland Museum of Natural History. Steelhead are not particularly sensitive to TFM, however, to prevent compromising angler attitudes about steelhead fishing, the Pennsylvania Fish and Boat Commission (PFBC) restricted the date of lampricide applications to before opening day of trout fishing in 2006 and 2008 and no later than October 13 in 2009.

Timing and Discharge Restrictions

Although there is general support for sea lamprey control, lampricide applications have created some conflicts with other agencies and user groups resulting in limited treatment windows. For example, in 2009, the PFBC limited the period for lampricide applications to between September and October 13 to avoid conflict with anglers' fishing for steelhead.

Restrictions on minimum flows can also influence when or if a stream can be treated. For example, in 2009, the Ohio Environmental Protection Agency added provisions to their approval of lampricide applications that included a minimum discharge criterion for each stream. The minimum discharge criterion for Conneaut Creek was 100 cubic feet per second (cfs) at the Pennsylvania-Ohio state line, and the minimum discharge criterion for the Grand River was 200 cfs at the U.S. Geological Survey Painesville gauging site.

These types of restrictions can result in changes to treatment application dates, which narrows the window of treatment opportunity and increases the risk of less-effective lampricide applications and treatment deferrals.

Stream-Treatment Deferrals

Treatment deferrals typically occur when stream discharge is too high or too low for successful treatment. Low discharge often requires numerous application points that can be labor intensive and, thus, more expensive. In addition, portions of streams may be disconnected from the main stream channel and lampricide bank, which leaves areas untreated. High discharge can be costly because of the volume of lampricide required and can create unsafe working conditions. Because of their hydrological qualities (i.e., steep gradient and fast runoff), most south-shore tributaries have a very narrow window of opportunity for treatment and, thus, have a higher risk of being deferred for treatment than streams with more stable flow. Streams deferred for treatment until the following year pose a higher risk of recruiting parasitic animals to the lake, particularly if they contain larvae that are likely to metamorphose during the originally scheduled year of treatment.

Historically, only three Lake Erie tributaries have been deferred for treatment due to unsuitable flow. Crooked Creek was deferred once in 1995 due to low discharge and once in 1998 due to high discharge. Conneaut Creek was deferred for treatment once in 1999 due to low discharge. Cattaraugus Creek was deferred in May 2004 due to high flows but was treated in September 2004.

Pollution Abatement

Pollution-abatement initiatives can lead to improvements in water quality that result in more favorable conditions for sea lamprey infestation (Sullivan et al. 2003), potentially increasing the distribution and reproductive capacity of sea lampreys as well as program costs. Although the GLFC strongly supports efforts to improve water quality, continued coordination between fishery and sea lamprey managers regarding such initiatives, particularly in streams that do not currently harbor sea lampreys, is essential in managing abundances to target levels.

Barrier Removal

The Environmental Objectives Subcommittee of the Lake Erie Committee (LEC) identified improved access to spawning and nursery habitat in rivers for native and naturalized fish species as an environmental objective. Balancing the benefit of enhancing connectivity of tributaries to Lake Erie with the goals of managing sea lampreys are clear challenges for the future because enhancing spawning and nursery habitat for native fishes increases the risk of sea lamprey recruitment and survival. Current threats include the loss of Daniels Park Dam on the Chagrin River due to a flood, the proposed removal of Ballville Dam on the Sandusky River to enhance walleye (*Sander vitreus*) recruitment, the proposed removal of dams on the East Branch of Conneaut Creek to facilitate passage of steelhead, and the potential loss of Harpersfield Dam on the Grand River due to deterioration. Removal of these and other barriers requires increased monitoring for sea lamprey recruitment and increases the risk of expanded distribution and production of sea lampreys.

Recruitment from Other Sources

Many aquatic species, including sea lampreys, have benefited from the implementation of pollution abatement following signing of the Great Lakes Water Quality Agreement by Canada and the United States in 1972. In particular, efforts to restore watersheds and natural processes over the past four decades have reduced concentrations of toxic metals, chemicals, and pesticides in sediments of the four interconnecting waterways, including the St. Clair and Detroit Rivers, contributing to the establishment of larval sea lampreys in all but the Detroit River.

Recruitment of sea lampreys to Lake Erie from the St. Clair River system and Lake Huron, although thought to be minimal, remains a possibility. Further knowledge of the contribution of parasitic-phase sea lampreys from these sources will be necessary to quantify the magnitude of this potential contribution.

Fish-Community Interactions

The LEC identified sea lampreys as a naturalized pest species requiring effective control to support the fish-community objectives for Lake Erie (Ryan et al. 2003). For the eastern basin, one of the goals identified by the LEC is to secure a predominantly coldwater fish community in the deep, offshore waters with lake trout and burbot (*Lota lota*) as key predators and to restore lake trout to levels of historical abundance (Ryan et al. 2003).

Sea lamprey marking, abundance, and nest-count data as well as that on abundance of host species are assembled by the LEC's Coldwater Task Group. These data are used to evaluate and guide sea lamprey control actions and are the basis for discussion of ongoing sea lamprey and fishery-management actions that impact the Lake Erie fish community.

The primary hosts for sea lampreys in Lake Erie include lake trout, burbot, and lake whitefish. More recently, angler observations suggest that marking rates on steelhead may be increasing, an indication that steelhead may be another important host for sea lampreys. Sea lamprey marks are also observed on walleye, smallmouth bass (*Micropterus dolomieu*), and muskellunge (*Esox masquinongy*), indicating that important warmwater fishes are also impacted by high sea lamprey abundance. For each of the sea lamprey's three primary hosts, management agencies determine relative abundance and marking rate (number of Type A, Stages I-III marks per 100 fish) from standardized gillnet surveys conducted every August. Historically, marking rates have been greatest on adult lake trout, followed by burbot, and lake whitefish. However, the relation between host survival and marking rate is poorly understood owing to changes in sea lamprey and host abundance. Because sea lampreys do not require specific intermediate or terminal hosts, sea lamprey control affects and is affected by the entire fish community. Consequently, the effects of sea lamprey control are difficult to interpret when exclusively evaluated through traditional estimates of spawning-phase sea lamprey abundance and the marking rate on lean lake trout >532 mm. The full effects of sea lamprey control should be measured throughout the fish community and not restricted solely to lean lake trout. Strategies to address damage assessment are discussed later in this plan.

Public Use

Lake Erie tributaries support a wide variety of public use, particularly during warm summer months and on weekends, when water-related activities typically peak. Although there are no restrictions to swimming, boating, or fishing during lampricide applications, to minimize exposure to lampricides, the public is informed of scheduled treatments through news releases and personal contact with user groups. Treatment supervisors often adjust the timing of treatments to minimize overlap with peak use of a river by the public because treating tributaries during times of high public use can result in a negative perception of the sea lamprey control program. However, it is difficult to avoid peak use by all user groups. Water withdrawn by irrigators also complicates lampricide application because it can lead to decreased discharge and flow and, therefore, the public is asked to cease irrigation (there is no authority to halt irrigation) during treatments.

Fish-Community Objectives

The LEC's original fish-community objectives (Ryan et al. 2003) did not include a specific objective for sea lampreys but recognized that effective sea lamprey control is needed to support lake trout restoration goals in the eastern basin of Lake Erie:

> *Eastern basin – provide sustainable harvests of walleye, smallmouth bass, yellow perch, whitefish, rainbow smelt, lake trout, rainbow trout, and other salmonines; restore a self-sustaining population of lake trout to historical levels of abundance.*

Sea Lamprey Suppression Targets

The overall goal for sea lamprey control in this plan is to suppress sea lampreys to target levels of spawning-phase sea lamprey abundance and marking established by the LEC and to maintain these levels over time.

In support of the fish-community objectives, the LEC established explicit target levels of abundance for spawning-phase sea lampreys in 2004 (Markham et al. 2008). The target of 3,000 ±1,000 animals was based on the average abundance of spawning-phase sea lampreys during the five-year period from 1991 to 1995 when sea lampreys were inflicting less than 5% mortality on lake trout and <5 Type A, Stages I-III marks per 100 lake trout >532 mm total length (Fig. 37). The target number of marks per 100 lake trout was set at 5.

Compared to the other Great Lakes, the Lake Erie target for spawning-phase sea lamprey abundance is relatively low. Thus, minor fluctuations in control efficacy can lead to increases in the number of sea lamprey larvae that survive treatment and, subsequently, large increases in spawning-phase sea lamprey abundance in relation to the target. For instance, an increase in spawning-phase abundance of 3,000 animals is a 100% increase over target for Lake Erie but less than a 10% increase over target for Lake Superior. Therefore, variation in control efficacy can have a large impact on fish damage in Lake Erie.

The current target and desired lake trout marking rate are components of the LEC's plan to restore lake trout in Lake Erie (Markham et al. 2008). Because lake trout marking rates can be influenced by changes in abundance of lake trout as well as sea lampreys, measures of relative abundance of lake trout are also collected and used to interpret lake trout marking data rate.

The strategic plan for the rehabilitation of lake trout in eastern Lake Erie (Markham et al. 2008) prescribed a total annual mortality of less than 40% to permit the establishment and maintenance of suitable stocks of spawning adults. Mortality was to be controlled through the management of fishery exploitation and continued suppression of sea lampreys.

Objectives and Strategies within Program Components

Lampricide Control

Populations of sea lamprey larvae in streams are generally controlled through the application of the lampricide TFM. In the past decade, 39 tributaries on Lake Erie were treated with TFM, and, since 2007, an average of 7 tributaries were treated per year (Table 18). An average of 3 tributaries was treated annually between 1999 and 2006.

Table 18. Sea lamprey treatment information for Lake Erie during 1999-2009. TFM and Bayluscide are reported as kilograms of active ingredient used.

Year	Number of treatments	TFM (kg)	Stream length (km)	Bayluscide (kg)	Bayluscide area (m^2)
1999	4	3,140	128	30.5*	NA
2000	1	553	84	0	NA
2001	4	4,162	149	0.6**	1,062
2002	1	52	7	0	NA
2003	3	3,327	192	0.3**	5,44
2004	2	4,074	152	0.5**	881
2005	2	75	14	0	NA
2006	5	3,583	217	.6**	1,062
2007	2	3,624	171	1.2**	2,150
2008	9	10,372	419	1.3**	2,332
2009	10	9,811	471	32.7*	NA

*B73 wettable powder used on Cattaraugus Creek treatment (not granules).
**Granular Bayluscide used on secondary applications (not lentic).

Beginning in 2008, a large-scale treatment strategy was initiated in Lake Erie that entailed treating all nine sea lamprey producing tributaries to Lake Erie in spring 2008 and fall 2009. This strategy is based on the hypothesis that most parasitic sea lampreys originated from larval sea lampreys that survived treatments (residuals) or from larvae that were not subjected to lampricides because they were in untreated areas with sensitive species (Sullivan et al. 2003). Treatments in the spring of 2008 were implemented to kill the majority of stream-dwelling larval sea lampreys. Treatments in the fall of 2009 were implemented to kill the progeny of sea lampreys that spawned in 2008, the progeny of animals that spawned in 2009, and sea lamprey larvae residual to the 2008 treatment. The first round of treatments was completed on all nine sea lamprey producing streams in 2008. The same nine streams were treated again in the fall of 2009. This large-scale treatment strategy should reduce abundance of parasitic sea lampreys in 2008-2009 and spawning-phase sea lampreys in 2010-2011. In 2009, larval assessment surveys identified a tenth Lake Erie tributary that contained larval sea lampreys (South Otter Creek). This tributary was treated in September 2009 and again in August 2010.

Objective 1: By 2012, increase the proportion of sea lampreys killed by the lampricide control program (stream- and lentic-specific strategies).

Strategy: Review the treatment history of streams, identify streams where treatment effectiveness may be improved, and develop and implement strategies to treat more effectively, such as maintaining concentrations in excess of minimum lethal concentration for at least nine hours; increasing the duration of application by one-three hours; applying lampricide to backwaters, rivulets, and seepage areas that would otherwise remain untreated during the primary treatment and thereby provide refuge to larvae; treating at the optimal time of the year to ensure appropriate discharges; and treating in the spring when larval sea lamprey fitness is lowest (Scholefield et al. 2008). Candidate streams include the Big Otter, Big, South Otter, Conneaut, Crooked, Raccoon, and Cattaraugus Creeks and the Grand River. Develop an annual list of actions and review for completion annually.

Cost: Included in the current base program.

Strategy: Review the treatment history of streams and annually identify tributaries from the stream-treatment rank list where treatment effectiveness can be increased by inventorying geographic features and increasing effort to conduct secondary lampricide applications. Candidates include the Conneaut and Cattaraugus Creeks.

Cost: Included in the current base program.

Strategy: Coordinate with state, provincial, and tribal management agencies to address challenges to successful treatment, including the communication of risks, goals, and benefits of lampricide control to stakeholders; requirements to protect species at risk through formal biological assessments, evaluations, and opinions; and ensuring that the entire infested area of a stream is treated.

Cost: Included in the current base program.

Strategy: Negotiate with the Seneca Nation to conduct annual treatments on Clear Creek.

Cost: If desired and successful, annual treatment costs would increase by the cost to treat Clear Creek.

Strategy: Beginning in 2011, use nets to capture and remove larvae activated during treatments of tributaries to larger untreated systems and tributaries that enter a lake when sea lamprey larvae have been observed in the associated estuary. The candidate is Clear Creek (a tributary to Cattaraugus Creek).

Cost: Included in the current base program.

Strategy: When necessary, apply lampricides for 24 hours at lower than normal concentrations to compensate for large pH fluctuations and minimize nontarget mortality. The candidate is Cattaraugus Creek.

Cost: Included in the current base program.

Objective 2: By 2014, modify lakewide stream-treatment strategies to reduce transformer escapement (whole-lake strategies).

Strategy: Beginning in 2012, identify and treat, on a shorter rotation (i.e., treat every two years vs. every three years) at least two large sea lamprey producing streams so that fewer transformers escape if a treatment is deferred. Candidates include the Big, Conneaut, and Cattaraugus Creeks.

Cost: Increase in the cost based on streams selected for treatment.

Strategy: Treat all streams with a history of annual recruitment on a three-year cycle (i.e., do not rank, just set application points and treat).

Cost: Analyses are currently being conducted. Likely to be cost neutral.

Strategy: Treat all streams known to contain sea lamprey larvae >100 mm (i.e., do not rank on cost-to-kill ratio).

Cost: Likely to increase treatments variably based on annual results of larval assessments.

Strategy: Reduce contribution of sea lampreys from lentic areas and estuaries by treating any lentic area containing larvae >100 mm with gB.

Cost: Included in the current base program.

Larval Assessment

Assessment of larval sea lampreys is used to prioritize streams for treatment, determine where lampricides should be applied, evaluate the relative effectiveness of treatments, evaluate effectiveness of barriers, and detect new infestations. Standard protocols (Slade et al. 2003) are used for assessing larvae in Lake Erie. Annual assessment effort ranges from about 20 to 40 streams and lentic areas. Because of flash flows in south-shore tributaries and agricultural runoff in north-shore tributaries, electrofishing surveys are often compromised by high or turbid water. Historically, Lake Erie tributaries have not ranked high for treatment because of a lower cost-benefit ratio compared with infested tributaries to other Great Lakes.

Objective 1: By 2012, maximize the effectiveness of larval assessments to provide enough among-stream information to prioritize streams for lampricide application and sufficient within-stream information to effectively plan a lampricide application.

Strategy: Continue to use expert judgment (selecting streams based on prior knowledge of annual recruitment and treatment history) to prioritize streams with multiple years of recruitment for treatment. Allocate effort saved to post-treatment assessments within one year of treatment to determine residual abundance and the potential for re-treatment. Candidates include the Cattaraugus, Conneaut, Crooked, Big Otter, Big, and Young's Creeks and the Grand River.

Cost: Included in the current base program.

Strategy: Conduct detection surveys for new populations of sea lamprey larvae every 5+ years in streams with suitable spawning and nursery habitats, and conduct evaluation surveys every three years in previously infested streams.

Cost: Need to calculate the increase in rate of detection surveys. Evaluation surveys are in the current base program.

Strategy: Ensure upstream and downstream limits of sea lamprey infestation are accurately determined either the year prior to or the year of treatment for each stream scheduled for lampricide application.

Cost: Included in the current base program.

Strategy: Continue assessments of the St. Clair River every three years to monitor sea lamprey production, and, if required, rank areas for gB treatment.

Cost: Included in the current base program.

Objective 2: By 2015, prioritize and treat lentic and estuarine areas that regularly recruit larval sea lampreys.

Strategy: Continue to use RoxAnn© mapping to quantify substrates in lentic and estuarine areas. The highest priority is the St. Clair River.

Cost: Included in the current base program.

Strategy: Continue to assess at least two new potential lentic areas annually (e.g., Detroit River, Western Lake Erie, and lentic areas associated with new infestations of a river) until all areas are assessed.

Cost: Included in the current base program.

Strategy: Revisit known infested lentic areas every two to three years to determine the need for treatment.

Cost: Included in the current base program.

Objective 3: By 2013, maximize the implementation of alternative methods to prioritize streams and lentic areas for lampricide application.

Strategy: Develop additional criteria to prioritize streams for treatment based on expanded EJ criteria or other non-ranking survey data in hand. Candidates include the South Otter, Raccoon, and Crooked Creeks.

Cost: Included in the current base program.

Strategy: By 2011, have the Assessment Task Force evaluate the potential to treat streams or lentic areas on a fixed cycle from the maximum historical points of infestation.

Cost: Currently being investigated. Savings may be used to conduct additional post-treatment surveys.

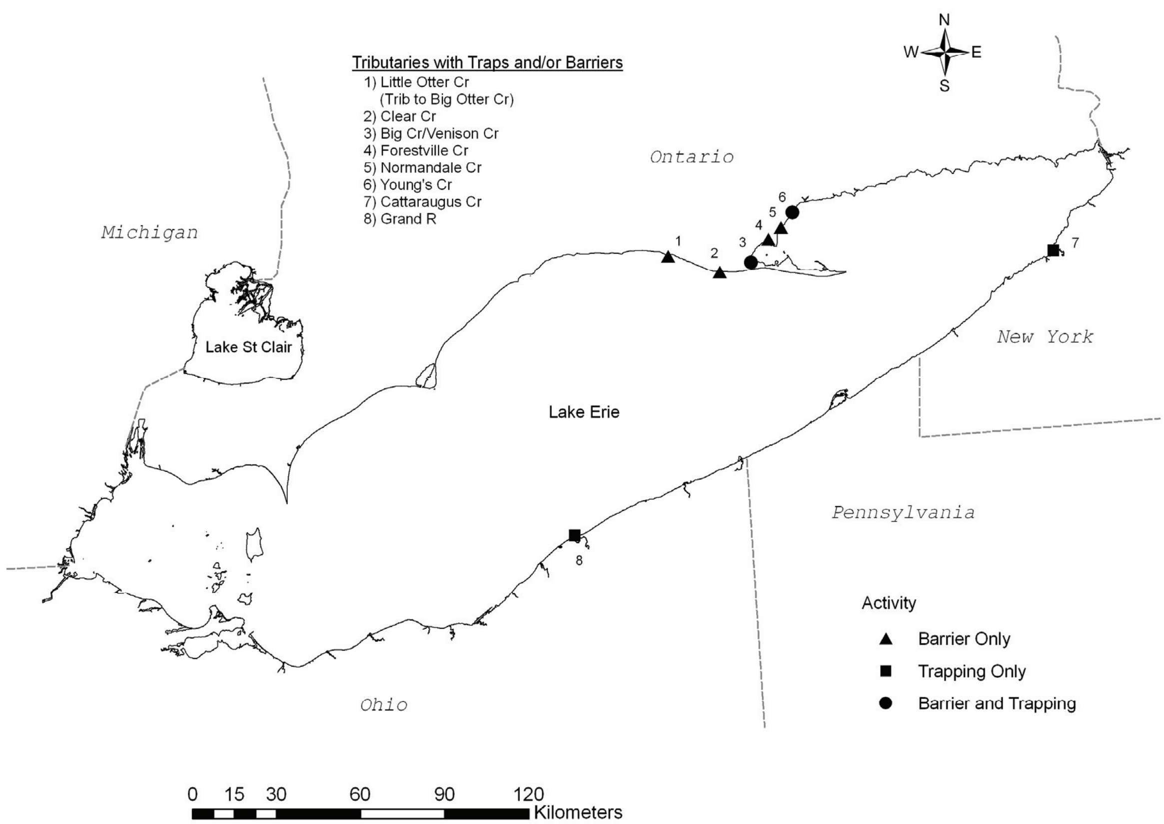
Trapping

Trapping of sea lampreys in the Great Lakes is used for assessment and control and occurs during spawning-phase and metamorphosing life stages. Based on life stage and purpose, trapping activities are described below.

Spawning-Phase Assessment

Spawning-phase sea lampreys are currently trapped in four Lake Erie tributaries (Fig. 42). Total annual catch has averaged 1,169 sea lampreys since 1999, and all of the animals were captured for assessment purposes.

Fig. 42. Locations of Lake Erie tributaries with barriers to and/or traps for spawning-phase sea lampreys.



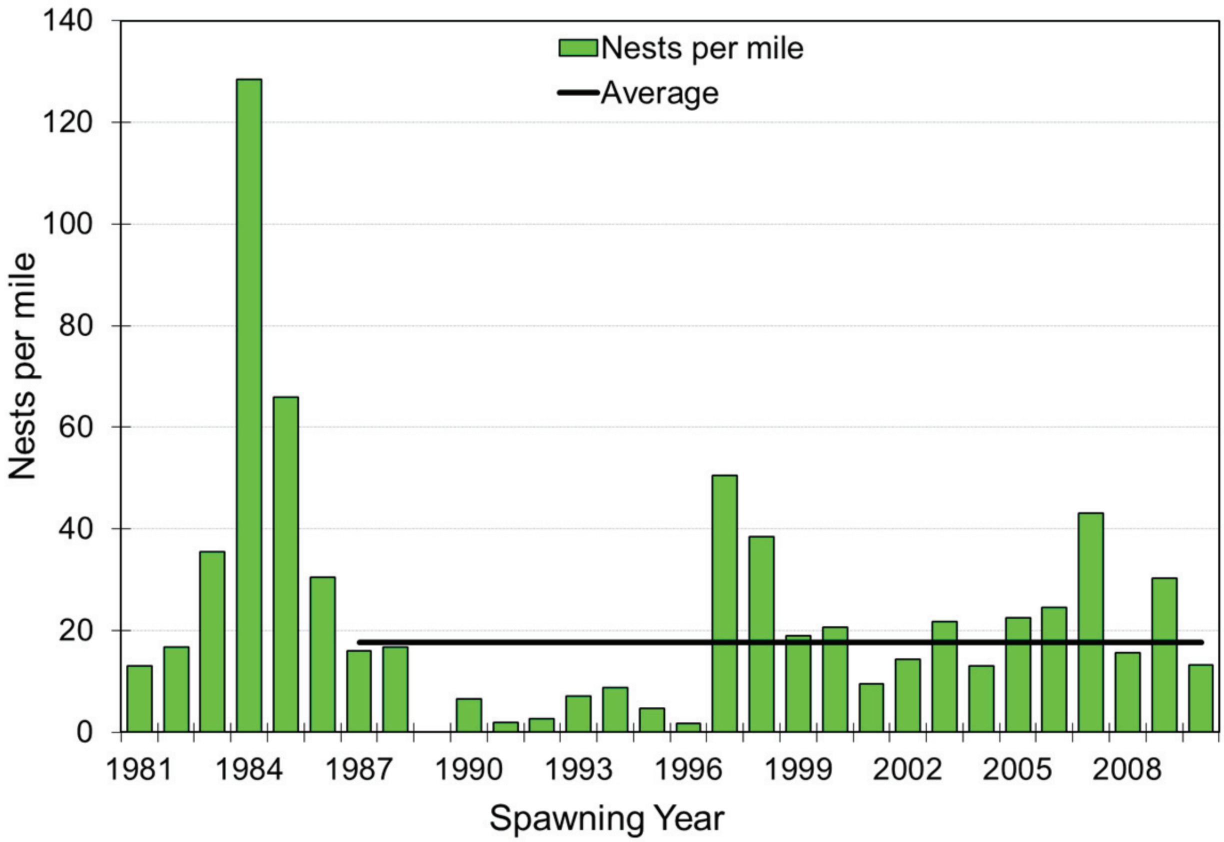
A review of the spawning-phase assessment program was conducted in 1997 (Bence et al. 1997). Recommendations to improve the stream-based estimates of spawning-phase sea lamprey abundance overwhelmingly favored development of methods to sample tributaries that contained the largest sea lamprey runs. Although three of the largest sea lamprey producing tributaries to Lake Erie are trapped (Big and Cattaraugus Creeks, Grand River), average precision around estimates of spawning-phase sea lamprey abundance over the past five years has been the lowest (44%) and most variable for any of the Great Lakes. Measures of precision are likely influenced by the low number of streams trapped throughout the basin and the fact that only one to three streams annually contribute to the lakewide estimate. The trapping operation on Cattaraugus Creek makes a major contribution to the lakewide estimate of spawning-phase sea lampreys and increases the precision of the estimate (J.V. Adams, U.S. Geological Survey, personal communication, 2010). However, the trapping operation was compromised when the powerhouse at the trap site was permanently shut down. A new permanent trap is currently being investigated at the Springville Dam. The trap would incorporate attractant flow routed through the powerhouse upstream of the dam. In the last decade, catches of spawning-phase sea lampreys in Big Creek have increased to the extent that, in 2009, they made up over 75% of the total Lake Erie catch.

An evaluation is under way of factors that influence precision and accuracy of the model used to estimate abundance of spawning-phase sea lampreys (Mullet et al. 2003). Results of the evaluation should provide ways to improve the accuracy and precision of estimates of spawning-phase sea lampreys abundance for each of the Great Lakes.

Nest Counts

Sea lamprey nest counts have been conducted annually on four Lake Erie tributaries in New York since 1981 by the New York State Department of Environmental Conservation (NYSDEC). Trends in nest counts agree with trends in sea lamprey marking rates and are thus important as a confirmation of the trends in sea lamprey abundance in Lake Erie. The majority of the nest counts are conducted on Clear Creek, a tributary to Cattaraugus Creek, and a major sea lamprey producing creek in the Lake Erie drainage. However, nest counts are also conducted on sections of the north branch of Clear Creek, Delaware Creek, and Canadaway Creek. Sea lamprey nest density declined to less than 10.0 nests per mile following the initial stream treatments in 1986-1987 and remained at these densities until 1997 (Fig. 43). Average nest density during this time was 5.0 nests per mile. In 1997, nest densities increased sharply to over 50.0 nests per mile and, with the exception of 2001, they have remained well above the 1990-1996 levels and near those found during the pre-treatment era. In 2010, nest densities dropped to 13.3 nests per mile, the lowest since 2004. The majority of sea lamprey nests found in this survey are in Clear Creek (Einhouse et al. 2009; Coldwater Task Group 2011).

Fig. 43. Sea lamprey nest density (nests per mile) in standard sections of New York tributaries to Lake Erie during 1981-2010. Nests were not counted in 1989. The solid horizontal line represents the post-treatment (1987-2008) average nest density of 17.7 nests per mile (Einhouse et al. 2009; Coldwater Task Group 2011).



Objective 1:	By 2015, determine the optimum level (suite of streams, size of streams, geographic coverage) of trapping needed to estimate lakewide abundance of spawning-phase sea lampreys with a precision of ±20%.
Strategy:	By 2012, evaluate factors that will improve the accuracy and precision of annual estimates of spawning-phase sea lamprey abundance. Use this information to determine if improvements are necessary and, if so, identify and recommend those actions that will improve accuracy and precision to the desired levels.
Cost:	Included in the current base program.
Strategy:	By 2013, based on previous analyses, recommend an optimum suite of streams to be trapped to estimate lakewide abundance of spawning-phase sea lampreys.
Cost:	Included in the current base program. Streams to be identified after analyses.

Objective 2: Investigate innovative trap designs and other techniques and technologies that could be used to estimate abundance of spawning-phase sea lampreys, especially in large rivers and streams without barriers and, if feasible, implement at least one new method by 2015.

Strategy: By 2012, identify potential alternative technologies and techniques that might be evaluated.

Cost: Included in the current base program.

Strategy: By 2012, develop a list of rivers where alternate methods can be evaluated and correlated with mark-recapture estimates of spawning-phase sea lamprey abundance.

Cost: Included in the current base program.

Strategy: By 2014, determine the ability of DIDSON™ camera technology to estimate the spawning-phase sea lampreys run in one or more rivers.

Cost: $80K for DIDSON™ + $20K per stream for operations.

Strategy: By 2013, develop methods to correlate nest counts with estimates of spawning-phase sea lamprey abundance and determine the usefulness of nest counts for providing estimates of spawning-phase abundance.

Cost: Included in the current base program.

Strategy: By 2014, based on the correlation of spawning-phase abundance with nest counts (Lake Erie data), develop a list of streams where nest counts may be an effective assessment tool and implement nest counts in at least one stream by 2015.

Cost: Included in the current base program.

Strategy: By 2015, evaluate the ability of pheromone and eDNA assays to quantify spawning-phase sea lamprey abundance in rivers.

Cost: Included in the current base program.

Metamorphosing Assessment

Lakewide mark-recapture studies designed to estimate abundance of metamorphosing sea lampreys have been conducted in the upper Great Lakes but not in Lake Erie. Results of studies in the upper Great Lakes suggest that mortality in the two years between the time of release and recapture may be as high as 80% (Sullivan and Adair 2010). Implementation of such a study in Lake Erie would require the capture, tagging, and release of metamorphosing sea lampreys and recapture of spawning-phase animals in assessment traps. Due to the limited spawning-phase trap network, the difficulty of collecting metamorphosing sea lampreys, and the relatively low target abundance for spawning-phase sea lampreys, these studies have not been recommended for Lake Erie.

Spawning-Phase Control

Trapping for control is primarily used on the St. Marys River to limit larval sea lamprey recruitment through the removal of spawning-phase sea lampreys. Spawners trapped in Lake Erie tributaries that are not used for mark-recapture are euthanized and discarded, likely reducing recruitment.

Trapping spawning-phase sea lampreys for control is optimized when trap placement and trap retention results in a sufficient proportion of the run being captured to reduce spawner densities to <0.2 spawning pairs per 100 m^2 of larval habitat (Dawson 2007). Trapping efficiencies to affect control are usually higher than those necessary for assessment.

Objective 1:	By 2015, increase the proportion of the spawning run that is captured in traps by 20%.
Strategy:	By 2015, increase annual effectiveness of traps to at least 25% of the estimated spawning run or 20% more than the 2006-2010 average catch in at least two of the four streams currently trapped through trap design improvements and large-scale application of pheromones. Candidates include the Big, Young's, and Cattaraugus Creeks and the Grand River.
Cost:	Need to select the streams and determine cost.
Strategy:	By 2020, incorporate permanent or semi-permanent traps into present or planned barriers. The candidate includes the Cattaraugus Creek.
Cost:	Needs to be determined pending site identification.
Strategy:	Investigate and implement novel technologies and techniques to capture more sea lampreys. Candidates include the Conneaut, Big Otter, and South Otter Creeks; Huron River (Michigan); and offshore of Conneaut, Big Otter, and South Otter Creeks.
Cost:	Needs to be identified.

Objective 2:	By 2015, develop a trap control strategy where spawning-phase sea lamprey populations have been reduced through regional or lakewide control efforts or are not currently being trapped.
Strategy:	Evaluate the ability to maintain low recruitment to the larval-phase by trapping low-abundance spawning runs with a combination of traditional and novel traps, manual removal, and nest destruction.
Cost:	Develop a technical assistance proposal to address where and how to implement this strategy.
Strategy:	Evaluate the feasibility of using trapnets to capture spawning-phase sea lampreys before they enter the stream. Candidates include locations in Lake Erie offshore of Conneaut, Big Otter, and South Otter Creeks.
Cost:	Approximately $10K to contract with commercial fisher.

Metamorphosing Control

An alternative application of trapping for population control is the capture of out-migrating, newly metamorphosed sea lampreys in fall and early spring, which reduces the recruitment of sea lampreys to the parasitic population in the lake. Trapping out-migrants has been implemented to capture transformers for mark-recapture studies, provide transformers for research, and monitor the effect of sea lamprey control in the St. Marys River. More recently, trapping was used to reduce recruitment from tributaries where metamorphosed sea lampreys were likely to be out-migrating in large numbers. Results of these efforts have met with variable success and are typically labor intensive, but, under certain circumstances, such as mitigating for a deferred or delayed lampricide treatment, they have proven to be effective.

This method of control has not been attempted on Lake Erie tributaries but, in specific instances, may be a cost-effective method of control.

Objective 1:	By 2013, reduce recruitment by capturing newly metamorphosed sea lampreys during their downstream migration to the lake.
Strategy:	By 2011, develop criteria for stream selection and gear placement to capture out-migrating sea lampreys.
Cost:	Included in the base program.
Strategy:	By 2012, capture out-migrating sea lampreys from streams where large numbers of metamorphosing-phase sea lampreys are known or suspected. Candidates include the Big, Cattaraugus, and Conneaut Creeks and the Grand River.
Cost:	Purchase ($27K) and operate ($22K) screw traps. Purchase ($10K) and operate ($22K) fykenets.

Alternative Control

Techniques other than traditional lampricide applications to control sea lamprey populations are considered alternative control methods. Alternative control methods (in addition to trapping for control) currently being implemented are the sterile-male release technique (SMRT) program and barriers. Application of pheromones and the sterile-female release technique are currently being evaluated in the upper Great Lakes. Migrations of spawning-phase sea lampreys into Lake Erie tributaries typically occur earlier than on the upper Great Lakes, and the logistics of transporting, sterilizing, and releasing sterile males preclude implementation of the SMRT program in Lake Erie tributaries. Therefore, this alternative control is currently not available for Lake Erie. Other potential alternative controls currently being researched include genetic manipulation, agonists and antagonists for chemical cues, manual destruction of sea lamprey nests, and repellents.

Pheromones

Pheromones are a promising new technique in the integrated control of sea lampreys (Li et al. 2007). Field trials involving the release of a component (3kPZS) of sea lamprey pheromone to attract migrating sea lampreys to traps were conducted in 2009 and 2010. Preliminary results indicate more sea lampreys can be attracted to a pheromone baited trap than to an un-baited trap, and application of the mating pheromone increases trap efficiency (Johnson and Li 2010). A detailed plan to implement pheromones in control applications will be developed after the ability to manipulate sea lamprey migratory behavior through *in situ* pheromone application is better understood.

Objective 1: By 2013, develop a lakewide integrated pheromone plan.

Strategy: Continue researcher and agent coordination and implementation of pheromone field studies to build expertise in pheromone handling, deployment, and application.

Cost: To be determined.

Strategy: As efficacy of various pheromone compounds is demonstrated, evaluate proposed strategies for their integration with other control techniques and implement at least one such strategy by 2013.

Cost: To be determined.

Strategy: Register pheromone compounds or secure experimental permits for their use to ensure the ability to implement new pheromone methodologies as they become available.

Cost: To be determined.

Barriers

Low-head barriers have been constructed on seven Lake Erie tributaries specifically for the purpose of blocking sea lampreys (Fig. 42; Table 19), and they have reduced or eliminated larval sea lampreys in each of the seven streams. In addition, existing dams on several other streams, including the Grand River (Ohio) and Cattaraugus Creek (New York), block access to large areas of suitable spawning and nursery habitat (Sullivan et al. 2003). As of 2009, 350 barriers in the United States were inventoried in the Lake Erie basin, and their importance to sea lamprey control is currently being assessed.

Table 19. Location, date of construction, and distance upstream for sea lamprey barriers built exclusively to block lamprey migrations on Lake Erie tributaries. Numbers correspond to those in Fig. 42.

Number	**Stream**	**Date of construction**	**Distance from stream mouth (km)**	**Notes**
1	Little Otter Creek	1990	24.00	Low-head dam
2	Clear Creek	1989	0.79	Low-head dam
3	Big Creek	1995	23.94	Inflatable low-head dam
4	Venison Creek	1995	10.30	Low-head dam
5	Forestville Creek	1988	0.51	Low-head dam
6	Normandale Creek	1988	0.10	Low-head dam rebuilt in 2010
7	Young’s Creek	1976	0.40	Stop log

Barrier removal is planned for the Ballville Dam on the Sandusky River, Ohio; a fish passage or dam removal is being considered for the barrier in Springville on Cattaraugus Creek, New York; and reconstruction and other options are being explored for the Harpersfield Dam on the Grand River, Ohio. Miles of suitable sea lamprey spawning and rearing habitat are upstream of the barriers on the Grand River and Cattaraugus Creek, and, although historic data suggest that removal of the Ballville Dam is unlikely to increase sea lamprey abundance, the increased habitat available for sea lampreys remains a concern.

Objective 1: Maintain the ability of the seven purpose-built sea lamprey barriers to block migrating spawning-phase sea lampreys.

Strategy: Conduct larval assessments upstream of barriers consistent with a stream’s treatment cycle to ensure that sea lampreys have not breeched the barrier.

Cost: Included in the current base program.

Strategy: Conduct annual inspections and repair or replace worn, broken, or missing parts before they affect barrier performance.

Cost: Included in the current base program.

Strategy: Evaluate and fix barriers that fail to block spawning-phase sea lampreys consistent with their design objectives. The candidate includes the inflatable barrier on Big Creek.

Cost: Need to develop an estimate for Big Creek. Monitoring is included in the current base program.

Objective 2: Annually investigate areas where purpose-built barriers can be constructed consistent with the Barrier Strategy and Implementation Plan.

Strategy: Meet with the U.S. Army Corps of Engineers semi-annually to discuss funding, research, and expertise to design, plan, and fund barriers in the United States. Work with the Ontario Ministry of Natural Resources (OMNR) to develop suitable plans for the Big Otter River by 2011.

Cost: May be dependent on the stream identified.

Strategy: Develop partnerships with others to obtain funding and support for barrier projects.

Cost: Variable, dependent on the stream.

Strategy: By 2013, develop a new process for selecting and ranking proposed sites for barriers.

Cost: Included in the current base program.

Objective 3: Ensure spawning-phase sea lampreys remain blocked at important non-purpose-built barriers.

Strategy: By 2012, include non-purpose-built barriers in the barrier database and, by 2013, develop a ranking method to prioritize their importance to sea lamprey control with condition and future maintenance issues noted. Ongoing projects in Cattaraugus Creek (Springville Dam) and the Grand River (Harpersfield Dam) are currently being addressed.

Cost: Included in the current base program (unless a programmer is needed for GIS or database applications).

Strategy: By 2013, develop a policy to work with partners to preserve the integrity of the furthest downstream barriers that currently block sea lampreys.

Cost: May be included in the current base program.

Strategy: By 2014, use the barrier database to develop a list of structures that currently do not block sea lampreys but have the potential to be converted to blocking structures and pursue their modification through the ranking process.

Cost: Included in the current base program.

Strategy: By 2012, establish a review process with state, provincial, tribal, conservation authorities, and First Nations regulators to notify sea lamprey control managers of in-stream fish passage or dam removal projects before permits are granted.

Cost: Included in the current base program.

Strategy: Update the GLFC website to include a barrier map and/or list of inventoried barriers, contact list for barrier removals, and concurrence request form.

Cost: Included in the current base program.

Strategy: By 2013, develop a ranked list of barrier repair and rebuild projects.

Cost: Included in the current base program.

Strategy: By 2011, complete an assessment of the structural integrity of the Grand River (United States) barrier.

Cost: Included in the current base program.

Objective 4: Integrate barriers with other methods of control to effectively manage sea lampreys.

Strategy: Identify potential sites where barriers, in combination with alternative methods, can contribute to effective control or suppression. Candidates include the Huron River, Michigan.

Cost: Identify alternative control methods and estimate additional cost.

Other Methods of Alternative Control

If proven effective, other methods of alternative control that could be implemented include nest destruction and manual removal of spawning-phase sea lampreys from spawning areas. Both techniques are designed to reduce recruitment. A reduction in larval abundance could extend the time between treatments or result in fewer residual larvae following treatments.

Objective 1:	Reduce larval recruitment in streams via alternate methods.
Strategy:	Measure the effectiveness of nest destruction and manual removal of spawning-phase sea lampreys through the development of a technical assistance proposal to the Sea Lamprey Research Board and implement nest destruction and manual removal on two tributaries with a history of regular recruitment and treatment. Candidates include the Clear and Young's Creeks.
Cost:	$20K/stream. Includes labor and travel.

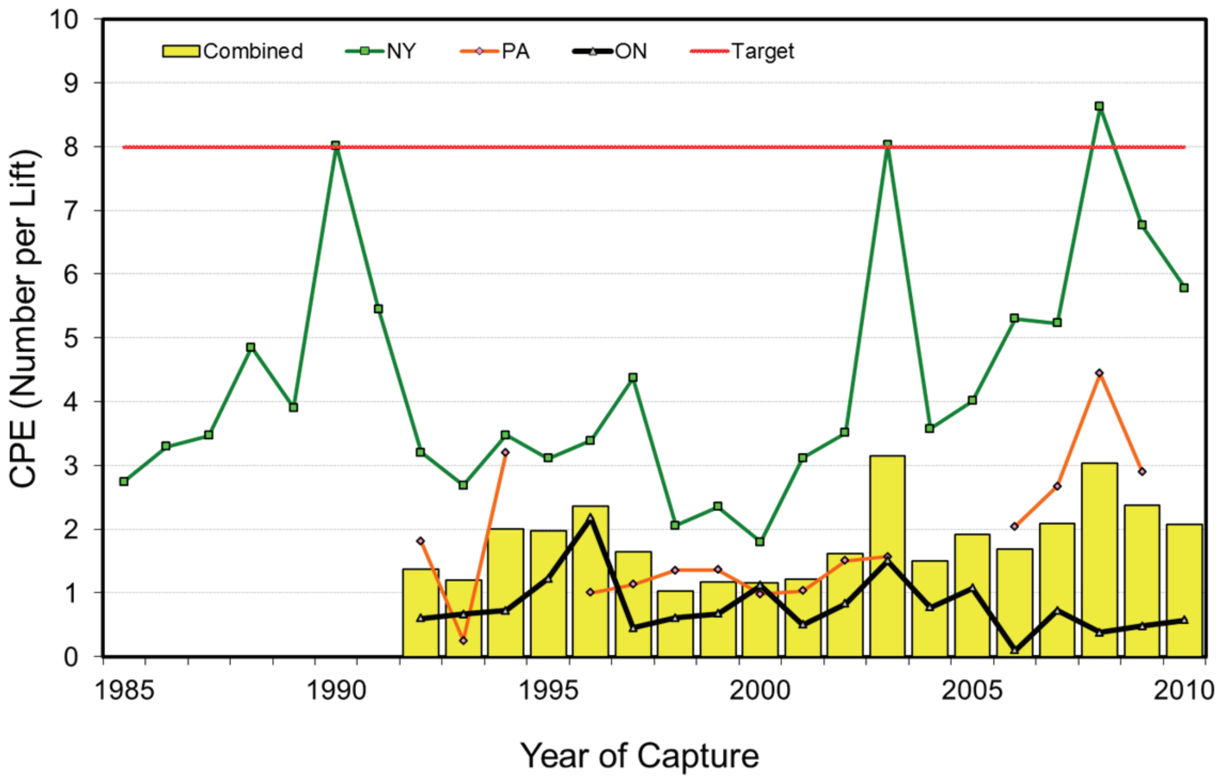
Metrics and Measures of Success

Current metrics for evaluating success of the Five-Year Plan are annual lakewide estimates of spawning-phase sea lamprey abundance and counts of sea lamprey marks on lean lake trout >532 mm. Relationships between marking rate, abundance of host species, abundance of sea lamprey causing marks, and control efforts are not as direct as might be expected. Understanding linkages between control efforts and predator-prey dynamics would enable a more complete understanding of the effects of control efforts and may enable these efforts to be targeted to lakes, regions of lakes, or fish stocks to maximize overall benefit.

Although the standard measures of sea lamprey control are spawning-phase sea lamprey abundance and lake trout marking rates, state and provincial management agencies also assess fish damage by collecting and reporting marking data on burbot and lake whitefish. These data are collected during a standardized lakewide assessment conducted with gillnets in August. Fresh Type A, Stage I marks are indicators of the attack rate for the year of sampling and Type A, Stage IV marks are the attacks accumulated over previous years. Marking data for burbot, lake whitefish, and steelhead are being assembled and reported by the Coldwater Task Group, but marking targets have not been developed for the species, and there is no current lakewide monitoring that assesses damage to the fish community.

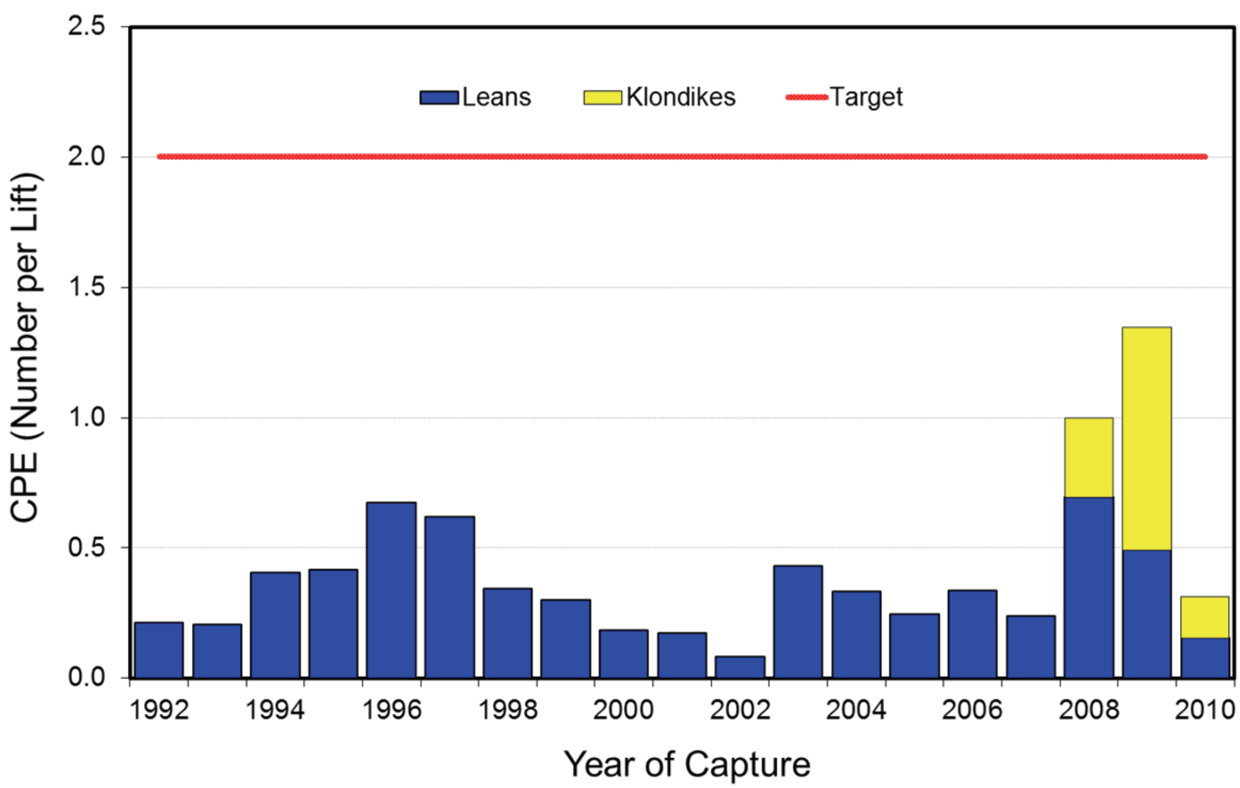
Trends in lake trout abundance in the eastern basin of Lake Erie demonstrate progress towards the fish-community objective to restore lake trout. Mean lake trout abundance in the eastern basin, all ages combined weighted by jurisdictional area, has generally been increasing since 2001. In New York waters, abundance since about 2003 has similar to, or greater than, the high levels observed from 1988-1991 (Fig. 44; Markham et al. 2008). Lake trout abundance has also increased in Pennsylvania waters in recent years whereas, in Ontario waters, abundance declined after 2003 and remained low during 2006-2010.

Fig. 44. Mean catch-per-effort (CPE) (number of fish per lift) by jurisdiction and all jurisdictions combined (weighted by area) for all ages of lake trout caught in assessment gillnets in the eastern basin of Lake Erie during August, 1985-2010. One lift is equal to 152.4 m of variable-mesh gillnet set overnight (Markham et al. 2008; Coldwater Task Group 2011).



Abundance of age 5 and older (adult) lake trout declined in 1998 following a five-year period (1992-1996) of steady growth and thereafter remained low through 2007. This period of low abundance corresponded to sharp reductions in the number of lake trout stocked during 1996-2003 (Coldwater Task Group 2011), poor post-stocking survival (Coldwater Task Group 2011), and increased abundance of sea lampreys (Fig. 36). Although stocking numbers remained depressed through 2007, the strains of age-1 fish stocked were changed to include the Klondike strain in 2004-2005. Adult lake trout abundance increased sharply in 2008 and continued to increase in 2009 (Fig. 45). In 2010, however, adult lake trout abundance declined sharply to levels observed in the mid-2000s. Klondike-strain lake trout contributed about 30% to the total relative abundance in 2008, over 60% in 2009, and about 50% in 2010. Trends in adult lake trout abundance appear to be influenced by the numbers and strains of stocked fish and by the abundance of spawning-phase sea lampreys (Markham et al. 2008; Coldwater Task Group 2011).

Fig. 45. Mean catch per effort (CPE) (number of fish per lift) weighted by jurisdictional area of age-5 and older lake trout sampled in standard assessment gillnets fished in the eastern basin of Lake Erie, August 1992-2010 (Markham et al. 2008; Coldwater Task Group 2011). The CPE is shown as the sum of the CPEs of two lake trout groups, Klondike strain and lean lake trout of various strains.



Although targets for sea lamprey marking on burbot have not been established, data collected by the NYSDEC demonstrate a sharp increase in sea lamprey attacks on burbot since 2004 (Fig. 46) and an 80% decline in burbot abundance since 2004 (Fig. 47).

Fig. 46. Number of Type A, Stages I-III and Type A, Stage IV sea lamprey marks per 100 burbot (all sizes) sampled in assessment gillnets in New York waters of Lake Erie during August 2001-2010 (Markham et al. 2008; Coldwater Task Group 2011).

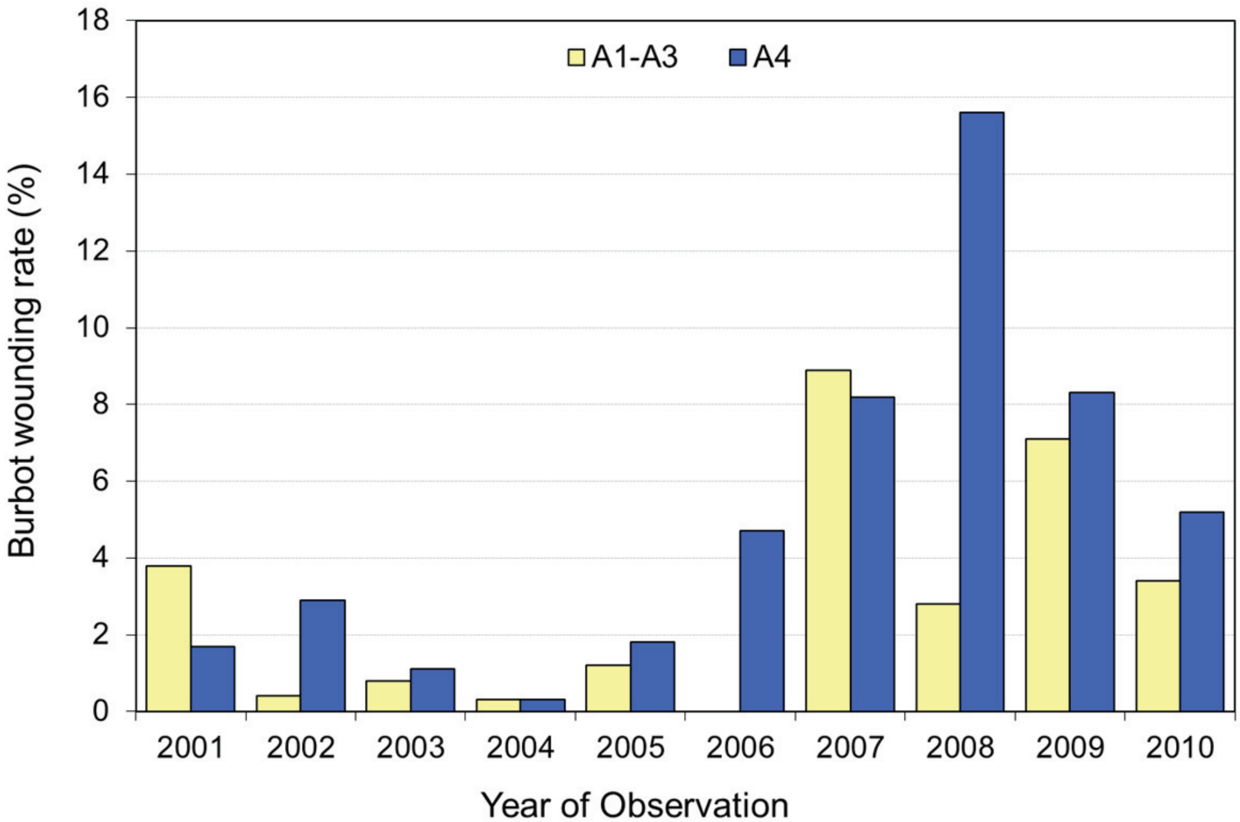
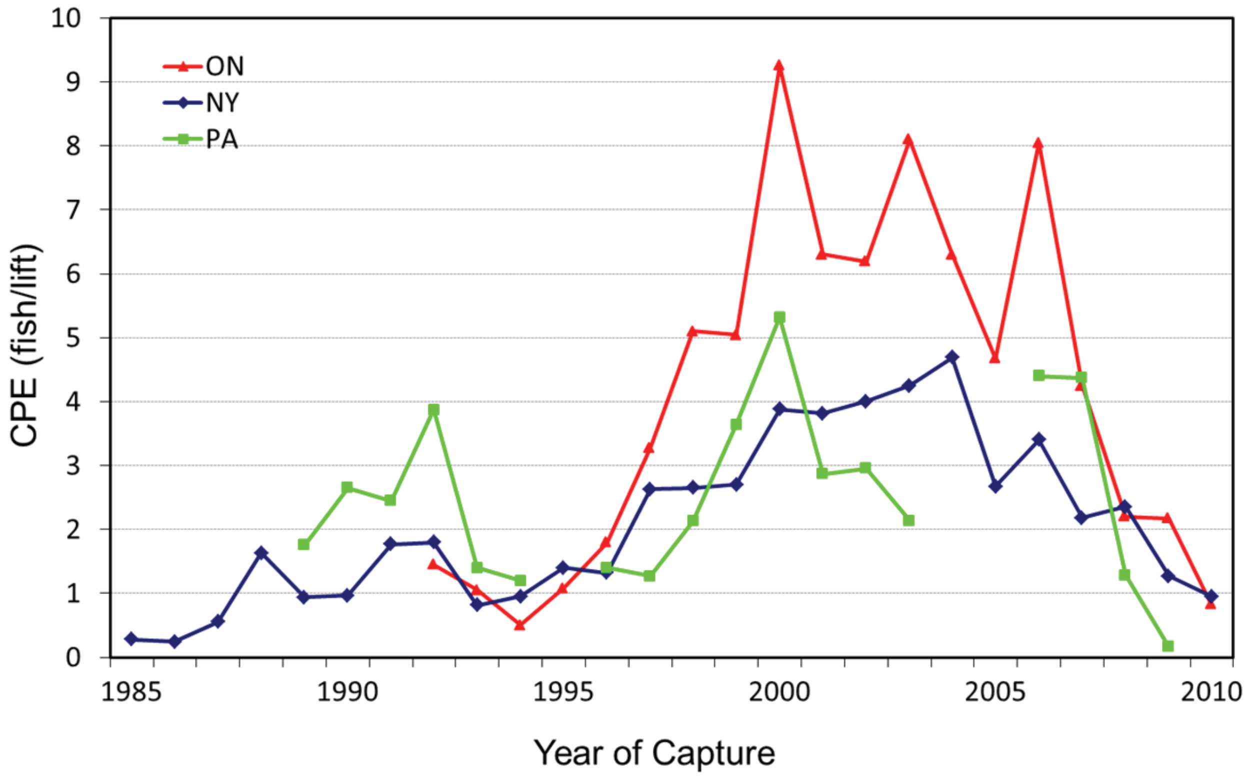


Fig. 47. Mean catch per effort (CPE) (number of fish per lift) weighted by jurisdictional area of burbot sampled in standard assessment gillnets fished in the eastern basin of Lake Erie, August 1985-2010 (Coldwater Task Group 2011).



The recovery of burbot in Lake Erie between 1987 and 2003 was attributed to effective sea lamprey control (Stapanian et al. 2006). The sharp increase in Type A, Stages I-III marks on burbot in 2007 corresponds to a decline in burbot abundance in 2008 (Fig. 47; Coldwater Task Group 2011) and increased sea lamprey abundance in Lake Erie from 2005 to 2007 (Fig. 36). Therefore, as sea lampreys and burbot increased in abundance, sea lamprey attacks on burbot increased, which likely led to increased mortality of burbot. Shifts in the species composition, relative abundance, and size of preferred hosts available for sea lampreys likely influence host selection. This situation further demonstrates the importance of sea lamprey control to achieving fish-community objectives.

Objective 1: By 2014, use sea lamprey marking rates to develop species or fish-community marking targets based on sea lamprey induced mortality rates for primary species vulnerable to sea lamprey attack in the Lake Erie fish community, including lake trout, burbot, lake whitefish, and steelhead.

Strategy: By 2012, define the relation between sea lamprey marking rates and host mortality for each primary host species.

Cost: Postdoc ($80K), Hammond Bay Biological Station (HBBS), etc. (determine the best way to do this).

Strategy: By 2012, define acceptable levels of sea lamprey mortality for each primary host species.

Cost: Postdoc, HBBS, etc. (determine the best way to do this).

Strategy: By 2015, develop predator-prey models that link the effects of sea lamprey control to as many species as practical.

Cost: Postdoc, HBBS, etc. (determine the best way to do this).

Strategy: Maintain standardization of sea lamprey mark identification through periodic workshops at intervals of no more than five years.

Cost: ~$4K

Strategy: Use five-year moving average and slope of five-year trend for reporting progress towards targets and spawning-phase sea lamprey abundance.

Cost: Included in the current base program.

Objective 2: By 2015, reevaluate targets for abundance of spawning-phase sea lampreys to determine if fishery managers agree they are consistent with fish-community objectives. If necessary, develop new targets.

Strategy: By 2012, develop regional targets for sea lamprey abundance (eastern, central, and western basins) for both sea lamprey marking on the fish community and abundance of spawning-phase sea lampreys.

Cost: Need to determine these costs.

Strategy: Evaluate potential methods of measuring annual recruitment of parasitic sea lampreys to Lake Erie from the St. Clair River.

Cost: Included in the current base program.

Strategy: Reevaluate methods used to determine abundance of spawning-phase sea lampreys with an emphasis on special coverage of traps and the influence of climate and stream environment, such as temperature and precipitation (flow), on the annual variation in catchability of spawning-phase sea lampreys in traps.

Cost: To be determined.

Recommended Strategies to Achieve Targets

The Five-Year Plan implements a base program of lampricide control, assessment, and alternative controls designed to support the fish-community objectives for Lake Erie at an annual cost of about $943,182 (based on the fiscal year 2011 budget). Despite these efforts, abundance of spawning-phase sea lampreys, as measured by the current five-year average (19,458), is about six times the target (3,264).

Results of the back-to-back treatment strategy completed in 2008-2009 on nine tributaries and in 2009-2010 on one tributary are currently being evaluated. Due to the two-year delay from the time of the second round of treatments to the return of the spawning cohort impacted by these treatments, the full effects of these actions will not be evident until the spring of 2012. The metrics used to evaluate these actions demonstrate encouraging results: declines in spawning-phase abundance, nest counts, recruitment to tributaries, and lake trout and burbot marking. Larval assessment surveys indicate effective stream treatments and no new populations of sea lampreys have been detected despite increased larval assessment effort. However, the positive signs following back-to-back treatments were preceded by the largest estimated population of spawning-phase sea lampreys ever observed in Lake Erie, which has resulted in uncertainty as to the primary source(s) of sea lampreys. To achieve target levels of sea lamprey abundance in Lake Erie, fishery managers will need to closely monitor the metrics used to evaluate control efficacy and take immediate actions to treat newly recruited populations before they metamorphose and migrate to the lake.

Historic lampricide treatment and larval assessment data suggest that the most likely source of parasitic-phase sea lampreys in Lake Erie is larvae that survive lampricide applications (residuals) in streams that contain the greatest numbers of larvae. However, uncertainty still exists regarding the contribution of sea lampreys from the St. Clair River. Analyses designed to forecast the effects of various treatment scenarios suggest that lakewide spawning-phase sea lamprey abundance can most reliably be affected through whole-lake selection of streams to treat for residuals. Lakewide spawning-phase abundance was used to measure program success as this is currently the best measure available. In addition, the construction, maintenance, and repair of both purpose-built and *de facto* barriers are direct actions that aim to minimize spawning-phase sea lamprey abundance. Recommended strategies to reach targets within the next five years are listed below.

Lampricide Control

Annual effort: Lake Erie accounts for 4% of the lampricide control effort expended throughout the Great Lakes basin, based on an average of control expenditures during 2005-2009. This effort will result in $470,840 being spent on lampricide control in 2011 and represents the level of control required to maintain the long-term average abundance of spawning-phase sea lampreys in Lake Erie.

To get to targets: Beginning in 2013, treat all streams found to contain sea lamprey larvae >100 mm in two consecutive years or all streams with known recruitment a minimum of once every three years.

Additional cost: To be determined based on 2011 and 2012 larval assessment surveys. Currently, only Cattaraugus and Conneaut Creeks are known to contain the 2010 cohort of larvae.

This recommendation is based on the assumption that the largest source of parasitic-phase sea lampreys in Lake Erie is larval sea lampreys that survive lampricide applications, metamorphose, and migrate to the lake. In addition, we also assume that we have accounted for all sources of sea lamprey production and that a reduction in the residual larval populations will have a commensurate effect on spawning-phase sea lamprey abundance and lake trout marking.

Larval Assessment

Annual effort: Current assessment supports the among-stream prioritization and within-stream targeting of lampricide control activities, including evaluating treatment effectiveness, assessing the success of barriers, and detecting new infestations of sea lampreys. The average cost of larval assessment to direct the current level of lampricide control in Lake Erie is $200,083 for 2011.

To get to targets: Continue assessments of the St. Clair River every three years to monitor sea lamprey production and, if required, rank areas for gB treatment.

Additional cost: No additional costs for assessment. Lampricide control costs could increase pending results of surveys.

To get to targets: Quantify larval habitat in the St. Clair River using RoxAnn© seabed classification sonar.

Additional cost: No additional costs at this time. Work is planned for 2011.

To get to targets:	Ensure upstream and downstream limits of sea lamprey infestation are accurately determined either the year prior to or the year of treatment for each stream scheduled for lampricide application.
Additional cost:	Costs will depend on the number of streams treated and are yet to be determined.

To get to targets:	Conduct detection surveys for new populations of sea lamprey larvae every 5+ years in streams with suitable spawning and nursery habitats.
Additional cost:	~$15K each year to increase the frequency of surveys on streams that have not been infested in the past to ensure all sources of sea lampreys are known.

Alternative Control Barriers

Annual effort:	Maintain the current barrier network, both purpose-built and *de facto* barriers, to limit sea lamprey recruitment and spawning-phase sea lamprey abundance. The forecasted cost of barrier inspection and maintenance was $183,331 for Lake Erie in 2011.
To get to targets:	Pending results of an ongoing feasibility study, replace or repair the existing barrier on the Grand River (Harpersfield Dam).
Additional cost:	Cost is currently unknown.

This strategy will minimize the number of sea lampreys infesting the 60 miles of tributary located upstream of the existing barrier.

Metrics of Success

Annual effort:	Stream-specific mark-recapture estimates of spawning-phase sea lamprey abundance are the foundation of a model that uses stream discharge, treatment history, and production potential to calculate regional and whole-lake population estimates. The average cost of spawning-phase assessment in Lake Erie was $88,928 for 2011. Along with marking rates on lake trout, collected and assembled by state and provincial fisheries managers, population estimates are used to evaluate performance of the Five-Year Plan. Evaluation of model performance is an ongoing task and benefits lake-specific population estimates across the Great Lakes basin. Alternative methods of estimating fish damage are currently being investigated by the Quantitative Fisheries Center (QFC) at Michigan State University.

To get to targets:	Continue to evaluate those parameters that will increase the precision of the model used to estimate spawning-phase sea lamprey abundance and implement recommended improvements.
Additional cost:	Dependent on results of ongoing analyses.

To get to targets:	Continue to work with the QFC and the LEC's Coldwater Task Group to investigate alternative methods of estimating fish damage based on marking in the entire fish community. This strategy is critical to the development of improved metrics to measure program success and the effects of sea lampreys on the Lake Erie fish community.
Additional cost:	~$100K over a two-year period for research.

To get to targets:	Maintain the standardization of sea lamprey mark identification through periodic workshops at intervals of no more than five years.
Additional cost:	~$4K every five years to sponsor workshops.

Maintaining Targets and the Judicious Use of Lampricides

Advancing alternative control technologies and techniques is critical to maintaining targets and applying lampricides in a judicious manner. Strategies, such as the application of pheromones to improve trap efficiency, are currently being evaluated whereas others, such as incorporating traps into planned barriers, are closely associated with strategies yet to be implemented (i.e., barrier construction). Deployment of additional strategies, such as increasing trapping effectiveness, reducing recruitment by manual removal of spawning-phase sea lampreys, and development of improved methods to evaluate program success, await research designed to evaluate their potential. New alternative controls will benefit actions designed to reduce sea lampreys to, or maintain them at, target levels throughout the Great Lakes and are not necessarily specific to Lake Erie. However, the costs for implementing these strategies are not well defined. Estimated costs to advance these technologies and techniques are included in Chapter 7 (Summary) and will require research related to these four general areas: application of pheromones, trapping techniques, methods to reduce recruitment, and sea lamprey-host interactions.

Research and Assessment Needs

A number of research needs were identified in a series of five research themes published in the Journal of Great Lakes Research in 2007. These research themes are generic to the sea lamprey control program, and all would benefit sea lamprey control in Lake Erie.

Currently, most parasitic sea lampreys are thought to originate from tributaries to Lake Erie's eastern and central basins. Although the contribution of parasitic sea lampreys from the St. Clair River and Lake Huron is believe to be minor, further research to confirm this belief and to estimate the proportional contribution from these sources remains a high priority.

Changes in parasitic-phase sea lamprey feeding behavior due to shifts in host abundance and size structure are poorly understood and confound interpretation of marking data on teleost hosts. Increased knowledge of how sea lamprey feeding, marking, and host mortality changes with variations in host abundance and size structure would enhance our understanding of damage to the fish community inflicted by sea lampreys.

Due to the limited trapping network in Lake Erie tributaries, estimates of the abundance of spawning-phase sea lampreys can have high levels of uncertainty. Research into alternative methods of estimating spawning sea lamprey abundance, particularly during periods of low abundance, would enhance our ability to measure the effectiveness of ongoing control actions. In addition, development of alternative methods of trapping for control is a high priority.

The primary actions directed at controlling sea lampreys (i.e., lampricide applications and barriers) in Lake Erie are based on knowledge of the presence, distribution, and abundance of larval sea lampreys. High density larval populations are readily detected by current sampling tools. However, because the current sampling tools are not very efficient (Steeves et al. 2003), low-density larval populations may go undetected. Enhancing techniques to detect low-density larval populations would improve assessment capabilities.

Control actions to reduce recruitment to the lake result in decreased contributions of newly metamorphosed animals. However, survival and compensatory mechanisms of this life stage are poorly understood, which potentially confounds the results of control actions. A better understanding of survival and compensatory actions of newly metamorphosed sea lampreys may provide insight into the results of control actions designed to limit their contribution to the in-lake population.

Communication

Sea lamprey control in Lake Erie is a cooperative effort led by the USFWS and Department of Fisheries and Oceans, Canada in cooperation with the NYSDEC, PFBC, Ohio Department of Natural Resources, Michigan Department of Natural Resources and Environment, OMNR, Seneca Nation, and First Nations in Ontario. Sea lamprey control operations are based in Ludington and Marquette, Michigan, and Sault Ste. Marie, Ontario. See Appendix A for information about who to contact about the sea lamprey control program.

CHAPTER 6: FIVE-YEAR PLAN FOR LAKE ONTARIO

Fraser Neave[8]

Introduction and History

The purpose of this chapter is to provide a specific plan for sea lamprey (*Petromyzon marinus*) control in Lake Ontario, building on the general, basinwide discussion of sea lamprey control outlined in Chapter 1 (Sea Lamprey Control in the Great Lakes Basin). The most recent synthesis of sea lamprey control in Lake Ontario (Larson et al. 2003) was published in Journal of Great Lakes Research in 2007 as a contribution to the Sea Lamprey International Symposium II. This paper is cited often in this plan and is a good document to review for those interested in additional information on sea lamprey control in Lake Ontario. The Great Lakes Fishery Commission, in collaboration with fisheries managers, has developed this lake-specific Five-Year Plan as an integrated sea lamprey control strategy that focuses on lakewide and locality-specific control tactics to maintain sea lamprey populations at or below target levels.

The first record of sea lampreys in Lake Ontario was in 1835 (Lark 1973). Their origin in the lake has been controversial due largely to the paucity of documentation of sea lampreys prior to 1900 (Christie 1973). For example, Smith (1995) contends that sea lampreys entered Lake Ontario via the Erie Canal sometime after its completion in 1817. Larson et al. (2003) support the Erie Canal entry theory via Oneida Lake. However, genetic analyses have indicated that sea lampreys may have had a long presence in the lake. Waldman et al. (2004) utilized mitochondrial DNA and Bryan et al. (2005) examined microsatellite genotypes. Both studies found a significant difference in genetic frequencies among Lake Ontario sea lampreys and those in the other Great Lakes, suggesting that sea lampreys are native to Lake Ontario. Subsequent to these analyses, Eshenroder (2009) argued that some of the assumptions by Waldman (2004) and Bryan et al. (2005) are not substantiated and suggests that the question of the origin of sea lampreys in Lake Ontario remains unanswered.

Regardless of the origin of sea lampreys, poor survival of stocked lake trout (*Salvelinus namaycush*) and other salmonids and a high marking rate on these fishes led to the implementation of sea lamprey control in Lake Ontario. Control started with the lampricide treatment of 23 Canadian streams in 1971 and 20 United States streams in 1972. Regular lampricide applications have continued to the present day, and, in recent years, an average of 11 Lake Ontario streams have been treated annually as part of the ongoing integrated control of sea

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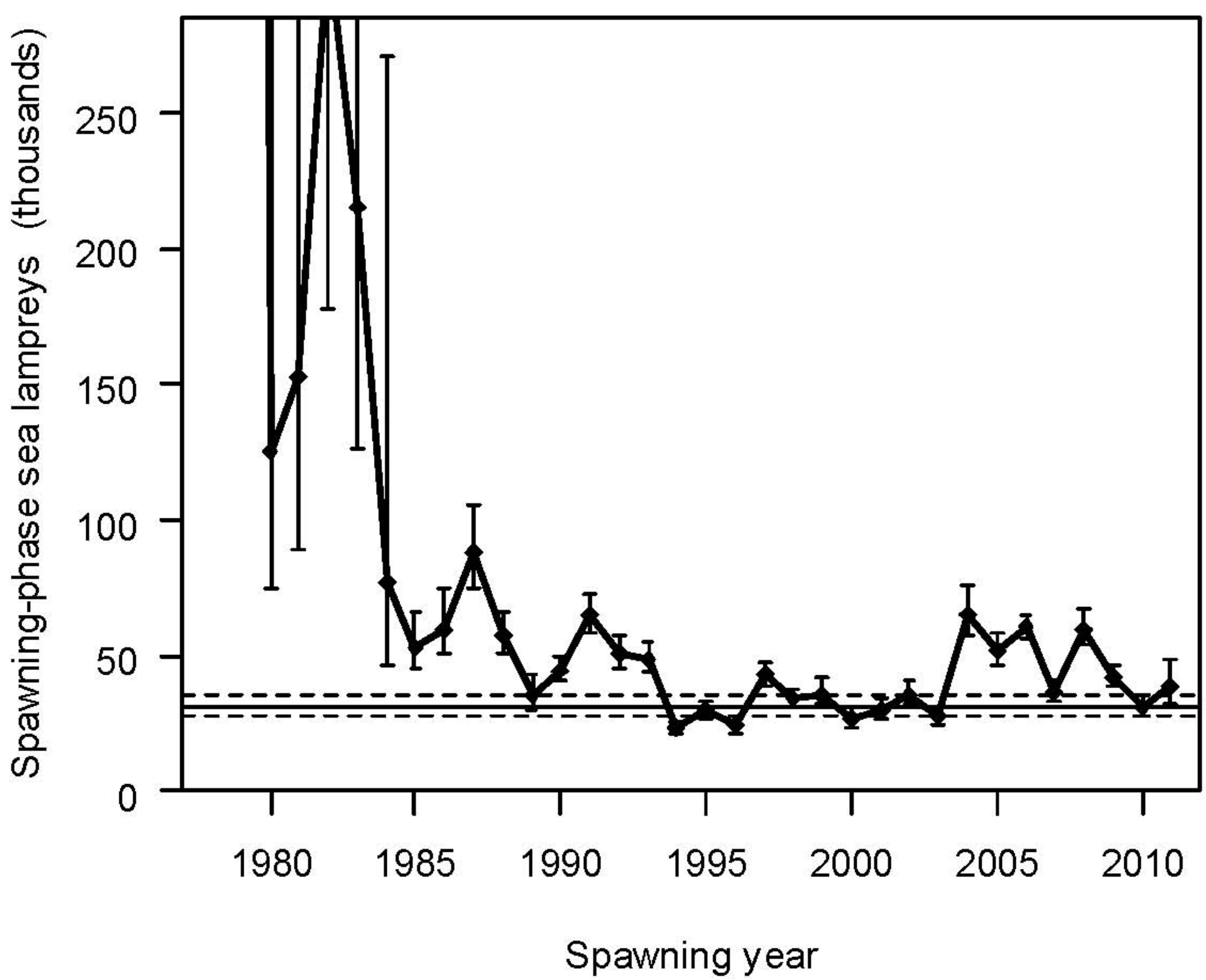
lampreys. As an alternative to lampricide application, sea lamprey barriers have been constructed on nine tributaries to the lake, and six dams, which were built for other purposes, have been modified to deny spawning-phase lamprey access to spawning habitat, thereby reducing or eliminating the need for lampricide treatment. Traps to capture spawning-phase sea lampreys are operated on ten streams each year. Trapping reduces the number of spawning-phase individuals in the stream, provides sea lampreys for mark-recapture studies used to estimate lakewide abundance, and provides lampreys for use in the sterile-male release technique (SMRT) program in the St. Marys River, which connects Lakes Superior and Huron.

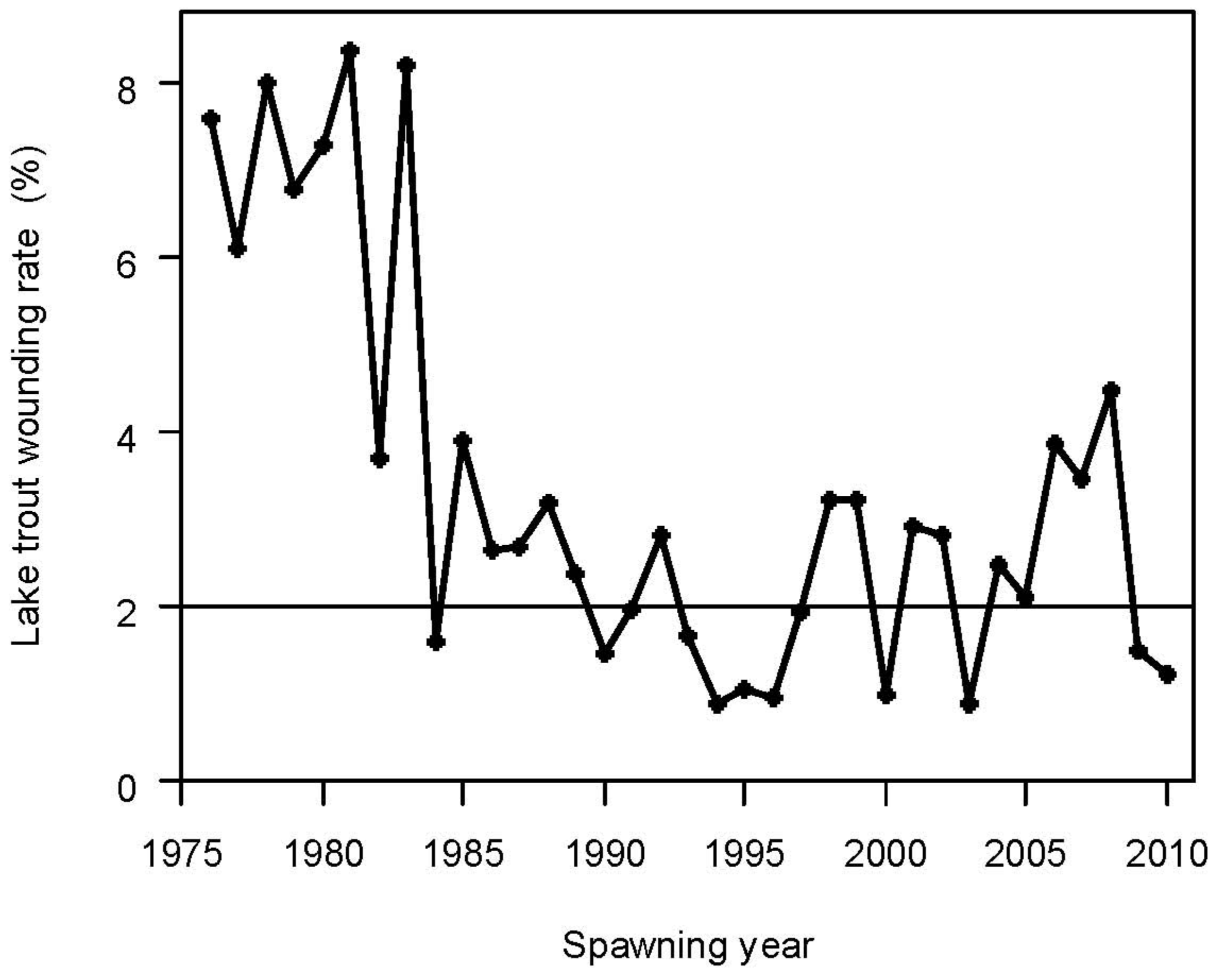
Although sea lamprey marking rates on salmonines declined dramatically following the first Lake Ontario lampricide treatments, a significant reduction in the lakewide abundance of spawning-phase sea lampreys, as occurred during the early period of sea lamprey control on the upper Great Lakes, was not immediately evident (Pearce et al. 1980). Untreated sources of potential recruitment included the Black River and tributaries to Oneida Lake. In the latter case, the capture of 12 newly-metamorphosed sea lampreys in 1977 below the Caughdenoy Dam, 6 km downstream of the outlet of Oneida Lake, suggested the possibility of newly metamorphosed sea lampreys from Oneida Lake emigrating to Lake Ontario through the Oneida and Oswego Rivers (Pearce et al. 1980). A substantial reduction in spawning-phase sea lampreys did not occur until the early 1980s following initial treatments of the Black River and the tributaries to Oneida Lake (Fig. 48). The sharp drop in abundance in the early 1980s was followed by a period of much lower abundance estimates, and, during 1994-2003, abundance was at or very near the target of 31,000 spawning-phase sea lampreys. In all but one year during 2004-2010, the number of spawning-phase sea lampreys was above the target level, and, during 2006-2010, the number of spawning-phase animals averaged 44,000.

Fig. 48. Annual lakewide estimates of sea lamprey abundance with ±95% confidence intervals (CI) in Lake Ontario during 1980-2010. The solid horizontal line represents the abundance target of 31,000 spawning-phase sea lampreys, and the dashed horizontal lines are the 95% CI for the target.



Marking rates on lake trout followed a pattern similar to the spawning-phase sea lamprey abundance (Fig. 49). The number of Type A, Stage I marks declined from about 8 per 100 lake trout to at or near the target of 2 per 100 lake trout. The timing of the drop in marking rates suggests that treatment of either the Black River or tributaries to Oneida Lake, or perhaps both, were instrumental in reducing sea lamprey marking on lake trout to around target levels (Elrod et al. 1995). It is also possible that the initial treatments of Lake Erie tributaries in 1986 and 1987 reduced the contribution of sea lampreys from Lake Erie to Lake Ontario (Elrod et al. 1995).

Fig. 49. Annual estimates of sea lamprey marking rates (Type A, Stage I marks) on lake trout 533 mm and larger in Lake Ontario during 1976-2010. The solid horizontal line represents the marking rate target of 2 marks per 100 lake trout. For ease of comprehension, marking rates are advanced one year from the year of observation to align with the spawning year of the sea lampreys that made the marks.



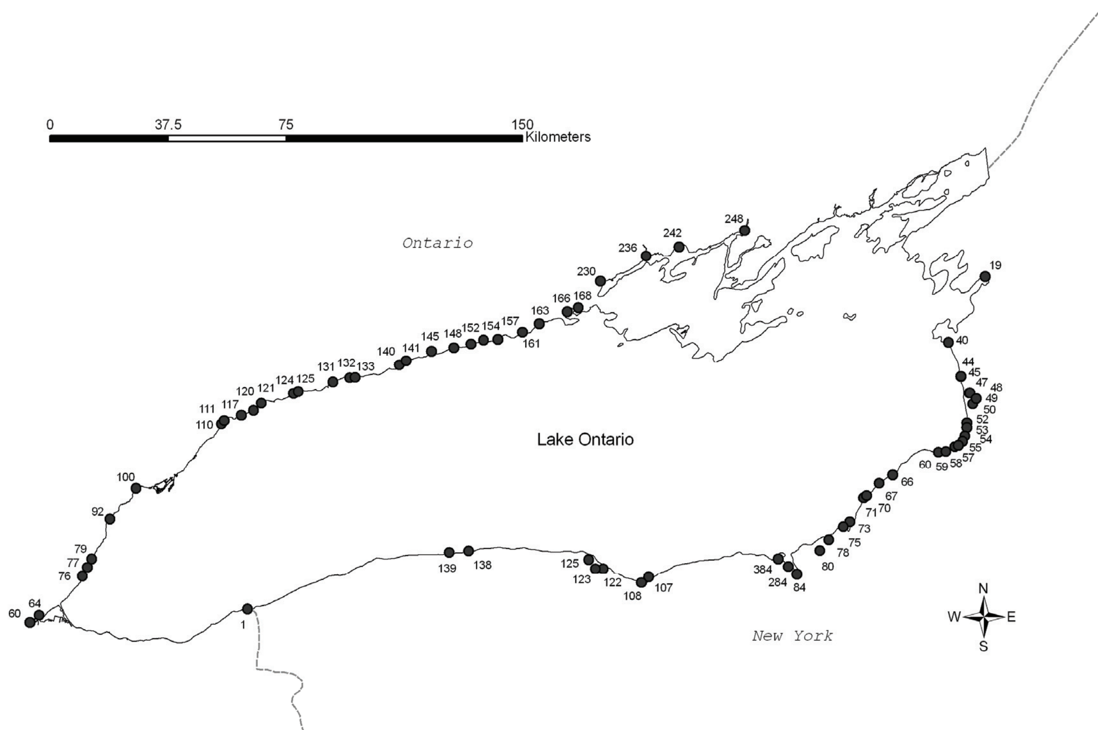
Features of the Lake

Lake Ontario is the smallest of the five Great Lakes with a surface area of approximately 19,000 km^2 (7,336 square miles), which is divided nearly equally between Ontario and New York. About 80% of Lake Ontario's water comes from the Niagara River, and the remaining 20% is supplied by other tributaries.

Eighty-five percent of the perimeter of the lake has nearly straight shorelines that slope rapidly into deep water. The bottom of the lake is relatively featureless, except for the Duck-Galloo Sill, which separates the northeastern outlet basin from the rest of the lake, and the Scotch Bonnet Ridge, which separates the deepest area of the lake into western and eastern basins. The maximum depth of Lake Ontario is 244 m (Stewart et al. 1999).

The areas of highest sea lamprey production in Lake Ontario are concentrated in two regions: between Burlington (60) and the Bay of Quinte (248) on the north side of the lake and east of Oswego (66) to Stony Point (40) on the south shore (Fig. 50). Many of the tributaries outside of these two areas are unsuitable for larval production because of low gradient, geology, or high summer temperatures, exacerbated by the loss of riparian vegetation due to agricultural development or urbanization.

Fig. 50. Location and number of Lake Ontario streams with records of larval sea lamprey infestation. Name of stream is cross-referenced with the stream numbers in Appendix B.



Unique Issues

Sea lamprey reproduction has been detected in 62 Lake Ontario tributaries, but only 44 of these tributaries harbored sea lampreys as of 2010. Sea lamprey production in some tributaries is highly variable. In recent years, larval production has ceased or decreased markedly in several streams (Rouge River and Skinner and Deer Creeks), while larval production has resumed in some streams where it has previously ceased (Cobourg Brook and Proctors and Marsh Creeks). New streams are also occasionally infested, as evidenced by the increase in the number of tributaries that have had detectable sea lamprey reproduction from 51 in 1978 (Pearce et al. 1980) to 57 in 1999 (Larson et al. 2003), and 62 in 2009 (Sullivan and Adair 2010).

Despite variable production of larval sea lampreys in some streams, production has been relatively constant in the majority of the infested Lake Ontario tributaries. The constant producers are typically cool, spring-fed streams with moderate to high gradients and substrates comprised predominately of gravel, cobble, and rubble, with silt and sand as minor components. The tributaries with the highest estimates of stream-specific larval production are located on the eastern shore of the lake in New York (Fig. 51; estimates of larval production in various tributaries are listed in Appendix B). An extended growing season and faster growth rates in the lower Great Lakes necessitate three-year treatment cycles (vs. an average of four years in the upper Great Lakes) to prevent out-migration of metamorphosed sea lampreys to the lake.

Fig. 51. Maximum estimates of larval-phase sea lamprey abundance in Lake Ontario tributaries during 1996-2010. Streams with the highest estimates, combining for more than half the Lake Ontario total, are identified by name. For reference, the maximum estimate of larval-phase sea lamprey abundance is 2.13M for the Little Salmon River. Estimates for all streams are listed in Appendix B.

Streams that produce large numbers of larval sea lampreys and are especially challenging to treat effectively with lampricides are listed in Table 20. The primary factors that complicate and create challenges to effective control in these streams include a narrow window for treatment due to the presence of sensitive life stages of certain species and the variable discharge from hydroelectric generating facilities or low discharge in midsummer; numerous backwaters, impoundments, oxbows, and rivulets that act as larval refugia and require secondary applications of lampricides; and the dendritic and complex watercourse. These challenges and the objectives and strategies to address them are discussed later in this document.

Table 20. Summary of challenges to effective treatment of sea lampreys in Lake Ontario. Sensitive species and variable discharge limit the period available for treatment.

Stream	**Sensitive species**	**Discharge**	**Secondaries***	**Dendritic**	**Lentic**	**Access**	**Beaver dams**	**pH**
Black River	Pacific salmon (*Oncorhynchus* spp.)	X	X		X			
South Sandy Creek	Pacific salmon							
Lindsey Creek			X				X	
Little Sandy Creek	Walleye (*Sander vitreus*)						X	
Salmon River	Pacific salmon	X	X	X		X	X	
Grindstone Creek			X				X	
Little Salmon River			X					
Fish Creek							X	
Credit River								X
Rouge River								X
Bronte Creek			X					

*Secondary lampricide treatments focus chemical application in areas of potential refuge such as backwaters, oxbows, or beaver dams. Treatment of these areas is labor intensive but improves treatment effectiveness.

Treatment evaluation surveys have identified residual larval populations in a number of New York streams. Beaver impoundments, which are particularly numerous in tributaries along the southeastern lakeshore, can impair lampricide treatment efficacy by impeding the flow of treated water and providing refugia to larvae. The influx of water from untreated springs and groundwater may contribute to the dilution of lampricide concentrations in these streams, resulting in greater numbers of residuals (larvae that escape a lethal dose of lampricide during treatment). Groundwater influx, however, has been largely discounted as a significant cause of larval survival (Swink and Neff 2008).

Based on a cost-benefit criterion, a number of Lake Ontario tributaries in New York have been treated more frequently than the typical three-year interval. Larson et al. (2003) reported 14 accelerated treatments between 1971 and 1999, whereas, between 2000 and 2009, 13 tributaries have been re-treated to control parasitic-phase recruitment from residual populations. In contrast, treatment efficacy for tributaries in Ontario has been exceedingly high, likely because impoundments and groundwater influx are less common.

- The Humber River supports the largest migration of spawning-phase sea lampreys in Lake Ontario (Fig. 52). However, with the exception of the capture of a single larva, successful recruitment to this stream has not been documented. Poor water quality, from a combination of urban runoff and high water temperatures in spring and summer, likely limit egg and larval survival in this tributary. Sea lamprey nest surveys conducted on the Humber River in the 1980s revealed that eggs were subject to a fungal or mold infection, possibly *Saprolegniosis* (R.B. McDonald, DFO, personal communication, 2010).
- The Salmon River (near Shannonville, Ontario) is an irregularly treated tributary that passes through land belonging to First Nations peoples and requires their continued cooperation to allow stream access for assessment.
- The Black River was first treated in 1980 and has been treated on average every five years since. There is a substantial dam complex located in Dexter, New York, approximately 2.4 km upstream from the lake, but sea lampreys regularly breach these dams despite remedial construction in the 1990s to prevent their passage.
- The Salmon River that flows through Pulaski, New York, and its tributaries, including Beaver Dam, Trout, and Pekin/Orwell Brooks, are infested with substantial numbers of sea lamprey larvae. Treatment of the Pekin/Orwell system is problematic due to landowner concerns, limited access, numerous beaver dams, and the presence of Gowdy Pond, a large pond that provides refuge for larvae during treatment. Construction of a sea lamprey barrier on this problematic tributary is scheduled in 2012.
- The Oswego River system is located north of Syracuse, New York. In this system, the majority of sea lamprey production occurs in Fish Creek, which flows into Oneida Lake. The Oneida River drains Oneida Lake into the Oswego River which joins Lake Ontario at Oswego, New York. Other tributaries to Oneida Lake have been infested by sea lampreys in the past (including Hall, Big Bay, and Scriba Creeks), but, of these, Scriba Creek is the only stream currently infested. The Seneca River flows into the Oneida River west of Oneida Lake, and several tributaries to the Seneca River have required treatment in the past, including Carpenter and Cold Spring Brooks. Black Creek, a tributary to the Oswego River between Fulton and Oswego, New York, was also treated in 1981.

Fig. 52. Five-year average stream spawning-phase abundance estimates for Lake Ontario during 2006-2010. Streams with the highest five-year average that combine for more than half the Lake Ontario total are identified by name. Colors indicate whether the source of most (at least three of the five) of the annual estimates were from mark-recapture (blue) or not (orange). For reference, the five-year average abundance of spawning-phase sea lampreys in the Humber River is 10,000. Estimates for all streams are listed in Appendix B.

Sources of Parasitic-Phase Sea Lampreys

In addition to sea lamprey larvae that survive treatment, another source of parasitic-phase recruitment in Lake Ontario is from untreated sources (Larson et al. 2003). These sources include a small number of streams (e.g., Napanee and Salmon Rivers in Ontario and Sandy Creek near Woodville, New York) with low-density populations that are not cost-effective to treat and tributaries that may have undetected infestations. Surveys to locate new populations have been increased recently resulting in the identification of several new producers, including Larkin, Forest Lawn, Sandy (near Adams, New York), Sandy (near Brockport, New York), and Johnson Creeks, of which only the latter two have warranted treatment. Significant production from an undetected population is unlikely because of extensive surveillance efforts in recent years and the lack of localized increases in marking rates that would indicate a new source of recently-metamorphosed parasitic-phase individuals.

A potential source of sea lamprey production in Lake Ontario is Black River Bay, the lentic area adjacent to the mouth of the Black River. During previous treatments of the Black River, gulls (*Larus* sp.) were observed feeding well off the mouth of the river, presumably on sea lamprey larvae activated by the lampricide. Prior lentic surveys in Black River Bay found such small numbers of sea lamprey larvae that treatment with granular Bayluscide (gB) would not have been cost effective. Recently, a large area of deposition, indicative of good larval habitat, located about 1.5 km from the mouth of the Black River was mapped with RoxAnn©. Preliminary surveys of the deposition area in 2010 revealed a very small lentic population. Further surveys in 2011 will determine the full extent of the infested area and identify any requirement for treatment.

Although the Trent and Moira Rivers have been sparsely populated with sea lamprey larvae in the past, larval abundance in both rivers has increased over the last few years. Sea lamprey production in both rivers is affected by dams that limit the amount of spawning and larval habitat, and, consequently, larvae are found mainly in the estuarine areas adjacent to Lake Ontario. Neither river has been treated with the lampricide 3-trifluoromethyl-4-nitrophenol (TFM), although Mayhew Creek, a tributary of the Trent River, has been treated with gB. In the mid-1980s, gB was applied to an area in the Trent River adjacent to the mouth of Mayhew Creek to control a lentic population that originated from production in the creek, and, in 2006, a broader area was treated to control larvae that were presumably produced by sea lamprey spawning in the main river. The Moira River ranked for TFM treatment in 2009, but low discharge precluded treating it. Localized treatment with gB was used as an alternate control measure, although dense aquatic vegetation likely limited treatment efficacy.

Special Concerns

Protected Species

Sea lamprey control practices in streams tributary to Lake Ontario have not been altered in response to species at risk. However, the presence of several protected species, including river redhorse (*Moxostoma carinatum*), channel darter (*Percina copelandi*), and lake sturgeon (*Acipenser fulvescens*), may require modifying control practices in the future (Table 21).

Table 21. Protected species that may require sea lamprey control personnel to avoid certain areas and periods in Lake Ontario. Formal federal, state, and provincial designations of species are T (threatened) or SC (special concern).

	Federal		State/provincial	
Species	**U.S.**	**Canada**	**NY**	**ON**
River redhorse		SC		T
Channel darter		T		T
Lake sturgeon			T	T

River Redhorse

Of all the Lake Ontario streams infested with sea lampreys, the river redhorse is found in only one, the Trent River. This river is within the jurisdiction of Parks Canada because it is part of the Trent Severn Waterway National Historic Site. Although the Trent River has never been treated with TFM, it does receive regular applications of gB to assess larval sea lamprey populations. In 2006, a 3-ha area of the Trent River was treated with gB to target high densities of sea lamprey larvae. The susceptibility of the river redhorse to lampricides has not been evaluated, but mortality during gB applications has never been observed.

Channel Darter

In Ontario, the Moira River is the only river where the presence of channel darters has been documented and sea lamprey control is required. The New York range of the channel darter does not include Lake Ontario tributaries as this species is only found in the lower part of the state (Rudolph et al. 2001). Similar to the Trent River, the Moira has had a low density of sea lampreys for some time and, until recently, it has not been cost effective to treat with TFM. However, gB surveys are conducted regularly in the Moira River and a larger treatment application was undertaken in 2009.

During spring and early summer, channel darters tend to occupy riffle areas (Committee on the Status of Endangered Wildlife in Canada 2002) which are not usually inhabited by larval sea lampreys. The channel darter is tolerant of TFM at or slightly above the minimum lethal concentration (MLC) required for controlling sea lamprey larvae (Neuderfer 2001). However, gB is a less selective lampricide and may cause mortality to species, such as the channel darter, that are physiologically bound to the bottom.

Lake Sturgeon

Lake sturgeon currently have no federal status in the United States or Canada. The Committee on the Status of Endangered Wildlife in Canada has listed each of the eight different populations of lake sturgeon in Canada as endangered, threatened, or of special concern. A decision to protect lake sturgeon within the federal Species at Risk Act is still pending. Lake sturgeon have been observed in the Black River, New York (Carlson 1995), and in the Trent, Salmon, and Niagara Rivers in Ontario, all of which are subject to lampricide assessment and/or control. A protocol for application of lampricides with populations of young-of-the-year lake sturgeon has been developed to treat rivers used by spawning lake sturgeon, and it prescribes restrictions to the timing of treatments and the concentrations of lampricides. However, to meet sea lamprey suppression targets, standard lampricide applications have always been used to treat Lake Ontario tributaries.

Timing and Discharge Restrictions

To maximize the number of larval sea lampreys killed, Lake Ontario streams are usually treated in the early spring when larval fitness is low and stream discharge is optimal. For streams with known spawning runs of walleye (e.g., Little Sandy, Scriba, and Sodus Creeks) or Pacific salmon (e.g., the Black, Salmon, and Little Salmon Rivers), treatment timing is adjusted to avoid coincidence with spawning migrations and the potential for nontarget mortality.

Treatment of the Black River is contingent on the cooperation of the Hudson River-Black River Regulating District, the agency that controls the river’s discharge. Lampricide application to the Salmon River (near Pulaski, New York) requires that a controlled discharge be provided by a hydroelectric company. Several smaller streams in New York, including Sandy Creek (near Brockport, New York) and tributaries to Oak Orchard and Salmon Creeks, require cooperation with landowners who adjust stream discharge for irrigation purposes through manipulation of inflow from the Erie Canal.

Stream-Treatment Deferrals

Since 1988, all stream-treatment deferrals on Lake Ontario were caused by excessive or inadequate discharge (Table 22). Deferred treatments are most often completed the following year. Recent deferrals can be partly attributed to the lack of flexibility in treatment schedules. When suboptimal flows are encountered, there are two options: wait for more favorable conditions or relocate to an area where streams are treatable. Unfortunately, the treatment schedule is fully determined prior to the field season. This tight schedule limits the opportunities to wait for optimal flows and makes deferral of treatments to later in the year difficult. Reducing the number of streams scheduled for treatment each year would provide flexibility and increase the likelihood that the occurrence of suboptimal flows could be accommodated, which would enable crews to perform treatments in the year they are scheduled.

Table 22. Stream-treatment deferrals for Lake Ontario during 1986-2009. Reason code definitions are H (excessive discharge), L (insufficient discharge), and U (unfavorable water chemistry).

Stream	1988	1989	2007	2008	Total
Fish Creek	H				
First Creek		L			
Sandy Creek (130)			L	L, U	
Marsh Creek			L		
Totals	1	1	2	1	5

Pollution Abatement

Water-quality improvements in degraded streams may boost sea lamprey recruitment by increasing reproductive success and survival of early life stages resulting in higher production in infested streams or new populations in previously uninfested streams. Poor water quality is believed to constrain reproduction in Toronto area streams, such as the Humber and Don Rivers. The Humber River attracts the largest spawning-phase sea lamprey migration in Lake Ontario, and pollution abatement may result in the establishment of a larval population in it. Should the Humber River be infested, it would require additional assessment and the initiation of lampricide treatment.

Industrial contamination of sediments in the Niagara River has likely acted to constrain sea lamprey production in the river. However, as environmental quality improves because of the elimination of point sources of pollution and remediation of existing contamination, sea lamprey production is anticipated to rise. With a discharge of 4,200 cubic meters per second, the cost to treat the Niagara River with TFM would be prohibitive, and spot treatment of high density areas with gB would be the only viable alternative.

Barrier Removal

Effective barriers play an important role in the sea lamprey control program by denying spawning-phase sea lampreys access to spawning and larval habitat. Given the current mandate of some agencies to increase the connectivity of river systems, there are potential conflicts between the need to control sea lampreys and efforts to enhance migratory fish passage. For example, dams on the Humber, Trent and Moira Rivers minimize sea lamprey reproduction. If upstream passage was allowed at these dams, it could substantially increase the area of infestation and hence production of larval and parasitic-phase sea lampreys, damage to the fishery, and sea lamprey control costs.

Recruitment from Other Sources

The Niagara River has the potential to produce large numbers of larval sea lampreys because of the availability of suitable spawning and larval habitats. Initial surveys in 1973 detected only American brook lamprey (*Lampetra appendix*) larvae, however, subsequent work, beginning in 1987, found sea lamprey larvae. In 1999, the larval sea lamprey population for the entire Niagara River was estimated at 40,680, of which 13,990 were expected to metamorphose (Larson et al. 2003). The Niagara River is the only known source of sea lampreys between Ancaster Creek in Hamilton, Ontario, and Johnson Creek in Lyndonville, New York—a distance of about 140 km.

The Niagara Bar, the depositional area off the mouth of the Niagara River, is another potential source of sea lampreys in Lake Ontario. The high velocity of the main river could easily carry larvae downstream to the lake. If larvae were deposited on the Niagara Bar, they could grow and metamorphose as they are known to do in lentic areas of the upper Great Lakes. Surveys using gB on the Niagara Bar have produced very few larvae, and recent remote substrate classification sampling (RoxAnn©) has shown that the majority of the substrate on the bar is hard-packed sand, which is marginal larval habitat. This habitat information indicates that the potential larval production on the Niagara Bar is likely low, and the contribution of parasitic-phase sea lampreys to Lake Ontario from the Niagara River is constrained to the river proper.

Only the portion of the St. Lawrence River upstream of Cornwall, Ontario, falls under the mandate of the Great Lakes Fishery Commission and its Five-Year Plan. Surveys on a number of tributaries to this reach conducted in 2006 and 2007, and, although they revealed no infestations, production within the main channel of the St. Lawrence River remains a possibility. Because newly-metamorphosed sea lampreys migrate with the currents, migrants from the St. Lawrence River or its tributaries would not contribute significantly to the parasitic-phase population in Lake Ontario. Sea lamprey production has been documented in tributaries downstream of the Moses-Saunders Power Dam, located on the St. Lawrence River near Cornwall, Ontario, but the dam is a formidable deterrent to upstream migration.

Fish-Community Interactions

Sea lampreys prey on a wide variety of fishes in the lake, including lake trout, lake sturgeon, brown trout (*Salmo trutta*), steelhead (*Oncorhynchus mykiss*), Atlantic salmon (*S. salar*), Chinook salmon (*O. tshawytscha*), and coho salmon (*O. kisutch*). Because sea lampreys do not require specific intermediate or terminal hosts, sea lamprey control affects, and is affected by, the entire fish community in Lake Ontario. Consequently, the impacts of sea lamprey control are difficult to interpret when exclusively evaluated through estimates of spawning-phase sea lamprey abundance and marking rates on the lake trout. The full effect of sea lamprey control may be more effectively measured throughout the fish community and not restricted solely to lake trout. Strategies to address damage assessment are discussed later in this plan.

Public Use

Many streams around Lake Ontario are heavily used for recreation. The Black River is popular river rafting. The Salmon River near Pulaski, New York, supports one of the largest recreational stream fisheries in the Great Lakes because of large spring and fall migrations of steelhead, Atlantic salmon, and Pacific salmon. Treatment in these streams is normally scheduled in the spring, in part, to avoid premature mortality to fall-spawning Chinook or coho salmon. Other stream uses include marinas in the estuaries of many Lake Ontario streams, particularly in the Toronto area.

Fish-Community Objectives

Fish-community objectives (FCOs) for Lake Ontario were developed by management agencies and encompass broad ecological concepts that provide for the development of a framework for more specific fisheries-management objectives. To maintain ecosystem function in Lake Ontario, one FCO is to reduce sea lamprey marking rates for lake trout (Stewart et al. 1999). Explicitly, this objective states:

> *Management actions that support healthy fish communities will include maintaining or improving ecosystem function, including maintaining sea lamprey marking rates <0.02 marks per fish for lake trout.*

The indicator, as listed in the FCOs, is:

> *Suppression of sea lamprey populations to early-1990's levels.*

This objective was set to facilitate recovery of the fish community, particularly lake trout, which was extirpated in the 1950s as a result of excessive harvest and sea lamprey predation (Christie 1973). Stocking of lake trout and Pacific salmon was undertaken in the 1950s and 1960s, but survival to maturity was poor (Pearce et al. 1980) until shortly after the advent of sea lamprey control in 1971. Effective sea lamprey control remains the key in both maintaining the strong sport fishery for Chinook salmon, coho salmon, steelhead, and brown trout and restoring self-sustaining populations of lake trout and Atlantic salmon.

Sea Lamprey Suppression Targets

The overall goal for sea lamprey control in this plan is to:

> *Achieve target levels of spawning-phase abundance and maintain these levels over time.*

Specifically, the suppression target for spawning-phase sea lampreys is 31,000 ± 4,000. This target is based on the average number of spawning-phase sea lampreys in Lake Ontario during 1993-1997, which inflicted about two Type A, Stage I marks per 100 lake trout >433 mm.

Objectives and Strategies within Program Components

Lampricide Control

A total of 57 Lake Ontario tributaries have been treated since the initiation of sea lamprey control in 1971, and an average of 11 tributaries have been treated each year since 1999 (Table 23). The quantity of TFM applied each year varies considerably due to changes in stream discharge and the particular set of streams treated. Between 1999 and 2010, the amount of TFM used annually range from 2,906 to 7,565 kg active ingredient, and the number of streams treated annually ranged from 9 to 15.

Table 23. Sea lamprey treatment information for Lake Ontario during 1999 to 2010. TFM and granular Bayluscide are reported as kilograms of active ingredient used.

Year	Number of treatments	TFM (kg)	Stream length (km)	Bayluscide (kg)
1999	9	5,030	133	47.5
2000	9	2,906	112	15.7
2001	9	5,837	204	4.7
2002	15	6,763	203	58.5
2003	13	4,958	218	2.6
2004	12	7,565	236	38.4
2005	10	3,256	181	0
2006	10	2,965	178	0
2007	9	4,853	198	0
2008	9	7,559	147	70.6
2009	13	3,830	218	2.5
2010	11	5,277	258	0

Objective 1:	By 2014, increase the proportion of sea lampreys killed during lampricide treatments by developing and implementing strategies for optimal success in all tributaries.
Strategy:	Identify streams where treatment effectiveness may be improved and develop and implement strategies to treat them more effectively, such as maintaining concentrations in excess of MLC for at least nine hours; increasing the duration of application by one to three hours; applying lampricide to backwaters, rivulets, and seepage areas that would otherwise remain untreated during the primary treatment and thereby provide refuge to larvae; treating at the optimal time of year to ensure appropriate discharges and minimize impact of aquatic vegetation in gB applications; and treat when larval sea lamprey fitness is lowest. Candidates include the Trent and Moira Rivers (vegetation issue).
Cost:	Included in the base program.
Strategy:	Coordinate with state, provincial, and tribal management agencies to address challenges to successful treatment, including communication of risks, goals, and benefits of lampricide control to stakeholders; requirements to protect species at risk through formal biological assessments, evaluations, and opinions; and ensure that the entire infested area of a stream is treated.
Cost:	Included in the base program.
Strategy:	Beginning in 2011, use nets to capture and remove larvae activated during treatments of tributaries to larger untreated systems and tributaries that enter a lake when sea lamprey larvae have been observed in the associated estuaries. Candidates include Marsh Creek (tributary to Oak Orchard Creek) and Mayhew Creek (tributary to the Trent River).
Cost:	An additional four staff days per stream (two to set nets prior to treatment and two to retrieve nests post-treatment).
Objective 2:	By 2014, modify lakewide stream-treatment strategies to reduce transformer escapement (whole-lake strategies).
Strategy:	Beginning in 2012, periodically implement treatments in two consecutive years in streams with a history of having a significant number of residual sea lampreys. For example, a stream with a three-year treatment cycle would be treated in years one, two, five, six, nine, and ten. Candidates include the Salmon River and Lindsey, Little Sandy, and South Sandy Creeks.
Cost:	Included in the base program, but the result would be lower-ranked streams being treated less often.

Strategy: Treat all streams with a history of annual recruitment on a three-year cycle (i.e., do not rank, just set application points and treat).

Cost: Analyses currently being conducted but likely cost neutral.

Strategy: Reduce the contribution of sea lampreys from lentic areas and estuaries by treating any lentic area containing larvae >100 mm with gB. Candidates include the Black River estuary.

Cost: Included in the base program.

Strategy: Beginning in 2012, implement consecutive treatments in the five largest producers of sea lamprey larvae (South Sandy Creek and Little Salmon, Salmon, Credit, and Black Rivers) to reduce escapement of residuals.

Cost: Dependent on the streams selected.

Strategy: When necessary, apply lampricides for 24 hours at lower than normal concentrations to compensate for large pH fluctuations to minimize nontarget mortality. Candidates include Johnson and Sandy Creeks.

Cost: Included in the base program.

Objective 3: By 2012, develop a regional treatment strategy that will not only kill sea lampreys but also reduce the long-term need for continuous treatment based on recolonization strategies.

Strategy: Review current sea lamprey mark-recapture information in the context of recolonization strategies and evaluate how sea lamprey reduction at the regional level might affect, and be affected by, the regional fish community. Use results from the Lake Huron North Channel strategy and the Lake Erie lakewide strategy to help inform this strategy and objective.

Cost: Dependent on strategy.

Larval Assessment

Larval assessment is used to determine the presence, abundance, size structure, and limits of infestation of sea lamprey larvae within a stream. To prioritize streams for lampricide application the following year, information on size structure, particularly the abundance of larvae >100 mm, and overall abundance is coupled with expected treatment cost. There is a requirement to prioritize among streams to be treated because, to date, there have not been enough resources available to treat all sea lamprey producing streams that have the potential to produce parasitic sea lampreys.

Objective 1: By 2012, maximize the effectiveness of the larval assessment program so that it provides enough among-stream information to prioritize streams for lampricide application and sufficient within-stream information to effectively plan a lampricide application.

Strategy: Continue to use expert judgment (EJ) to prioritize treatment of streams with multiple years of recruitment and allocate the effort saved to post-treatment assessments within one year of treatment to determine residual abundance and the potential for re-treatment.

Cost: Included in the base program.

Strategy: Ensure that detection surveys for new populations of sea lamprey larvae are conducted every 5+ years in streams with suitable spawning and nursery habitats and that evaluation surveys are conducted every three years in previously infested streams.

Cost: Increased cost to conduct detection surveys. Evaluation surveys are already included in the base budget.

Strategy: Continue three-year assessments of the Niagara River and Niagara Bar to monitor sea lamprey production and, if required, rank areas for gB treatment.

Cost: Included in the base program.

Strategy: Ensure the upstream and downstream limits of sea lamprey infestation are accurately determined either the year prior to or the year of treatment for each stream scheduled for lampricide application.

Cost: Included in the base program.

Objective 2: By 2015, prioritize and treat lentic and estuarine areas that regularly recruit larval sea lampreys.

Strategy: Continue to use RoxAnn© mapping to quantify substrates in lentic and estuarine areas. Candidates include the Trent and Moira Rivers.

Cost: Included in the base program.

Strategy: Continue to assess potential lentic areas (e.g., Black River Bay and Duffins, Oshawa, and Wilmot Creeks) until all are accounted for.

Cost: Included in the base program.

Strategy: Evaluate the feasibility of implementing annual TFM treatments on streams with lentic populations >500 larvae/ha.

Cost: Included in the base program.

Strategy: Revisit known infested lentic areas every two or three years to determine the need for treatment.

Cost: Included in the base program.

Objective 3: By 2013, maximize the implementation of alternative methods to prioritize streams and lentic areas for lampricide application.

Strategy: Develop additional criteria to prioritize streams for treatment based on expanded EJ criteria or other non-ranking survey data in hand.

Cost: Included in the base program.

Strategy: By 2011, have the Assessment Task Force evaluate the potential to treat streams or lentic areas on a fixed cycle from the maximum historical points of infestation.

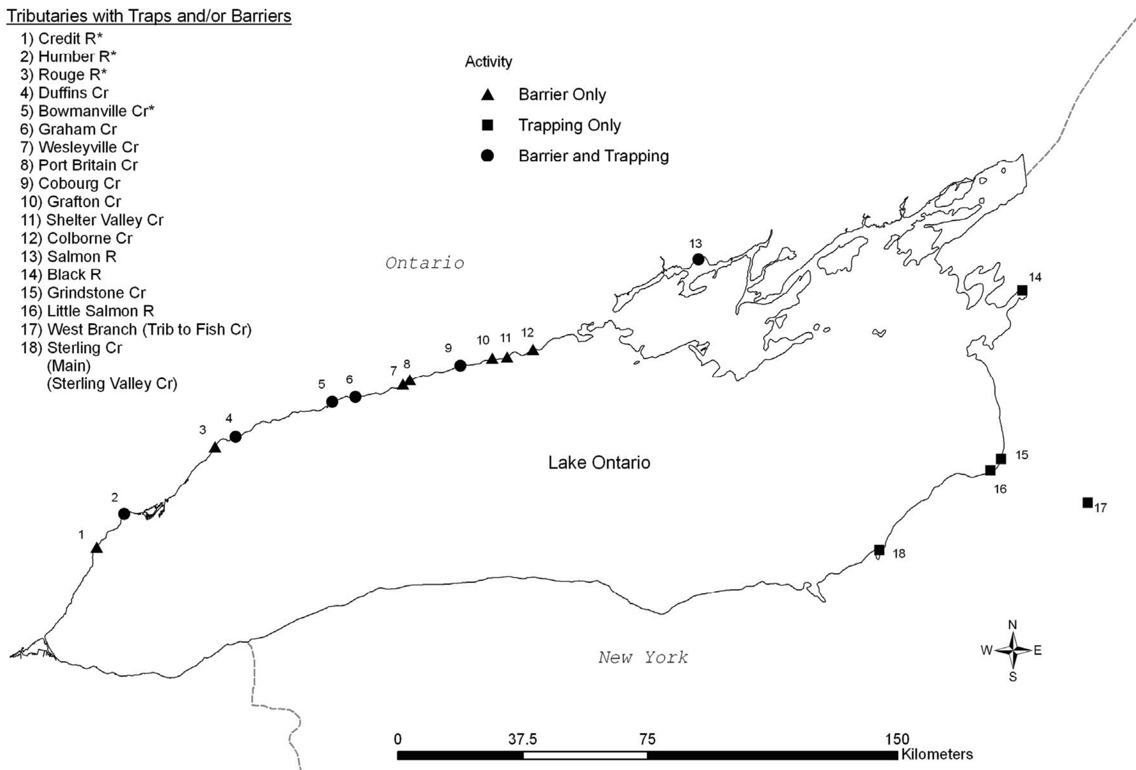
Cost: Included in the base program.

Trapping

Spawning-Phase Assessment

Spawning-phase sea lampreys are currently trapped in ten tributaries that flow directly into Lake Ontario (Fig. 53). Lakewide abundance estimates have averaged 42,016 from 1999 to 2010. Most sea lampreys have been trapped for assessment, but, on average, about 1,800 of the lampreys trapped each year contributed to control because they were used for the SMRT program.

Fig. 53. Locations of Lake Ontario tributaries with barriers and sea lamprey traps.



Lakewide abundance is estimated from a combination of mark-recapture studies at trap sites; historical estimates of trapping efficiency at sites where mark-recapture is not conducted; and modeling of expected spawning runs based on tributary-specific values for drainage area, geographic region, larval sea lamprey production, time of the last lampricide application, and year (Mullett et al. 2003).

Large rivers, particularly those without barriers, pose a challenge for capturing spawning-phase sea lampreys. A review of the adult assessment program in 1997 identified a need to trap more tributaries where large spawning runs are expected. Expanding the current trap network to include more large rivers will improve abundance estimates for runs that are currently estimated through extrapolation by the spawner-discharge model (Mullett et al. 2003), exact further control through removal of spawners, and provide more sea lampreys for the SMRT program.

Objective 1: By 2015, determine the optimum level (suite of streams, size of streams, and geographic coverage) of trapping of spawning-phase sea lampreys needed to obtain accurate estimates of lakewide abundance with a precision of ±20%.

Strategy: By 2012, evaluate factors that will improve the accuracy and precision of annual estimates of abundance. Use this information to determine if improvements are necessary and, if so, identify which factors will improve accuracy and precision to the desired level and recommend appropriate actions.

Cost: Included in the base program.

Strategy: By 2013, based on previous analyses, recommend the optimum suite of streams that must be trapped to estimate lakewide abundance of spawning-phase sea lampreys. Candidates include the Credit River and Bronte Creek.

Cost: Included in the base program. Streams to be identified after the analyses.

Objective 2: Investigate innovative trap designs and other techniques and technologies to estimate spawning-phase abundance, especially in large rivers and streams without barriers, and, if feasible, implement at least one new method by 2015.

Strategy: By 2012, develop a list of rivers where alternate methods can be evaluated and correlated with mark-recapture estimates of spawning-phase sea lamprey abundance.

Cost: Included in the base program.

Strategy: By 2014, determine the ability of DIDSON™ camera technology to estimate the number of spawning-phase sea lampreys in one or more rivers.

Cost: $80K for DIDSON™ + $20K per stream for operations.

Strategy: By 2014, based on data analyses correlating spawning-phase abundance with nest counts (Lake Erie data), develop a list of streams where nest counts may be an effective assessment tool, and implement nest counts in at least one stream by 2015.

Cost: Included in the base program.

Strategy: By 2015, evaluate the ability of pheromone and eDNA assays to quantify spawning-phase sea lamprey abundance in rivers.

Cost: Included in the base program.

Trapping for Control

Trapping for control is primarily used in the St. Marys River to limit larval sea lamprey recruitment through the removal of spawning-phase sea lampreys. At other trap sites, the portion of the catch that is not directed towards mark-recapture or to supply the SMRT program is euthanized and discarded, likely reducing recruitment in these rivers. Trapping for control is optimized when trap placement and trap retention results in capturing enough spawning-phase sea lampreys to reduce spawner densities to very low levels (<0.2 spawning pairs per 100 m^2 of larval habitat; Dawson 2007). Trapping efficiencies to affect control are usually higher than those necessary for assessment.

An alternative application of trapping for control targets out-migrating, newly metamorphosed sea lampreys in the fall and early spring and, by their removal, reduces the recruitment of sea lampreys to the parasitic population in the lake. This method has been implemented to capture transformers for mark-recapture studies, provide transformers for research, monitor the effects of sea lamprey control in the St. Marys River, and, more recently, with the sole objective of reducing recruitment from tributaries to Lakes Ontario, Huron, and Superior.

Objective 1: By 2015, increase the proportion of the spawning run that is captured in traps by 20%.

Strategy: By 2015, increase the annual effectiveness of traps to at least 25% of the estimated spawning run or 20% more than the 2006-2010 average catch in at least two of the ten streams currently trapped through trap improvements and control-scale application of pheromones. Candidates include the Humber and Black Rivers.

Cost: Dependent on the streams selected.

Strategy: By 2020, incorporate permanent or semi-permanent traps into present or planned barriers.

Cost: Dependent on the streams selected.

Strategy: Investigate and implement novel technologies and techniques to capture more sea lampreys.

Cost: Unknown at this time.

Objective 2:	By 2015, develop a trapping-for-control strategy where spawning-phase sea lampreys have been reduced through regional or lakewide control efforts or are not currently being trapped.
Strategy:	Evaluate the ability to minimize recruitment to the larval phase by trapping low-abundance spawning runs using traditional and novel traps, manual removal, and nest destruction.
Cost:	Develop a technical assistance proposal to address where and how to implement this strategy.

Objective 3:	By 2013, reduce recruitment by capturing newly metamorphosed sea lampreys during their downstream migration to the lake.
Strategy:	By 2011, develop criteria for stream selection and gear placement to capture out-migrating sea lampreys.
Cost:	Included in the base program.

Strategy:	By 2012, capture out-migrating sea lampreys from streams where large numbers of metamorphosing-phase sea lampreys are known or suspected.
Cost:	Purchase ($27K) and operate ($22K) screw traps. Purchase ($10K) and operate ($22K) fykenets (necessary only if streams are deferred for treatment).

Alternative Control

Techniques other than traditional methods used to control sea lamprey populations (lampricide applications) are considered alternative control methods. Alternative control methods currently being implemented are the SMRT program, trapping for control, and barriers. Trapping for control was previously discussed. Application of pheromones is currently being evaluated via control-scale field applications. Migrations of spawning-phase sea lampreys into Lake Ontario tributaries typically occurs earlier than on the upper Great Lakes and logistics of transporting, sterilizing, and releasing sterile males preclude implementation of the SMRT program in Lake Ontario tributaries. Therefore, this alternative control is currently not available for Lake Ontario. Other potential alternative controls currently being researched include genetic manipulation, agonists and antagonists for chemical cues, manual destruction of sea lamprey nests, and repellents.

Pheromones

Pheromones have promise as an alternative control methodology (Li et al. 2007). Although pheromones have been envisioned in a variety of applications, their first use will likely be to augment trapping efficiency. Field trials using the synthetic pheromone 3kPZS to attract migrating, spawning-phase sea lampreys to traps were initiated in ten United States rivers in 2009 and expanded to an additional ten Canadian tributaries in 2010, including six tributaries to Lake Ontario: the Humber River; Cobourg Brook; and Duffins, Bowmanville, Graham, and

Shelter Valley Creeks. Preliminary results indicated that more sea lampreys were attracted to the pheromone baited traps than the un-baited traps. Field trials are scheduled to continue in 2011. Additional pheromone components are being investigated for inducing behavioral responses in spawning-phase sea lampreys. A detailed plan to implement pheromones in control applications will be developed once the ability to manipulate sea lamprey migratory behavior through *in situ* applications is better understood.

Objective 1: By 2013, develop a lakewide, integrated pheromone plan.

Strategy: Continue researcher and agent coordination and implementation of pheromone field studies to build expertise in pheromone handling, deployment, and application.

Cost: To be determined.

Strategy: Evaluate proposed strategies for integration as efficacy of various pheromone compounds is demonstrated for their integration with other control techniques and implement at least one such strategy by 2013.

Cost: To be determined.

Strategy: Register or secure experimental use permits for pheromone compounds to ensure the ability to implement new pheromone methodologies as they become available.

Cost: To be determined.

Barriers

Barriers to block migrating, spawning-phase sea lampreys have been constructed or modified on 14 Lake Ontario tributaries and one Oneida Lake tributary (Fig. 54). Nine of these are low-head dams that allow for passage of jumping fishes, and they have reduced or eliminated production of larval sea lampreys (Table 24). The remaining six barriers were constructed for other purposes but have been modified to also block sea lamprey migration. Construction of another low-head dam is planned in 2012 on Pekin Brook, a tributary to the Salmon River (near Pulaski, New York). Efforts are undertaken annually to ensure that blockage of sea lamprey migration occurs at barriers other than those built for sea lamprey control, often referred to as *de facto* barriers. As of 2009, 144 barriers were inventoried in the Lake Ontario basin, and their importance to sea lamprey control is being assessed.

Fig. 54. Locations of Lake Ontario tributaries with sea lamprey barriers. Structures that have been modified to prevent the upstream migration of sea lamprey are indicated by an asterisk (*).

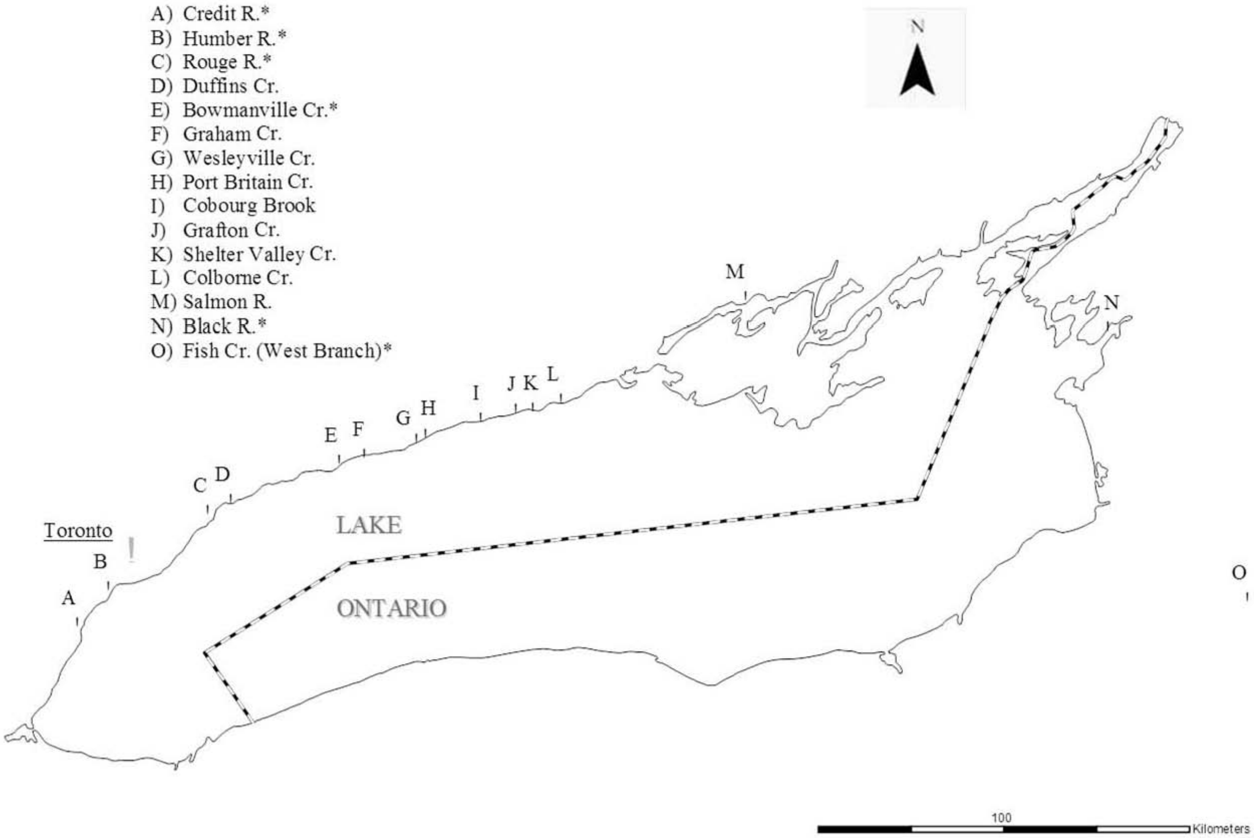


Table 24. Location, date of construction, and distance upstream for sea lamprey barriers purposely built exclusively to block sea lamprey migrations on Lake Ontario tributaries. Letters correspond to those in Fig. 54.

Letter	Stream	Date of construction	Distance from stream mouth (km)	Comments
D	Duffins Creek	1980	6.0	Low-head dam with built-in trap
F	Graham Creek	1984	1.0	Low-head dam with built-in trap
G	Wesleyville Creek	2003	0.5	Low-head dam
H	Port Britain Creek	1989	1.0	Low-head dam with built-in trap
I	Cobourg Brook	1996	0.9	Low-head dam with built-in trap
J	Grafton Creek	1987	0.2	Low-head dam
K	Shelter Valley Creek	1985	0.5	Low-head dam with built-in trap
L	Colborne Creek	1984	0.9	Low-head dam
M	Salmon River	1997	3.0	Low-head dam with built-in trap

Objective 1: Maintain the ability of the nine purpose-built and six modified *de facto* sea lamprey barriers to block spawning-phase sea lampreys.

Strategy: Conduct larval assessments upstream of barriers consistent with a stream's treatment cycle to ensure that sea lampreys have not breached the barrier.

Cost: Included in the base program.

Strategy: Conduct annual inspections and repair or replace worn, broken, or missing parts before they affect barrier performance.

Cost: Included in the base program.

Strategy: Evaluate and fix barriers that fail to block spawning-phase sea lampreys consistent with their design objectives. The candidate is Duffins Creek.

Cost: Variable, depending on the stream. Monitoring is included in the base program.

Objective 2: Annually investigate areas where purpose-built barriers can be constructed consistent with the Barrier Strategy and Implementation Plan.

Strategy: Meet with the U.S. Army Corps of Engineers semi-annually to discuss funding, research, and expertise to design, plan, and fund barriers in the United States.

Cost: Dependent on the stream identified.

Strategy: Develop partnerships with others to obtain funding and support for barrier projects.

Cost: Variable, depending on the stream.

Strategy: By 2013, develop a new process for selecting and ranking proposed sites for barriers.

Cost: Included in the base program.

Objective 3: Ensure spawning-phase sea lampreys remain blocked at important *de facto* barriers.

Strategy: By 2012, include *de facto* barriers in the barrier database. By 2013, develop a ranking method based on each barrier's importance to sea lamprey control and note the barriers condition and future maintenance issues.

Cost: Included in the base program.

Strategy: By 2013, develop a policy and work with partners to agree to preserve the integrity of the furthest downstream barriers that currently block sea lampreys.

Cost: Included in the base program.

Strategy: By 2014, use the barrier database to maintain a list of structures that currently do not block sea lampreys but have the potential to be converted to a successful barrier and pursue modification through the ranking process.

Cost: Included in the base program.

Objective 4: Integrate barriers with other methods of control to effectively control sea lampreys.

Strategy: Identify potential sites where barriers, in combination with alternative methods, can contribute to effective control or suppression.

Cost: Dependent on site selection.

Metrics and Measures of Success

Background

In 2004, the Lake Ontario Committee established a target number of spawning-phase sea lampreys based on the estimated number of spawning-phase sea lampreys present during 1993-1997 and the fact that this number of lampreys produced a low marking rate on lake trout, an average of 1.3 Type A, Stage I marks per 100 fish >433 mm. The lakewide number of spawning-phase sea lampreys was estimated from a combination of mark-recapture estimates of spawning-phase migrants in streams with traps and, in streams without traps, the number of spawning-phase migrants predicted by a regression model. Model estimates are updated each year after the model is calibrated with data on the catch of spawning-phase migrants. In 2010, the calculated target abundance using current data was 31,000 ± 4,000 sea lampreys.

The use of Type A, Stage I marks (vs. Type A, Stages I-III marks) is unique to Lake Ontario and is supported by Schneider et al. (1996) who found that among all the mark types and their combinations, Type A, Stage I marks had the highest correlation with the number of lake trout killed by sea lampreys in Lake Ontario. The marking target in Lake Ontario has been set at two Type A, Stage I marks per 100 lake trout (Stewart et al. 1999).

Objective 1:	By 2012, use sea lamprey marking rates to develop sea lamprey abundance targets for other species vulnerable to sea lamprey attack in the Lake Ontario fish community.
Strategy:	Maintain the standardization of sea lamprey mark identification through periodic workshops at intervals of no more than five years.
Cost:	~$4K.
Strategy:	By 2013, evaluate present sea lamprey targets (two Type A, Stage I marks per 100 lake trout >433 mm and 31,000 spawning-phase sea lampreys) to determine if fishery managers agree that fish-community objectives are being met.
Cost:	Included in the base program.
Strategy:	By 2014, analyze time-series data to evaluate if there are effects of climate change on sea lamprey length, weight, growth, feeding duration, fecundity, and host mortality.
Cost:	Requires research or a technical assistance proposal.
Strategy:	For reporting progress towards targets, use five-year moving averages and slopes of five-year trends of lake trout marking rate and spawning-phase sea lamprey abundance.
Cost:	Included in current base program.

Objective 2: By 2012, reevaluate targets for abundance of spawning-phase sea lampreys and, if necessary, develop new targets.

Strategy: By 2012, develop regional targets for sea lamprey abundance based on marking in the entire fish community and the revised objectives proposed in this plan.

Cost: Requires research or a technical assistance proposal.

Strategy: Reevaluate the methods used to determine abundance of spawning-phase sea lampreys and measure the influence of climatic factors, such as temperature and precipitation (flow), on annual variation in trap catchability. Coordinate with Objective 1 in Trapping.

Cost: Requires research or a technical assistance proposal.

Recommended Strategies to Achieve Targets

The Five-Year Plan implements a base program of lampricide control, assessment, and alternative controls designed to support the fish-community objectives for Lake Ontario at an annual cost of about $1,659,766 (based on the fiscal year 2011 budget). Despite these efforts, the number of spawning-phase sea lampreys during 2006-2010 averaged 44,066, well above the target of 31,000. Maintaining the target level of sea lamprey abundance in Lake Ontario will require implementation of additional control actions.

Historic lampricide treatment and larval assessment data suggest that the most likely source of parasitic-phase sea lampreys is larvae that survive lampricide applications (residuals) in streams that contain the greatest numbers of larvae. Analyses designed to forecast the effects of various treatment scenarios suggest that lakewide abundance of spawning-phase sea lampreys can most reliably be affected through whole-lake selection of streams to treat for residuals. Lakewide spawning-phase abundance is used to measure program success because this is currently the best measure available. In addition, the construction, maintenance, and repair of both purpose-built and *de facto* barriers are direct actions that aim to minimize spawning-phase sea lamprey abundance. Recommended strategies to reach targets within the next five years are listed below.

Lampricide Control

Annual effort: Lake Ontario accounts for 8% of the lampricide control effort expended throughout the Great Lakes basin, based on an average of control expenditures during 2005-2009. In 2011, $935,700 will be spent on lampricide control in Lake Ontario, and these funds will provide the level of control required to maintain the long-term average abundance of spawning-phase sea lampreys in the lake.

To get to targets:	Within the next five years, allocate additional staff days for back-to-back treatment of streams with the largest potential for producing residual sea lampreys. Treatments would be conducted in two consecutive years in the Salmon, Little Salmon, Credit, and Black Rivers and South Sandy, Lindsey, and Little Sandy Creeks. This strategy is expected to reduce the residual population by 66% over a two-year period. Moreover, this strategy should result in a commensurate reduction of spawning-phase sea lampreys and marking on lake trout to target levels beginning two years after completing the back-to-back treatments.
Additional cost:	~$297,234 in year one and $343,284 in year two (based on implementation in 2012).

This recommendation is based on the assumption that the largest source of parasitic-phase sea lampreys in Lake Ontario is larval lampreys that survive lampricide applications, metamorphose, and migrate into the lake. In addition, we also assume that we have accounted for all sources of sea lamprey production, that production in the streams treated back-to-back has been quantified correctly in relation to other streams, that lampreys randomly disperse throughout the lake, and that a reduction in the residual larval populations will have a commensurate effect on spawning-phase sea lamprey abundance and lake trout marking rates.

Larval Assessment

Annual effort:	Current assessment supports the among-stream prioritization and within-stream targeting of lampricide control activities, including evaluating treatment effectiveness, assessing the success of barriers, and detecting new infestations of sea lampreys. In 2011, the cost of larval assessment to direct the current level of lampricide control in Lake Ontario is $256,654.
To get to targets:	Ensure upstream and downstream limits of sea lamprey infestation are accurately determined for the Salmon, Credit, Little Salmon, and Black Rivers and South Sandy, Lindsey, and Little Sandy Creeks.
Additional cost:	~$10K in year one and ~$5K in year two to conduct distribution surveys on the additional streams scheduled for treatment.

To get to targets:	Increase the frequency of surveys to detect new populations of sea lamprey larvae from once every ten years to once every five years in streams with suitable spawning and nursery habitats.
Additional cost:	~$5K each year. Increased assessment is designed to ensure that all sources of sea lampreys are known.

Alternative Control Barriers

Annual effort:	Maintenance of the current barrier network, both purpose-built and *de facto* barriers, limits sea lamprey recruitment and increases in spawning-phase sea lamprey abundance. For Lake Ontario in 2011, the forecasted cost of barrier inspection and maintenance is $247,512.
To get to targets:	Evaluate and fix the barrier on Duffins Creek. Spawning-phase sea lampreys have breached this barrier in recent years. Repairing it will help ensure that migrating spawning-phase sea lampreys are blocked and lampricide treatment costs are reduced.
Additional cost:	Cost is dependent on the evaluation of the escapement route and subsequent repairs.

Metrics of Success

Annual effort:	Stream-specific mark-recapture estimates of spawning-phase sea lamprey abundance are the foundation for a model that uses stream discharge, treatment history, and production potential to calculate regional and whole-lake population estimates. The cost of spawning-phase assessment in Lake Ontario is $219,901 for 2011. Along with marking rates on lake trout, which are collected and assembled by federal, state, and provincial fisheries agencies, spawning-phase estimates are used to evaluate performance of the Five-Year Plan. Evaluation of model performance is an ongoing task and benefits lake-specific estimates of spawning-phase sea lamprey abundance across the Great Lakes basin. Alternative methods of estimating fish damage are currently being investigated by the Quantitative Fisheries Center at Michigan State University.
To get to targets:	In the model used to estimate spawning-phase sea lamprey abundance, continue to evaluate parameters that will increase the precision of estimates and implement recommended improvements.
Additional cost:	Dependent on the results of ongoing analyses.

To get to targets:	Maintain standardization of sea lamprey mark identification through periodic workshops at intervals of no more than five years.
Additional cost:	~$4K every five years to sponsor workshops.

Maintaining Targets and the Judicious Use of Lampricides

Advancing alternative control technologies and techniques is critical to maintaining targets and applying lampricides in a judicious manner. Strategies, such as the application of pheromones to improve trap efficiency, are currently being evaluated whereas others, such as incorporating traps into planned barriers, are closely associated with strategies yet to be implemented (i.e., barrier construction). Additional strategies, such as increasing trapping effectiveness, reducing recruitment by manual removal of spawning-phase sea lampreys, and development of improved methods to evaluate program success, rely on research designed to evaluate their potential. New alternative controls will benefit actions designed to reduce or maintain sea lampreys at target levels throughout the Great Lakes and are not necessarily specific to Lake Ontario. However, the costs for implementing these strategies are not well defined. Estimated costs to advance these technologies and techniques are included in Chapter 7 (Summary) and will require research related to these four general areas: application of pheromones, trapping techniques, methods to reduce recruitment, and sea lamprey/host interactions.

Communication

See Appendix A for information about who to contact about the sea lamprey control program.

CHAPTER 7: SUMMARY

Michael Siefkes[9]

Introduction

This chapter provides a summary of the economic importance of the sea lamprey (*Petromyzon marinus*) control program and the recommended strategies for each program element to achieve sea lamprey targets in each of the Great Lakes. Current and recommended funding for each element of the control program in each lake is summarized in Table 25. Additionally, the Five-Year Plan and budget decision process of the Great Lakes Fishery Commission (GLFC) is briefly outlined. This chapter concludes with a look to the future of sea lamprey control, including the process used to identify and communicate research priorities and how the evaluation of program success can be enhanced through better integration of sea lamprey control and fishery management. The GLFC, in collaboration with fisheries managers, has developed this lake-specific Five-Year Plan as an integrated sea lamprey control strategy that focuses on lakewide and locality-specific control tactics to maintain sea lamprey populations at or below target levels.

Table 25. For each Great Lake and for all lakes combined, the cost of various elements of the sea lamprey control program in fiscal year 2011 (October 1, 2010-September 30, 2011) and the recommended funding needed to achieve targets in the next five years.

Lake/program	Program element	FY2011	Recommended to reach targets
Superior	Lampricide control	$3,254,167	$4,354,200
	Larval assessment	$901,398	$1,012,400
	Adult assessment	$484,731	$484,731
	Barriers	$381,517	$381,517
	Measures of success	$0	$27,000
	Total	$5,021,812	$6,259,848

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Table 25, continued

Lake/program	Program element	FY2011	Recommended to reach targets
Huron	Lampricide control	$3,912,855	$3,100,000
	St. Marys River	$2,100,000	$2,100,000
	Larval assessment	$842,600	$842,600
	Adult assessment	$502,317	$502,317
	Barriers	$476,387	$556,387
	SMRT	$792,294	$792,294
	Measures of success	$0	$30,000
	Total	$8,626,454	$7,923,598
Michigan	Lampricide control	$3,848,883	$6,149,000
	Larval assessment	$999,535	$1,112,000
	Adult assessment	$425,963	$425,963
	Barriers	$282,997	$282,997
	Trail Creek construction	$57,000	$0
	Manistique River construction	$820,000	$1,680,000
	Days River construction	$0	$150,000
	Measures of success	$0	$22,000
	Total	$6,434,378	$9,821,960
Erie	Lampricide control	$470,840	$470,840
	Larval assessment	$200,083	$215,100
	Adult assessment	$88,928	$88,928
	Barriers	$183,331	$183,331
	Measures of success	$0	$22,000
	Total	$943,182	$980,199
Ontario	Lampricide control	$935,700	$1,255,700
	Larval assessment	$256,654	$269,000
	Adult assessment	$219,901	$219,900
	Barriers	$247,512	$325,000
	Measures of success	$0	$22,000
	Total	$1,659,766	$2,091,600
Basinwide program	Lampricide control	$12,422,444	$15,329,740
	St. Marys River	$2,100,000	$2,100,000
	Larval assessment	$3,200,270	$3,451,100
	Adult assessment	$1,721,840	$1,721,839
	SMRT	$792,294	$792,294
	Barriers (operation/maintenance)	$1,571,743	$1,729,232
	Trail Creek construction	$57,000	$0
	Manistique River construction	$820,000	$1,680,000
	Days River construction	$0	$150,000
	Measures of success	$0	$123,000
	Total	$22,685,592	$27,077,205

Economic Importance

Rehabilitated fish communities are the key to a healthy Great Lakes ecosystem and sustainable, economically valuable fisheries. For more than 50 years, sea lamprey control has been an integral component of the suite of actions taken to rehabilitate Great Lakes fish communities supporting the millions of dollars of investments federal, provincial, state, and tribal governments make each year to restore and protect the fishery. Today, the Great Lakes support a thriving fishery worth an estimated $7 billion annually to the people of Canada and the United States. Without sea lamprey control, the Great Lakes ecosystem would be devastated, and the fishery would collapse along with the local economies it supports.

Summary of Strategies to Reach Targets

To ensure recovery and sustainability of the Great Lakes ecosystem, fishery, and fishery-supported economies, each lake committee has identified specific fish-community objectives that include objectives to reduce sea lamprey abundance and marking rates on lake trout (*Salvelinus namaycush*) to specific targets in each lake. The recommended strategies to reach targets are described in detail at the end of each lake chapter. A summary of the GLFC's approach to allotting funds among the individual program elements and the current cost of sea lamprey control are shown in Table 25 along with the funds needed to implement the recommended strategies.

Lampricide Control

Application of the lampricides 3-trifluoromethyl-4-nitrophenol (TFM) and 5,2'-dichloro-4'-nitrosalicylanilide (Bayluscide) to streams and lentic areas that harbor larval sea lampreys is the primary method of sea lamprey control. The current lampricide treatment strategy is to apply a base amount of effort across all lakes based on the cost-per-kill of large larvae. Recently, however, extra effort has been allocated to apply large-scale treatment strategies to lakes or portions of lakes where sea lamprey abundance and lake trout marking are greater than targets. In particular, all known sea lamprey producing tributaries to Lake Erie were treated in consecutive years (2008-2010) to reduce an excessively large sea lamprey population to the target level. In 2010, the GLFC and the control agents initiated a second large-scale treatment strategy in the St. Marys River and the North Channel and Detour Passage area of Lake Huron. This strategy is designed to suppress sea lampreys in Lake Huron to target level for the first time and to protect a lake trout population that is edging closer to restoration, as evidenced by recent increases in natural reproduction. Other large-scale treatment strategies have been developed and are being evaluated for implementation during 2012.

Larval Assessment

Larval assessment is primarily used to guide lampricide control by monitoring the presence, distribution, and relative abundance of sea lampreys in tributaries and offshore lentic areas of the Great Lakes. Larval assessment determines where, when, and how often lampricide treatments should occur and the efficacy of past treatments. Recently, the GLFC has been striving to identify the minimum amount of larval assessment needed to best guide lampricide control. Reducing assessment may allow for the re-direction of resources to treat more streams with lampricides. Further refinement of the Five-Year Plan to ensure the optimum mix of larval assessment and control is ongoing.

Spawning-Phase Assessment

Spawning-phase sea lamprey abundance is the primary performance indicator of the Five-Year Plan. For each Great Lake, the lakewide abundance of spawning-phase sea lampreys is estimated by summing population estimates generated using mark-recapture and extrapolated trap catches for tributaries with traps and, for tributaries without traps, model estimates of sea lamprey numbers based on stream-specific variables. Currently, spawning-phase sea lamprey traps used to generate tributary-specific population estimates are located on about 72 tributaries across the Great Lakes. Efforts are under way to improve and expand the trapping network and to better evaluate the accuracy and precision of model-based estimates of spawning-phase sea lampreys in tributaries without traps. Results of these efforts will likely improve the GLFC's ability to assess the performance of the Five-Year Plan.

Barriers

Sea lamprey barriers prevent spawning-phase sea lampreys from reaching suitable spawning habitat and thus reduce or eliminate larval sea lamprey production and the subsequent need for lampricide treatment. Sea lamprey barriers include purpose-built barriers, structures that were specifically built to block spawning-phase migrations, and *de facto* barriers, dams, or other structures not specifically built for sea lamprey control (i.e., water control, hydroelectric production, recreation, etc.) but that also serve to block spawning-phase migrations. As an alternative to lampricide application, barriers are the most effective form of sea lamprey control. Across the Great Lakes basin, there are about 60 purpose-built sea lamprey barriers and hundreds of *de facto* barriers.

The GLFC's Sea Lamprey Barrier Policy focuses on the maintenance of existing purpose-built barriers, cooperation with partners to maintain *de facto* barriers, and construction of new purpose-built barriers in critical tributaries. Currently, deteriorating *de facto* barriers on the Black Sturgeon (Lake Superior), Manistique (Lake Michigan), Saugeen (Lake Huron), and Grand (Lake Erie) Rivers have the potential to open large areas of spawning and larval habitat to sea lampreys and, therefore, pose a major threat to the Five-Year Plan. Escalating costs of barrier construction and maintenance pose significant challenges to the barrier program, especially in lean budget years. Additional challenges include human safety, navigation, and the impacts on the passage of non-jumping migratory fishes.

Sterile-Male Release

The release of sterilized male sea lampreys into a breeding population paired with removal of fertile males and females from the same population reduces the reproductive potential of the population. Male sea lampreys are collected for sterilization from about 25 trap sites across all lakes except Lake Erie. Currently, the sterile-male release technique (SMRT) program is only applied in the St. Marys River where, due to cooler water temperatures, the spawning migration starts later than in other Great Lakes tributaries. The later spawning migration allows for the transport, sterilization, and release of males captured from other areas of the Great Lakes, which facilitates the release of more sterile males over a longer period of time. The limited number of male sea lampreys available for sterilization prevents application of the SMRT program in other areas. If trapping performance can be enhanced to provide more males, the SMRT program could be applied in areas where lampricide control and barriers are ineffective or unfeasible or where populations have been suppressed by conventional means. Further investigation into the efficacy of the SMRT program will also better guide its application in the future.

Trapping for Control

Trapping for control consists of capturing and removing spawning-phase sea lampreys from tributaries across the Great Lakes basin as well as capturing and removing metamorphosing sea lampreys on their downstream migration. Currently, trapping for control of spawning-phase sea lampreys is most effective in providing male sea lampreys for the SMRT program because not enough sea lampreys can be removed through trapping (efficiency is typically only 40%) to affect the reproductive potential of the spawning population. Trapping of metamorphosing sea lampreys removes sea lampreys that have a high probability of marking fish, but applications of this type of trapping are limited and the efficiency of capture is low. As more information is gained about sea lamprey behavior (including the pheromone-induced behaviors) and as new trapping technologies are designed and developed, trapping for control will become more effective, and its role in sea lamprey control will expand.

Pheromones

Sea lamprey pheromones have the potential to significantly contribute to the Five-Year Plan by disrupting mating through the manipulation of pheromone-induced behaviors, acting as attractants to improve trapping efficacy, or both. The GLFC continues to invest much research and effort into identifying and synthesizing sea lamprey pheromones, resulting in the elucidation of chemical cues that affect migration, mating, and avoidance behaviors. Additionally, one component of the male sea lamprey mating pheromone, 3kPZS, is currently being developed as a trap bait to increase the efficacy of sea lamprey traps. Other potential strategies using sea lamprey pheromones for control purposes are also being explored.

Program Decision and Budget Process

Each year, the GLFC decides on the next year's sea lamprey control program and budget at its annual and interim executive meetings held in June and December. Final decisions on the program and budget are made during the December interim meeting. Fiscal constraints preclude the implementation of all the recommended strategies to reach targets for spawning-phase sea lamprey abundance and lake trout marking. Therefore, decisions must be made annually on how best to apply sea lamprey control and allocate fiscal resources across the Great Lakes basin.

To assist the GFLC in its decision-making process, the Sea Lamprey Integration Committee (SLIC) serves as an advisory committee with membership including sea lamprey control agents, fishery managers, Great Lakes ecologists, integrated pest-management experts, and other specialists. Technical subcommittees, including the Assessment, Barrier, Lampricide Control, and Reproduction Reduction Task Forces and a Program Integration Work Group that synthesizes task-force budgets provide the SLIC with program and budget recommendations. The SLIC meets twice a year (spring and fall) to develop recommendations for the GLFC to consider during their executive meetings.

In addition to the SLIC and its technical subcommittees, the GLFC also receives input directly from the lake committees through the Council of Lake Committees (CLC) and GLFC advisors, government-appointed members of the public who represent different groups of stakeholders. The CLC also meets twice a year during the spring and fall and usually coordinates recommendations to the GLFC with the SLIC. Advisors to the GLFC meet during lake committee meetings held in March and also during the plenary session of the GLFC’s annual meeting held in June.

All recommendations are coordinated and presented to the GLFC by the GLFC’s Secretariat staff who assist at every level of the GLFC advisory process. The GLFC takes all recommendations into consideration when deciding on programs and budgets for the coming year. Once GLFC decisions are made, they are then communicated to agencies and the public through the Secretariat staff.

Future Directions

Currently, the sea lamprey control program implements an integrated pest-management approach that uses assessment to guide and evaluate a variety of control strategies. These techniques have been developed over the past 50 years, and their development will continue and new technologies will be integrated as they emerge.

The GLFC’s sea lamprey research program investigates new control technologies. When research projects are ready to be developed and tested at management scales for incorporation into the sea lamprey control program, the GLFC’s development program takes over. To help guide research and development of new control tactics, there are five research theme papers in the Journal of Great Lakes Research in 2007 that capture current knowledge and identify research needs for lampricide control, barriers and trapping, sea lamprey population dynamics, sterile-male release, and the incorporation of pheromones into the sea lamprey control program (currently in development). Additionally, the SLIC's technical subcommittees annually present research priorities to the Sea Lamprey Research Board to help guide recommendations for funding research projects. A list of research needs is presented in Chapter 1 (Sea Lamprey Control in the Great Lakes Basin). Beyond the principal sea lamprey control program areas, sea lamprey pheromones, repellents, and genetics are emerging areas that show promise for use in sea lamprey control.

Improving methods to evaluate the success of various control actions is a priority of the Five-Year Plan. Plans are under way to better estimate sea lamprey marking rates and how they are affected by the species composition, size structure, abundance, and temporal and spatial distribution of host fishes. These analyses will better link sea lamprey control to the fish community as a whole and allow for a more thorough assessment of the impacts of the sea lamprey control program.

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APPENDIX A

Additional information on any aspect of the sea lamprey control program can be obtained by contacting the following people.

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APPENDIX B

Lake Superior

Lake Superior tributaries with a history of sea lamprey infestation. Stream number corresponds to values in Fig. 7, denoting the location of stream mouth.

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
1	East Davignon Creek	1972			
2	West Davignon Creek	2004	23,007	2,486	
4	Little Carp River	2008	37,108	2,350	144
5	Big Carp River	2007	43,598	21,188	24
23	Cranberry Creek	2004	60,914	5,146	9
24	Goulais River	2009	2,468,165	1,488,050	1,160
34	Havilland Creek		5,494		
36	Stokely Creek	2008	17,557	4,706	
	Lentic	2010		4,831	
39	Harmony River	2009	4,511	6,272	89
41	Sawmill Creek	1968	5,050		
48	Chippewa River	2004	105,784	7,607	514
	Lentic			167,257	
49	Unnamed Tributary		380		
50	Unger Creek		45		
52	Batchawana River	2007	276,616	503,411	696
	Lentic	2007		369,912	
53	Digby Creek				
54	Carp River	2009	18,712	19,856	262
56	Pancake Creek	2008	65,894	73,733	220
58	Westman Creek		845	100	
93	Agawa River	2010	13,453	4,202	185
	Lentic	2010			
100	Sand River	1971			
105	Baldhead River		20,227		
116	Gargantua River	2009	23,282	7,950	134
167	Michipicoten River	2008	571,612	1,541,200	2,620

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
	Lentic	2010			
202	Dog River	1963			
301	White R., Main	2005	239,835	103,578	
305	Pic River	2006	3,299,459	147,624	734
322	Little Pic River	1994	513,206	2,536	811
327	Prairie River	1994			264
335	Steel River	2008	67,329	106,593	
360	Pays Plat River	2007	101,207	221,362	65
361	Little Pays Plat R.	2007	14,206	10,889	
368	Gravel River	2008	203,057	372,860	421
	Lentic	2009		317,056	
369	Little Gravel River	2008	20,390	68,397	122
373	Little Cypress River		240		
374	Cypress River	2009	20,527	30,272	214
	Lentic	2009		9,212	
385	Jackfish River	2008	128,349	19,289	623
392	Nipigon River		1,802,825		5,757
	Upper	2009		191,470	
	Lower	2006		94	
	Cash Creek	2009		184,151	
	Stillwater Creek	2009		1,395	
	Lake Helen Lentic	2010		2,181	
457	Big Trout Creek	2010	24,314	28,169	
482	Otter Cover Creek	1971			
509	Black Sturgeon River	2005	458,455	4,741	2,704
517	Wolf River	2007	67,144	17,390	295
518	Coldwater Creek	2007	52,154		
528	Pearl River	2010	15,111	27,853	18
529	D'Arcy Creek	2010	5,296		
545	Blende Creek				
556	Mackenzie River	2008	377	1465	
	Lentic			16,326	
567	Current River				

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
	Lentic	2010			
571	Neebing-McIntyre Floodway		314,745	13,697	1,663
572	Kaministiquia River	2010	1,478,318	1,962,201	2,918
	Lentic	2010			
587	Cloud River	2008	103,856	988	114
589	Pine River	1973			
592	Pigeon River	2007	218,902	2,262	3,633
	Lentic	2010	52,204		
10003	Waiska River	2007	52,227	34,824	
10007	Sec. 11SW Creek		356		
10013	Pendills Creek	1988	2,487		
10014	Grants Creek	2008	2,445	1,700	
10017	Naomikong Creek	1963	15,101		
10018	Ankodosh Creek	2008	17,289	1,083	
10019	Roxbury Creek	2008	8,232	1,642	
10021	Galloway Creek	2007	10,354	3,636	25
10022	Tahquamenon River	2006	991,827	58,522	5,394
10027	Betsy River	2006	151,012	25,982	638
10050	Three Mile Creek	1962	6,063		
10051	Little Two Hearted River	2008	148,385	31,919	190
10053	Two Hearted River	2010	716,282	585,637	468
10063	Dead Sucker River	1975	43,014		
10064	Sucker River	2010	268,263	106,669	383
10073	Chipmunk Creek		2,860		
10074	Carpenter Creek	2010	1,609	602	
	Lentic	2010	99,957		
10076	Sable Creek	1989	9,038		
10077	Hurricane River				
10078	Sullivans Creek	2010	2,132	4,339	
10079	Seven Mile Creek	1967	28,142		
10090	Beaver Lake Creek (Alger)	2010	34,091		
10095	Mosquito River	1973	34,663		
10096	Miners River	2010	37,887	20,316	470

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
10097	Munising Falls Creek	1964	5,491		
10104	Anna River	1965	36,722		
10105	Tourist Park Creek				
10108	Furnace Creek	2010	15,510	1,654	485
	Lentic	2010	83,365		
10109	Five Mile Creek	2007	2,585	2,487	7
10110	Au Train River	2008	399,197	131,942	235
10115	Rock River	2002	113,514	14,047	856
10121	Deer Lake Creek (Sucker Run)	1970	11,097		
10122	Laughing Whitefish River	2009	26,041	8,569	34
10124	Sand River	1985	12,241		
10126	Chocolay River	2009	255,776	851,585	594
10150	Carp River	2009	25,326	68,998	13
10153	Dead River	2010	110,699	207,028	
	Lentic	2010	174,420		
10155	Harlow Creek	2010	39,971	51,344	158
10156	Little Garlic River	2009	34,032	62,805	60
10157	Garlic River	2009	77,630	61,904	285
10158	Iron River	2009	140,415	67,366	381
10159	Salmon Trout River	2009	97,039	476,355	765
10160	Pine River	2004	97,019	7,582	
10181	Huron River	2009	86,795	98,433	363
10188	Ravine River	2010	12,939	18,789	51
	Lentic	2010	52,609		
10189	Slate River	2009	625		
10190	Silver River	2010			472
10194	Falls River	2010	9,347		1,208
	Lentic	2010	187,369		
10196	Six Mile Creek	1963	3,300		
10200	Sturgeon River	2010	1,576,214	275,231	1,232
10220	Pilgrim River	1962	42,900		
10222	Trap Rock River	2009	87,011	230,321	19
	Lentic	2010	42,087		127

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
10224	McCallum Creek	1963	9,152		
10226	Traverse River	2009	44,077	203,722	
10232	Little Gratiot River	1972	29,058		
10242	Eliza Creek	2007	1,283	4,618	
10248	Gratiot River	2006	11,466	26,887	
10257	Smiths Creek	1964	8,008		
10260	Boston-Lily Creek	1962	10,982		
10270	Salmon Trout River	2008	2,940		2,239
10271	Mud Lake Outlet	1973	48,963		
10280	Graveraet River	1963	27,113		
10281	Elm River	2007	21,507		
10284	Misery River	2007	194,847	10,691	385
10287	East Sleeping River	2008	85,913	61,419	368
10288	West Sleeping River	2009	23,597		
10289	Firesteel River	2008	304,174	83,497	66
10292	Flintsteel River				
10295	Ontonagon River	2008	2,099,778	4,033,535	11,865
10313	Potato River	2008	73,104	9,673	247
10314	Floodwood River		64,329	23,457	
10315	Cranberry River	2008	81,603		228
10323	Mineral River	2010	29,014		
10324	Big Iron River				
10325	Little Iron River	1975			
10328	Union River	1964	16,702		
10366	Black River	1981	78,076		
10420	Montreal River	1975	17,961		
10500	Washington Creek	1980	23,795		
10611	Bad River	2008	2,219,333	1,683,808	13,096
10634	Fish Creek (Eileen Twp.)	2007	221,610	3,013	
10641	Sioux River				
10648	Red Cliff Creek	2007	15,491	4,089	85
	Lentic			27,586	
10649	Raspberry River	1963	27,456		

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
10660	Sand River (Bayfield)	2007	46,647		133
10671	Cranberry River		13,728		
10676	Iron River	2007			
10677	Reefer Creek	1964	39,532		
10678	Fish Creek (Orienta Twp.)	1964	4,576		
10679	Brule River	2009	105,025	320,095	3,266
10701	Poplar River	2008	56,084	48,997	327
10703	Middle River	2008	75,232	5,833	927
10705	Amnicon River	2009	60,336	309,485	2,707
10712	Nemadji River	2009	365,698	286,649	2,613
10726	St. Louis River	1987	138,424		
10820	Sucker River		8,122		
10848	Gooseberry River	1976	6,063		
10849	Split Rock River	1976	8,694		
10889	Poplar River	1977	11,898		
10901	Arrowhead River	2009	19,219		

* Estimate based on average measures of infested area and proportions of larval habitat.

Lake Michigan

Lake Michigan tributaries with a history of sea lamprey infestation, year last treated, estimated areas of larval habitat, maximum estimate of larval sea lamprey abundance, and five-year average abundance of spawning-phase sea lamprey. Stream number can be referenced in Fig. 16 to note spatial location of stream mouth.

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
4	Brevort River	2008	194,457	24,151	22
	Lentic				
9	Paquin Creek	1987	21,218		
	Lentic				
11	Davenport Creek	1963	28,759		
12	Hog Island Creek	2009	13,060	36,928	378
	Lentic	2007	44,880		
13	Sucker Creek	1961	8,061		
14	Black River	2009	82,087	330,726	459
	Lentic				
19	Mattix Creek	2010	2,169	763	
21	Mile Creek	1972	2,119	117	
	Lentic				
23	Millecoquins River	2010	224,940	79,196	2,240
	Lentic				
29	Rock River	2006	11,455	71,269	66
31	Crow River	2009	36,491	392	
32	Cataract River	2010	9,592	11,814	
	Lentic				
33	Point Patterson Creek	1983	9,586		
35	Hudson Creek	2008	5,739	4,382	11
39	Swan Creek	1992	6,411		8
40	Seiners Creek	1984	12,821		
46	Milakokia River	2008	309,355	269,261	1,588
	Lentic				
48	Bulldog Creek	2008	3,629	540	121
50	Gulliver Lake Outlet	2007	8,005	386	34
53	Marblehead Creek	2010	15,064	84,538	26

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
59	Manistique River	2009	5,514,746	1,251,400	35,976
	Lentic	2009	140,426	14,582	
60	Southtown Creek	1977	24,416		
62	Thompson Creek				
63	Johnson Creek	1981	1,378	179	
64	Deadhorse Creek	2009	7,560	1,760	72
67	Gierke Creek				
68	Bursaw Creek	2010	15,244	18,892	110
	Lentic				
70	Parent Creek	1991	5,831	17,085	131
71	Poodle Pete Creek	2001	1,398	11,502	100
84	Valentine Creek	2008	15,756	15,830	142
87	Little Fishdam River	2001	6,171	13,228	142
88	Fishdam River	2008	146,444	64,445	824
93	Sturgeon River	2010	688,424	379,160	1,271
102	Ogontz River	2010	60,682	100,811	223
	Lentic				
117	Squaw Creek	2000	12,097	16	
118	Hock Creek	1981	9,586		
119	Whitefish River	2008	544,545	765,136	1,457
	Lentic				
130	Rapid River	2009	66,981	90,728	1,094
	Lentic				
134	Tacoosh River	2007	18,541	34,399	167
137	Days River	2010	42,361		554
	Lentic				
140	Escanaba River				
	Lentic				
142	Portage Creek	2009	24,950	2,642	250
	Lentic				
143	Ford River	2010	1,294,194	3,210,444	1,872
	Lentic				
152	Sunny Brook	1971	11,400		

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
156	Bark River	2007	79,533	127,972	208
165	Cedar River	2010	1,200,897	403,329	1,434
	Lentic	2010	114,121	11,759	
177	Sugar Creek (Ruleau Creek)	2008	2,653	523	
180	Arthur Bay Creek	2010	2,203	12,531	
181	Rochereau Creek	1963	9,586		
182	Johnson Creek	1963	2,796	2,967	
185	Bailey Creek	2009	4,732	7,596	62
186	Beattie Creek	2009	5,528	1,943	109
	Lentic				
187	Springer Creek	2008	7,161	785	
189	Menominee River	2007			2,596
	Lentic				
197	Little River	1977	31,827		
200	Peshtigo River	2009	687,529	35,159	4,261
216	Oconto River	2009	507,406	27,127	381
221	Pensaukee River	1977	180,039		
234	Suamico River				
271	Ephraim Creek	1963	9,586		
276	Hibbards Creek	2007	32,875	26,397	66
277	Whitefish Bay Creek	1987	25,520		
279	Lily Bay Creek	1963	16,122		
290	Bear Creek		16,122		
292	Door County No. 23 Creek	2007	904	744	
303	Ahnapee River	1964	25,232		
305	Three Mile Creek	2008	17,757	1,007	
313	Kewaunee River	2007	25,394	1,307	
339	East Twin River	2008	81,140	5,589	381
352	Fischer Creek	1987	12,821		
432	French Farm Creek				
433	Carp Lake River	2009	74,089		3,840
	Lentic				
434	Big Stone Creek	2007	2,864	2,541	22

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
436	Big Sucker Creek	2007	22,048	10,323	43
437	Wycamp Lake Outlet	2008	10,889	5,776	25
441	Bear River				
	Lentic	2007	16,187		
455	Horton Creek	2009	4,421	3	1,055
	Lentic	2009	5,000		
458	Boyne River	2010	86,169	161,576	877
	Lentic	2010	30,351		
459	Porter Creek	2009	25,615		256
	Lentic				
467	Jordan River	2007	364,675	371,415	2,156
	Lentic	2007	32,375		
470	Monroe Creek	2007	5,718	854	
	Lentic				
473	Loeb Creek	2008	11,334	37	
476	McGeach Creek	1999	25,509	56,292	
491	Elk Lake Outlet	2004	30,616	30,727	8,522
496	Yuba Creek	2006	7,174	4,435	
497	Acme Creek	1963	35,252		
500	Mitchell Creek	2008	19,393	29,295	64
	Lentic				
501	Boardman River	2010	43,381	38,351	905
	Lentic				
508	Leo Creek				
512	Leland River				
	Lentic				
513	Good Harbor Creek	2007	49,734	21,282	4
514	Crystal River	1972	143,988		
519	Platte River	2009	352,128	1,411,053	3,573
	Lentic				
523	Betsie River	2006	1,116,348	723,014	2,841
	Lentic				
529	Bowen Creek	2009	18,089	29	

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
534	Manistee River	2009	3,499,468	2,119,572	5,042
	Lentic				
	Little Manistee River	2008	626,697	614,518	
	Lentic	2008	29,282		
556	Gurney Creek	2009	10,341	521	113
557	Cooper Creek	2008			
560	Lincoln River	2006	235,152	181,804	973
562	Pere Marquette River	2009	3,947,133	2,383,715	1,023
572	Bass Lake Outlet	1978			
577	Pentwater River	2007	230,280	100,696	1,200
580	Stony Creek	1987		3,545	
586	Flower Creek	1981	59,276	2,659	
591	White River	2007	1,970,692	1,801,967	1,768
610	Duck Creek	1984			
613	Muskegon River	2008	5,999,787	3,116,735	3,367
627	Black Creek	2008	186,072	27,381	
639	Grand River				1,534
	Crockery Creek	2009	361,673	97,623	
	Norris Creek	2008	31,308	4,740	
	Bass River	2004	38,289	3,565	
	Sand Creek		71,869	1,279	
662	Pigeon River	1964			
665	Pine Creek	1964	31,454		
674	Gibson Creek	1984	16,122		
675	Kalamazoo River			NA	3,586
	Bear Creek	2004	19,161	14,595	
	Mann Creek	2010	7,274	4,378	
	Rabbit River		824,216		
	Sand Creek	2010	9,991	1,487	
	Swan Creek		77,742	79	
683	Allegan 3 Creek	1965	16,122		
684	Allegan 4 Creek	1978	2,223		
685	Allegan 5 Creek				

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
691	Black River	2007	694,506	206,964	1,751
700	Brandywine Creek	1985	11,583	229	
701	Rogers Creek	1998	16,073	641	149
707	St. Joseph River				3,593
	Paw Paw River	2009	1,937,578	106,676	
	Blue Creek		43,535	6,926	
	Pipestone Creek	2010	72,067	25,419	
725	Galien River (Upper Main)	2009	443,639	30,281	1,157
	South Branch and Galina Creek		181,592	11,643	
735	State Creek	1986	31,827		
739	Trail Creek	2006	138,845	18,785	220
744	Donns Creek	1966	22,800		
747	Burns Ditch	1999	227,235		821

*Estimate based on average measures of infested area and proportions of larval habitat.

Lake Huron

Lake Huron tributaries with a history of sea lamprey infestation, last year treated, estimated areas of larval habitat, maximum estimate of larval sea lamprey abundance, and five-year average of spawning-phase sea lamprey. Stream number corresponds to those in Fig. 26.

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
0	St. Marys River	2010		5,200,000	19,474
	Whitefish Channel	2010	4,843	15,333	
3	Root River	2010	153,569	141,095	1,450
4	Garden River	2010	1,218,042	3,599,785	6,301
10	Echo River	2010	337,014	14,056	8,951
15	Bar River	2009	67,976	34,117	
39	Sucker Creek	2005	7,076	11	201
50	Two Tree River	2010	22,706	53,862	42
51	Richardson Creek	2010	10,692	530	19
57	Watson Creek	2010	6,851	3,167	159
58	Gordon Creek	2010	6,950	916	144
59	Browns Creek	2010	6,891	13,567	123
62	Koshkawong River	2010	5,802	5,772	285
65	Unnamed River	1975			
68	Unnamed River	1975	83		
87	McBeth Creek	1967			
88	Thessalon River	2010			4,585
	Carpenter-Rock	2007	317,923	30,909	
	Rydal Bank	2009	431,696	103,630	
92	Livingstone Creek	2000	8,509	4	30
102	Mississagi River	2010	2,784,275	429,736	37,971
110	Blind River	1984	5,750	77	
112	Lauzon Creek	2007	2,600	2,541	93
	Lentic	2008	48,600	38,121	
113	Spragge Creek	1995	2,964		35
114	No Name River	2006	1,728	10,667	26
116	Serpent River	2008	294,040	56,161	8,015
	Grassy River		2,912	15,375	
134	Spanish River	2010	6,424,628	461,652	4,157

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
234	Kagawong River	1967			
267	No Name River	2008	2,799	1,629	
272	Silver Creek	2004	17,477	3,892	36
281	Sand Creek	2001	4,511	5,748	39
305	Mindemoya River	2010	17,974	92,450	1,627
310	Timber Bay Creek	2010	14,818	15,872	233
313	Manitou River	2007	4,271	57	2,805
314	Blue Jay Creek	2010	85,046	32,598	797
331	Kaboni Creek	1978			
420	Chikanishing River	2003	7,454	2,697	41
606	French River				496
	O.V. Channel	2006	11,106	4,192	
	Wanapitei River	2010	583,110	1,929	
676	Key River	1972			
726	Still River	1996	78,831		91
745	Magnetawan River	2010	1,660,037	67,123	2,741
	Lentic		9,900	157	
821	Naiscoot River	2008	259,029	179,829	67
983	Shebeshekong River		131,441	267	
1053	Boyne River	2008	24,684	12,806	40
1281	Musquash River	2005	334,746	51,134	226
1343	Sturgeon River	2007	12,872	3,909	525
1345	Hog Creek	1978			
1354	Lafontaine Creek	1968			
1360	Nottawasaga River	2009	2,554,281	313,443	115
1369	Pretty River	1972			
1376	Silver Creek	1982			
1393	Bighead River	2010	141,949	197,932	
	Rocklyn Creek		2,156	867	
1421	Bothwell's Creek	1979			
1422	Sydenham River	1972			
1477	Sauble River	2004	106,153	54,790	546
1492	Saugeen River	1971	84,173		

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
1681	Bayfield River	1970			
10002	Mission Creek				
10003	Frechette Creek				
10004	Ermatinger Creek				
10008	Charlotte River	2010	274,777		
10029	Little Munuscong River	2010	34,433	134,601	1,253
10033	Munuscong River	2010	43,306	67,714	310
10044	Carlton Creek	2001	3,217	323	
10054	Canoe Lake Outlet	1970	8,875		
10063	Caribou Creek	2010	2,010	8,588	20
	Lentic	2010	38,445		
10064	Bear Lake Outlet	2010	1,255	317	
10065	Carr Creek	1978	7,463		
10066	Joe Straw Creek	1975	563	123	
10067	Saddle Creek				
10068	Huron Point Creek		1,301		
10069	Albany Creek	2010	37,165	24,760	387
10071	Trout Creek	2010	5,436	21,727	63
10074	Beavertail Creek	2010	30,357	9,502	467
10075	Prentiss Creek	2010	10,221	8,502	25
10076	McKay Creek	2010	16,843	19,578	432
	Lentic	2007	22,300	24,522	
10077	Flowers Creek	1983			
10078	Ceville Creek	2005	4,991	143	14
10080	Hessel Creek	2010	5,509	45,157	7
10082	Steeles Creek	2010	4,302	10,146	
10086	Nuns Creek	2001	5,268	7,229	65
10089	Pine River	2010	873,206	222,212	4,504
10094	McCloud Creek	1972	7,463		
10095	Carp River	2010	708,134	221,324	163
	Lentic	2010	94,300	296,174	
10098	Martineau Creek	2007	8,546		125
10128	266-20 Creek	1976	4,991		

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
10141	Beaugrand Creek				
10142	Little Black River	1967	9,923	102	
10144	Cheboygan River				19,857
	Lapperell Creek		7,095	847	
	Main stream	1994	6,371	3,726	
	Maple River	2007	123,201	45,747	
	Myers Creek	1999	6,141	1,498	
	Pigeon River	2007	400,151	274,854	
	Sturgeon River	2008	370,020	98,341	
10173	Elliot Creek	2008	12,347	42,757	248
10175	Greene Creek	2007	11,525	22,701	255
10177	Grass Creek	1978	4,816		
10184	Mulligan Creek	2009	1,492		291
10197	Grace Creek	2009	5,713	4,045	
10199	Black Mallard Creek	2009	36,113	43,626	465
10200	Seventeen Creek	1967	7,463		
10202	Ocqueoc River	2009	425,379	65,963	5,521
10205	HBBS Creek				
10206	Johnny Creek	1970			
10210	Schmidt Creek	2008	14,189	38,359	364
10212	Nagels Creek				
10216	Trout River	2007	48,618	31,233	130
10218	Swan River	2007	24,241	18,704	33
10220	Grand Lake Outlet		30,071	946	
10226	Middle Lake Outlet	1967	7,463		
10227	Long Lake Creek	2008	10,502	9,285	
10234	Squaw Creek (Cranberry Creek)	1967	9,385	4,259	
10235	Devils River	2008	43,226	90,516	569
10243	Black River	2007	81,910	104,568	66
10247	Mill Creek				
10255	Au Sable River	2010	1,412,348	819,585	3,175
10260	Pine River	1979			
10271	Tawas Lake Outlet				789

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
	Main stream and Cold Creek	2009	102,241	31,936	
	Silver Creek	2009	65,206	273,219	
	Sims Creek	2009	9,104	1,646	
10286	East Au Gres River	2009	144,770	124,727	2,787
10290	Au Gres River	2007	525,653	289,190	1,249
10296	Rifle River	2008	2,044,838	1,097,964	1,425
10329	Saginaw River				1,351
	Big Salt Creek	2009	122,462	306	
	Big Salt River	2006	383,014	80,681	
	Carroll Creek	2007	17,344	1,316	
	Cass River	2008	1,477,086	33,598	
	Chippewa River	2009	2,842,006	91,685	
	Juniata Creek	2005	15,738	1,415	
	Shiawassee River	2010	1,307,343	566,198	
10391	Rock Falls Creek				
10436	Cherry Creek				
10492	Mill Creek	1985	5,134	38	

*Estimate based on average measures of infested area and proportions of larval habitat.

Lake Erie

Lake Erie tributaries with a history of sea lamprey infestation, last year treated, estimated areas of larval habitat, maximum estimate of larval sea lamprey abundance, and five-year average of spawning-phase sea lamprey. Stream number corresponds to values in Fig. 38.

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
78	East Creek	1987			
87	Catfish Creek	1987			
89	Silver Creek	2009			
99	Big Otter Creek	2009	625,338	29,012	4,644
100	South Otter Creek	2010	59,461	8,002	
101	Clear Creek	1991			324
104	Big Creek	2009	686,823	213,413	5,638
111	Forestville Creek	1989			
112	Normandale Creek	1987			
113	Fishers Creek	1987			
121	Young's Creek	2009	21,880	8,651	570
149	Grand River		12,345		
10001	Buffalo River		168,882	4,671	
10021	Delaware Creek	2005	8,035		
10023	Cattaraugus Creek	2009	200,795	57,104	512
10024	Halfway Brook	1986	15,621		
10037	Canadaway Creek	1986	9,054	759	
10136	Crooked Creek	2009	17,539	5,665	519
10140	Raccoon Creek	2009	7,949	1,795	308
10153	Conneaut Creek	2009	226,673	105,700	2,187
10166	Ashtabula River	2009			
10175	Wheeler Creek				
10196	Grand River	2009	113,975	17,162	2,835
10199	Chagrin River				
10505	Black River				
	Mill Creek		24,417	270	
10512	Pine River				
10513	Belle River		424,687		

Stream number	Stream	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
10529	Clinton River		76,767		
10960	St. Clair River		36,132,544	154,000	

*Estimate based on average measures of infested area and proportions of larval habitat.

Lake Ontario

Lake Ontario tributaries in Ontario and New York with a history of sea lamprey infestation, year last treated, estimated areas of larval habitat, maximum estimate of larval sea lamprey abundance, and five-year average of spawning-phase sea lamprey.

Stream number	Ontario streams	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
1	Niagara River		15,412,628	39,578	
60	Ancaster Creek	2003	15,781	2,224	
76	Bronte Creek	2010	83,283	114,287	1,042
79	Sixteen Mile Creek	1982			
92	Credit River	2008	275,368	1,043,449	2,444
100	Humber River				9,998
110	Rouge River	2007	47,335	33,836	1,013
111	Petticoat Creek	2004	2,240		
117	Duffins Creek	2009	97,756	12,971	3,046
120	Carruthers Creek	1976			
121	Lynde Creek	2009	43,059	23,229	720
124	Oshawa Creek	2009	54,378	200,950	677
125	Farewell Creek	2007	5,833	2,898	694
131	Bowmanville Creek	2008	56,949	251,704	1,608
132	Wilmot Creek	2009	17,147	51,258	626
133	Graham Creek	1996			265
140	Unnamed/Wesleyville Creek	2002	2,073	7,908	
141	Port Britain Creek	2007	3,244	2,454	424
145	Gage Creek	1971			
148	Cobourg Creek	1996	1,143	57	405
152	Covert Creek	2005	4,467	45,881	261
154	Grafton Creek	2007	3,907	7,352	371
157	Shelter Valley Creek	2003	12,693	37,351	641
161	Colbourne Creek	2009	382	409	499
163	Salem Creek	2009	5,547	46,096	188
166	Proctors Creek	2009	5,936	11,575	570
168	Smithfield Creek	1986			
230	Trent River		20,480	3,953	

Stream number	Ontario streams	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
230	Mayhew Creek (Trent River Tributary)	2009	63,798	21,033	439
236	Moira River		27,936	17,111	
242	Salmon River	2000	145,623	53,672	137

*Estimate based on average measures of infested area and proportions of larval habitat.

Stream number	New York streams	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
19	Black River	2008	633,594	339,904	9,125
40	Stony Creek	1982			
44	Sandy Creek		140,856		
45	South Sandy Creek	2008	133,765	345,787	1,159
47	Skinner Creek	2005	17,766	91,869	513
48	Lindsey Creek	2008	30,941	46,960	431
49	Blind Creek	1976			
50	Little Sandy Creek	2010	23,331	62,357	531
52	Deer Creek	2004	12,587	36,547	509
53	Salmon River	2010	409,870	1,243,812	1,809
54	Grindstone Creek	2010	81,306	227,358	822
55	Snake Creek	2008	21,346	226,994	339
57	Sage Creek	1978			
58	Little Salmon River	2009	130,066	2,134,323	968
59	Butterfly Creek	1972			
60	Catfish Creek	2009	33,487	328,703	558
66	Big Bay Creek (Oswego River system)	1993			
66	Black Creek (Oswego River system)	1981			
66	Carpenter Brook (Oswego River system)	1994			
66	Cold Spring Brook (Oswego River system)	1996			
66	Fish Creek (Oswego River system)	2010	550,742	55,762	933
66	Scriba Creek (Oswego River system)	2010		625	
67	Rice Creek	1972			
70	Eight Mile Creek	2007	26,135	91,240	
71	Nine Mile Creek	2005	45,675	81,338	602
73	Sterling Creek	2009	13,624	33,937	1,967
75	Blind Sodus Creek	1978			
78	Red Creek	2010	60,815	31,448	52

Stream number	New York streams	Last treated	Larval habitat (m^2)	Maximum estimated number of larval sea lampreys*	Five-year average of spawner abundance (2006-2010)
80	Wolcott Creek	1979			
84	Sodus Creek	2010	3,391	1,126	549
107	Forest Lawn Creek		2,270	257	
125	Salmon Creek	2005	116,766	814	703
130	Sandy Creek	2009	7,571	1,824	
138	Marsh Creek (Oak Orchard Creek Tributary)	2008			
139	Johnson Creek	2010	65,909	12,526	
284	Third Creek	1972			
384	First Creek	1995			38

*Estimate based on average measures of infested area and proportions of larval habitat.