FACT SHEET 5

Sea Lamprey Control in the Great Lakes

A remarkable success!

THE SEA LAMPREY is an incredibly destructive invasive species. Since entering Lake Ontario in the mid-1800s, and the upper Great Lakes beginning in 1921, sea lampreys have inflicted significant economic damage, harmed the fishery and ecosystem, and changed the way of life in the region. Fact sheet 4 describes the devastating impact of sea lampreys on the Great Lakes.

Of the more than 180 non-native species in the Great Lakes basin, sea lampreys are the only invader that is controlled basin-wide and is the only example in the world of a successful aquatic vertebrate pest control program at an ecosystem scale.

Sea lampreys must be controlled to maintain and improve the fishery as we know it and to protect the integrity of the ecosystem. The good news is they can be controlled! The Great Lakes Fishery Commission, pursuant to the Convention on Great Lakes Fisheries, delivers sea lamprey control in partnership with the U.S. Fish and Wildlife Service, Fisheries and Oceans Canada, and the U.S. Army Corps of Engineers. The U.S. Geological Survey conducts critical sea lamprey research to aid in control. This control program has reduced sea lamprey populations by 90% in most areas of the Great Lakes, a remarkable success!

How are sea lampreys controlled?

Sea lampreys spend a significant portion of their lives in tributaries as filter feeding larvae, so sea lamprey control begins when biologists assess tributaries to determine which ones contain larval sea lampreys. Larval assessment is critical in determining the presence, distribution, size structure, and abundance of larval sea lampreys in infested tributaries. This information helps the commission decide where and when control should be implemented. Sea lamprey control works because the commission has several tools available to significantly knock-down the populations.

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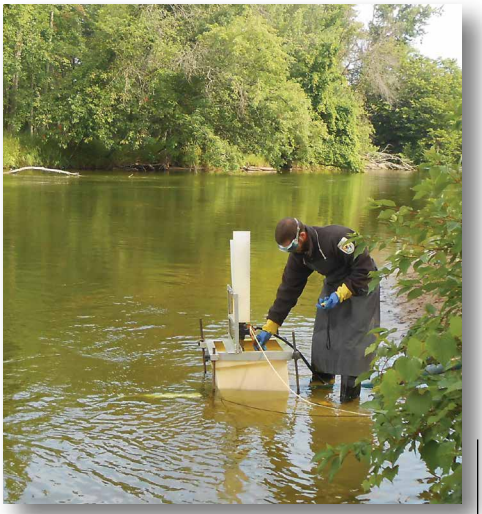
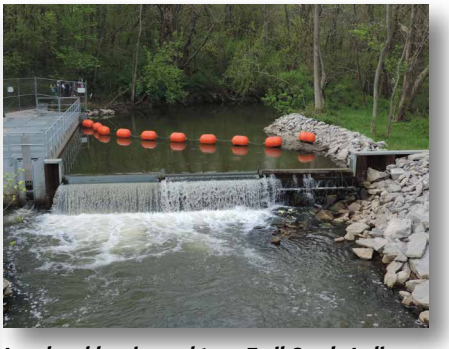


Lampricide treatment on the Manistee River, Michigan.

The commission and its partners maintain an "integrated" sea lamprey control program that combines several control methods to attack sea lampreys on many fronts. These methods include:

Lampricides

The primary method to control sea lampreys is the application of the lampricide TFM to target sea lamprey larvae in their nursery tributaries. In the concentrations used, TFM kills larvae before they develop lethal mouths and migrate to the lakes to feed on fish, while most other organisms are unaffected by TFM. TFM disrupts energy metabolism in sea lampreys, which have low levels of the enzymes used to eliminate TFM from their bodies. Another compound called Bayluscide is less costly and during some treatments, a liquid or powdered form of Bayluscide is combined with TFM to reduce the amount of TFM needed during treatments. Additionally, a granular form of Bayluscide, consisting of Bayluscide-coated grains of sand covered with a time-release coating, is applied to slow-moving or stationary waters where it sinks to the bottom before releasing its payload. This enables control of larvae in areas where TFM cannot be used. About 200 Great Lakes tributaries and larval "hot spots" are regularly treated with lampricides to kill larvae before they have a chance to prey on fish. *See fact sheet 5a for more information.*



Low-head barrier and trap, Trail Creek, Indiana.

Pheromone field tests, Trout River, Michigan.

Barriers

To successfully reproduce, sea lampreys require access to tributaries containing spawning gravel and soft substrates for larval sea lampreys to burrow into. The jumping ability of adult sea lampreys is limited, so barriers function to block adult access to spawning habitat and, therefore, reduce the amount of habitat that sea lampreys can infest. In addition to power generating and other dams, low-head barriers specifically designed to block adults have been constructed in strategic locations around the Great Lakes. Most low-head barriers allow jumping fish to pass while other barriers incorporate "trap and sort" fishways, which permit the passage of non-jumping species (trapped sea lampreys are removed). Barriers have reduced or eliminated the need for lampricide treatments in thousands of miles of tributaries. *See fact sheet 5b for more information.*

Traps

Sea lampreys are vulnerable to capture as adults when they move into tributaries to spawn or as juveniles when they move out of tributaries to prey on fish. Adult traps are typically built into or placed immediately downstream of sea lamprey barriers and capture up to 40% of the adult population from a tributary. Unfortunately, traps typically do not capture a high enough proportion of the adult population to eliminate reproduction entirely or the subsequent need for lampricide treatments. Nevertheless, trapping provides a critical way to assess adult populations and gauge the success of the sea lamprey control program. Juvenile traps are typically free-standing, removable nets or other devices that target sea lampreys before they kill fish. *See fact sheets 5c and 5d for more information.*

Pheromones and alarm cues

Sea lampreys have an extremely keen sense of smell, and since the 1990s, the commission and its research partners have been developing ways to exploit that sense for sea lamprey control. Pheromones and alarm cues are natural odors organisms use to affect certain behaviors or physiological functions. Sea lampreys emit pheromones to attract adults to suitable spawning tributaries and to mates within the tributary. Alarm cues emanate from dead or injured sea lampreys and warn other sea lampreys of impending danger, causing a flight response. Together, pheromones and alarm cues could be used in a "push-pull" technique – luring adults to traps, unsuitable spawning habitat, and areas that are easy and inexpensive to treat with lampricides, and repelling them from areas with productive spawning habitat and areas where control tactics are hard or expensive to implement. *See fact sheet 5d for more information.*

THE BAD NEWS:
Without sea lamprey control, the fishery is lost.

THE GOOD NEWS:
Sea lamprey control works!

The fishery depends on sea lamprey control.

Success means more quality fish and fishing opportunities for ourselves and for future generations!

Fish are part of the fabric of the Great Lakes.

– The Great Lakes fishery is worth more than $7 billion annually to people.
– The fishery supports 75,000 jobs, in addition to hundreds of thousands of jobs related to tourism, navigation, etc.
– More than 5 million people fish the Great Lakes annually.
– Commercial fishing is the backbone of many Great Lakes communities. Charter fishing is an important business.
– Subsistence fishing is a right and a way of life for tribal and aboriginal communities.

Sea lamprey populations have been reduced to a fraction of what they were before control began, creating conditions for the recovery of native and desirable fishes and the ecosystem. Today, agencies stock hundreds of millions of trout and salmon into the lakes, enhancing the resource.

Sea lamprey control must continue.

Sea lamprey control is a major contributor to the value of the Great Lakes fishery. Sea lampreys are resilient beasts. When control is relaxed for even a short time, they bounce back with a vengeance and inflict major harm. Elevated sea lamprey abundances take years to remedy and higher populations set back fishery and ecosystem recovery by decades.

Robust, ongoing control is essential.

History shows that with fewer fish, the region's economy and environment suffer greatly:
– More sea lampreys mean a degraded ecosystem, increased damage to the fish community, and fewer fish.
– The people who depend on the $7 billion fishery suffer economically when sea lampreys prey on Great Lakes fish.
– Waterfront communities decay and people move away.
– More sea lampreys jeopardize tribal treaty obligations.

Photos: V. Dzsurdzsa, T. Lawrence, M. Ryan, M. Twohey, J. Wingfield

Lampricides and Sea Lamprey Control

Above: Application of granular Bayluscide.

By the 1950s, the Great Lakes fishery had collapsed and the ecosystem was nearly destroyed. In the years since, the sea lamprey invasion has been identified as one of the major causes of these two significant declines. The governments of Canada and the United States recognized that a healthy and vibrant Great Lakes fishery is good for the economy and the environment, and that unless something was done to control sea lampreys, the fishery would be lost. Today, the commercial, recreational, and tribal fisheries of the Great Lakes are collectively valued at more than $7 billion annually and support more than 75,000 jobs. Without sea lamprey control, the Great Lakes fishery would not exist as we know it. Lampricides are the primary weapon in the sea lamprey control arsenal and have been successfully applied in the Great Lakes since 1958.

What are lampricides?

In the late 1950s and early 1960s, under the direction of the U.S. Fish and Wildlife Service, scientists at the Hammond Bay Biological Station in northern Michigan began testing compounds to combat the unchecked sea lamprey populations. The primary goal at the time was to find a pesticide that would selectively kill sea lamprey larvae without significantly harming other plants or animals, or having any long-term impacts on the ecosystem.

After testing more than 6,000 compounds, scientists were fortunate to discover two compounds that were effective at controlling sea lampreys: one called TFM (3-trifluoromethyl-4-nitrophenol), and the other Bayluscide (2′, 5-dichloro-4′-nitrosalicylanilide).

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TFM is the more widely used lampricide of the two and is applied in liquid form at a precise concentration to treat tributaries infested with larval sea lampreys. TFM acts physiologically to disrupt energy metabolism in larvae. Compared to other fish, sea lampreys have low levels of the enzymes used to eliminate TFM from their bodies, which eventually leads to their death. Most other organisms are unaffected by TFM at the concentrations applied.

During some treatments, TFM is combined with less-expensive liquid or powdered forms of Bayluscide, thereby reducing the amount of TFM while still maintaining treatment effectiveness. The money saved is used for additional sea lamprey control. A granular form of Bayluscide is typically applied to slow-moving or stationary waters where it sinks to the bottom before releasing its payload. This enables control of sea lamprey larvae in areas where TFM cannot be used.

TFM and Bayluscide break down in a matter of days after treatment and do not bioaccumulate in the aquatic environment, making them effective and environmentally conscientious control tools.

How are lampricides used?

Sea lampreys are most vulnerable to lampricides during their larval stage. During this stage, sea lampreys live burrowed in the bottom of Great Lakes tributaries or in areas near stream mouths for three to ten years, before the next stage of their life cycle when they metamorphose, migrate into the Great Lakes, and harm or kill fish as parasitic juveniles. Depending on the characteristics of the area where larval populations are found, and taking into account the duration of the larval stage, TFM, Bayluscide, or a combination of the two, are applied at regular intervals, typically every three to five years.

Assessment surveys are conducted annually in tributaries to determine the presence, distribution, and abundance of sea lamprey larvae, which helps biologists determine whether tributaries need to be treated with lampricides. Larvae are usually not found throughout an entire tributary, so only the infested areas within each tributary are treated.

Prior to a lampricide treatment, extensive sampling is done to understand the chemical and physical conditions of the tributary. Stream discharge, temperature, pH, and alkalinity, for instance, all influence treatment effectiveness. During a lampricide treatment, water parameters are monitored and, when necessary, adjustments are made to the concentration of the lampricide to ensure maximum effectiveness, efficiency, and environmental safety. A typical treatment takes between 48 and 72 hours to complete, but could take as long as a week, depending on the size of the treatment area.

TFM and Bayluscide are registered by the U.S. Environmental Protection Agency and Health Canada Pest Management Regulatory Agency. Registration requires scientific studies to show that lampricides can be used with minimal risk to people or the environment. Both agencies have extensively reviewed human health and environmental safety data for lampricides and have concluded that the concentrations of TFM and Bayluscide used to control sea lampreys pose no unreasonable risk to the general population or the environment. Further information is available at the Environmental Protection Agency's website: <www.epa.gov/oppsrrd1/REDs/3082red.pdf>

Sea lamprey control program experts before and during TFM application.

Photos: GLFC, T. Lawrence, R. McDaniels

Sea Lamprey Barriers

Limiting sea lamprey access to spawning habitat

BARRIERS TO SEA LAMPREY migration are physical structures placed in tributaries that block access of adult sea lampreys to spawning habitat.

The network of sea lamprey barriers consists of purpose-built barriers as well as numerous dams constructed for other purposes that also serve to block upstream migration of adult sea lampreys. The location and design of purpose-built barriers are determined by a team of experts and are generally designed to block adults while allowing jumping fish to pass safely.

The commission partners with the U.S. Army Corps of Engineers to design and construct physical structures for sea lamprey control.

While purpose-built barriers are inspected on a regular basis and repaired or replaced when necessary to ensure they continue to block adult sea lampreys, many dams constructed for other purposes are being removed to improve fish passage or have been permitted to deteriorate, threatening their ability to block migrating adults. The current network of barriers prevents adults from accessing thousands of miles of habitat, thereby reducing sea lamprey production and saving millions of treatment dollars, but dam removal and deterioration pose an ongoing threat to effective sea lamprey control.

Prior to the discovery of the lampricide TFM in the late 1950s *(see fact sheet 5a)*, sea lamprey control relied exclusively on crude mechanical and electrical barriers to prevent adult sea lampreys from accessing spawning habitats. These barriers were unreliable, expensive to operate, and dangerous to humans and wildlife; they were eventually phased out in favor of lampricides. In the 1970s, the commission re-evaluated the importance of barriers and concluded that properly constructed barriers could block adults and minimize the need for lampricide treatments. The commission has built approximately 50 barriers since, all serving to limit adult access to spawning habitat, the extent of infestation, and the need for lampricide treatments. Roughly 20 more dams that were constructed for other purposes have been modified to block adult migrations. Currently, the focus of the barrier program is on maintenance of existing barriers and the construction of new barriers with built-in traps designed to capture adults.

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Sea lamprey barrier designs

Most purpose-built sea lamprey barriers use a "low-head" crest design. Because adult sea lampreys cannot jump very high, the creation of a two to four foot vertical drop is sufficient to stop adults from migrating upstream. A horizontal lip along the crest of the barrier keeps adults from using their suction-cup mouth to climb over it. Traps are typically installed during new barrier construction to remove adults before they have a chance to spawn and enable assessment of their populations *(see fact sheet 5c)*. Inclusion of a jumping pool downstream of the barrier allows most jumping fish to pass easily. To pass non-jumping fish, some barriers have a "trap-and-sort" fishway – where sea lampreys are trapped, sorted, and removed while desirable fish are moved upstream.

Many dams built for other purposes also block adult sea lampreys; such structures are numerous around the Great Lakes and are of great importance to sea lamprey control. Maintaining the integrity of these barriers is critical because many of them are old and in poor condition such that their ability to block adults will be compromised in the near future. Additionally, many of these barriers are located on large tributaries with huge sea lamprey production potential, making it all the more critical to maintain their integrity.

Adjustable stop log sea lamprey "low-head" barrier, Carp River, Ontario.

Fishway at Brule River sea lamprey barrier, Wisconsin.

Dam removal considerations

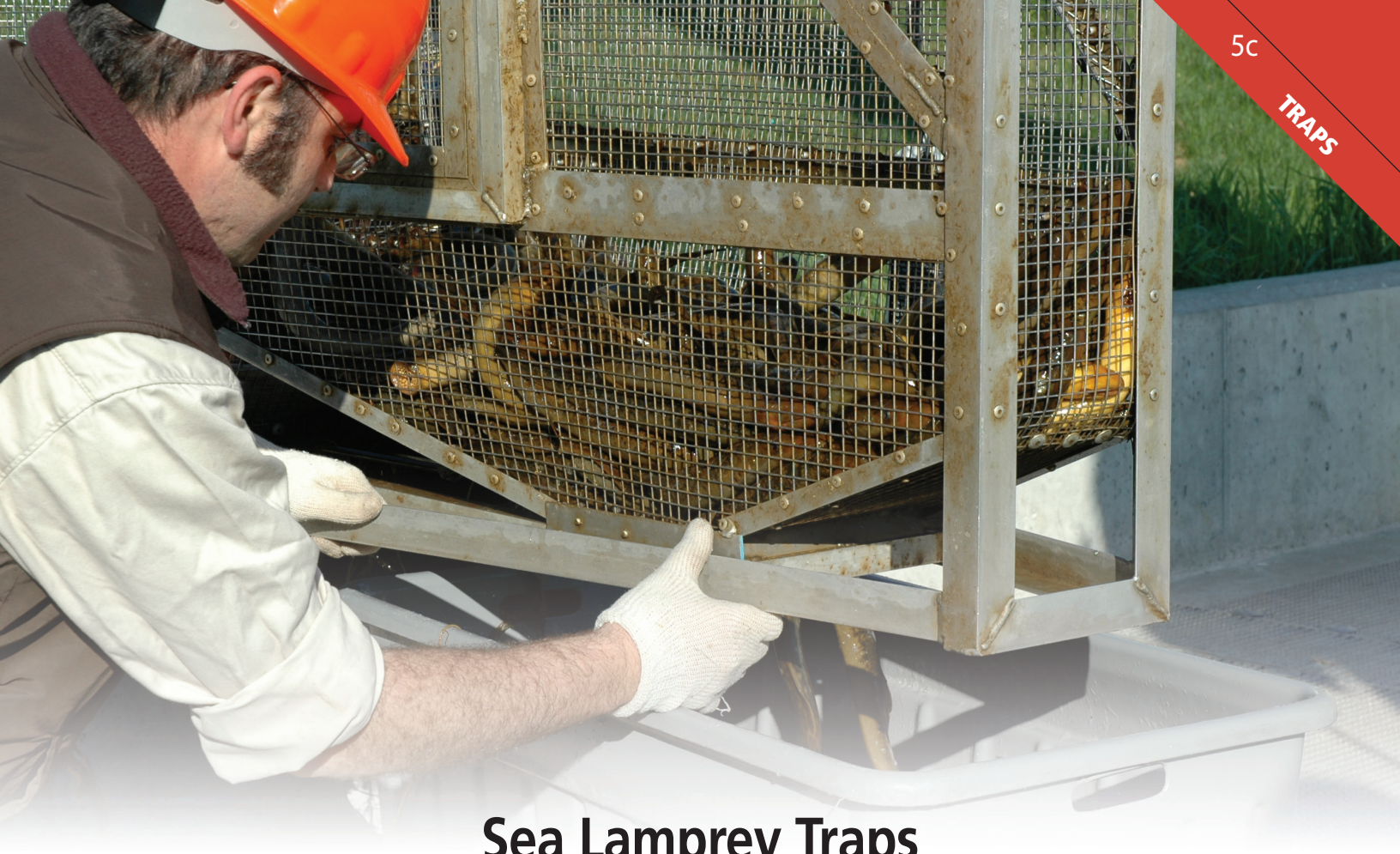
Dam removal in the Great Lakes basin can have tremendous overall benefits to a tributary system. At the same time, however, there are significant drawbacks to consider. Although dam removal will increase habitat connectivity and often aids in the rehabilitation of an ecosystem, it also allows for the spread of invasive species into new ecosystems. Balancing the use of sea lamprey barriers with dam removal is a growing issue that will need to be managed to ensure the viability of sea lamprey control and to protect the Great Lakes fishery.

A typical "low-head" barrier, Carp Lake Outlet, Michigan.

Cheboygan River Dam, Michigan
This dam, constructed privately for a paper company, is an effective sea lamprey barrier.

Ocqueoc River, Michigan
A one-of-a-kind electrical "low-head" sea lamprey barrier. Electricity kicks in to block sea lampreys when water is high.

Photos: C. Krueger, T. Lawrence, M. Moriarty, M. Siefkes, NYSDEC



Sea Lamprey Traps

Sea Lamprey Traps are an important component of the sea lamprey control program. Traps are carefully designed to capture either juvenile sea lampreys as they migrate from tributaries to the open lake to prey on fish, or adult sea lampreys as they return to tributaries to spawn. Scientists are testing new trap designs and studying sea lamprey behavior that may be exploited to increase catch. In addition, scientists are evaluating the effectiveness of "baiting" traps with pheromones, odors sea lampreys give off to attract mates, and investigating the use of alarm cues and repellants, which are odors that cause a flight response. Both attractant and repellant odors might help boost trapping effectiveness *(see fact sheet 5d).*

Trapping juvenile sea lampreys

After larval sea lampreys metamorphose into juveniles, they are vulnerable to capture as they migrate downstream to the lake to feed on fish. Juvenile traps typically consist of nets or other removable devices that are placed in tributaries when juveniles are migrating. Trapping juveniles removes sea lampreys during the part of their life cycle that immediately precedes their lethal, predatory stage. Since juveniles have a high probability of harming fish if not removed during their downstream migration, trapping this life stage is potentially valuable to sea lamprey control, providing that sufficient numbers of juveniles are captured. Ongoing research on juvenile trap designs and tactics is expected to enhance juvenile trapping and provide additional sea lamprey control.

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Improving trap effectiveness with pheromones and alarm cues

Sea lampreys have an extremely well-developed sense of smell; they can detect scents given off by other sea lampreys at very low concentrations. One pheromone, released by larval sea lampreys, helps adults determine which tributaries are suitable for spawning by indicating the existence of larvae in that tributary. Another pheromone, given off by spawning males, attracts a female to a mate. Scientists have demonstrated that baiting adult traps with sea lamprey pheromones can enhance trapping efficiency in some tributaries. Alarm cues are odors injured or dead and decaying sea lampreys emit that serve to warn live sea lampreys of danger. This "smell of death" causes a powerful flight response away from the odor. Alarm cues could be used to cause sea lampreys to avoid areas that are difficult or expensive to treat with lampricides or that have suitable spawning habitat and instead "push" them toward traps, areas that have poor spawning habitat, or areas that are easy and inexpensive to treat with lampricides.

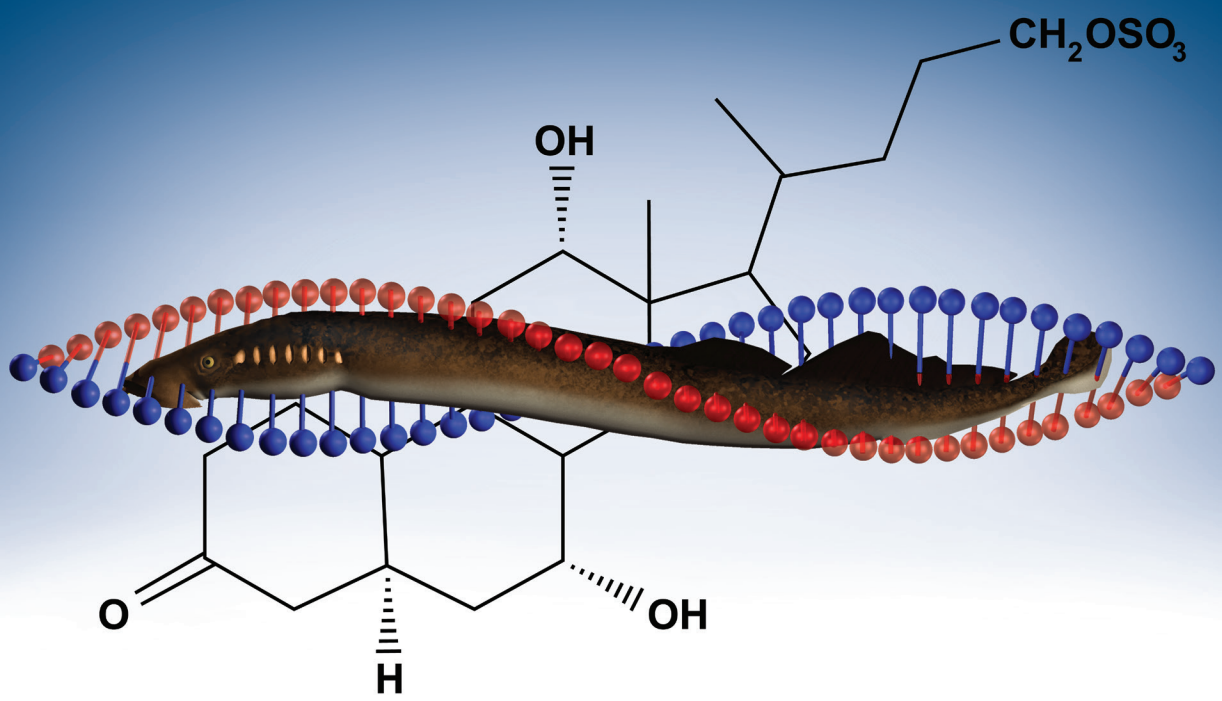
A typical sea lamprey trap, Cheboygan River, Michigan.

A fyke net is used to capture migrating juvenile sea lampreys before they enter the lake to destroy fish.

A new, experimental screw trap being tested on Carp Lake Outlet, Michigan.

Setting a sea lamprey trap (above) and checking the catch (right).

Photos: M. Gaden, T. Lawrence, M. Siefkes, J. Slade



The Future of Sea Lamprey Control

The Great Lakes Fishery Commission has had tremendous success in controlling sea lampreys in the Great Lakes. The commission uses science-driven innovation to find the best, most cost-effective ways to deliver its control program. Enhancing existing and developing new control techniques is critical to keeping the program current and effective at stopping the noxious sea lamprey.

An effective pest control program is integrated, meaning it relies on several techniques to attack the problem from many different angles. Accordingly, the Strategic Vision for the Great Lakes Fishery Commission 2011–2020 outlines a series of goals and strategies for improved sea lamprey control through the assessment and deployment of new tactics and technologies.

Why go beyond lampricides if they work?

The lampricides TFM and Bayluscide remain the workhorses of the program because they are enormously effective, selective, and do not harm the environment. Nevertheless, lampricides are expensive and, worldwide, used only by the commission – resulting in a vulnerability if supplies are disrupted. Moreover, sea lampreys could develop resistance to lampricides or adopt behaviors that render them less susceptible to the effects of lampricides.

"The probability of reaching control targets can be tipped appreciably more in the commission's favor if new technologies can be implemented to increase suppression beyond that achieved by the application of lampricides and the existing barrier network."

— *Strategic Vision of the Great Lakes Fishery Commission 2011–2020*

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What is the commission's vision for the future?

The commission sustains an aggressive sea lamprey research program that supports control efforts by improving understanding of sea lamprey behavior, biology, and ecology, and using this knowledge, develops new control technologies and techniques. For instance:

The **sea lamprey genome** has been sequenced, providing an understanding of the genes that determine the animal's behavior and physiology, such as migration, mating, and responses to danger and environmental stressors. This monumental achievement will allow scientists, for years to come, to perhaps customize control techniques to exploit points of weakness that interrupt the sea lamprey's life cycle. No other aquatic pest control program has this advantage, and the commission is intent on using genomic knowledge to develop innovative tools and tactics for suppressing sea lamprey populations.

Understanding the potential of sea lampreys to develop **TFM and Bayluscide resistance,** as well as developing the next generation of lampricides, is another high priority. TFM has been safe and effective in controlling sea lamprey populations in the Great Lakes basin for 60 years. Using data provided by the genome project and related studies, scientists will determine if sea lampreys are becoming less susceptible to TFM and will evaluate proactive measures and strategies to prevent or mitigate lampricide resistance. Moreover, with a greater understanding of sea lamprey biology and life-history – which is certainly more robust than decades ago when TFM was first discovered – the development of a potentially less expensive, even more effective lampricide is a realistic objective.

Influencing sea lamprey behavior, primarily during migratory and mating periods, through the use of **pheromones and alarm cues** – natural odors used by sea lampreys to communicate – is another central theme of the sea lamprey research program. Pheromones could be used to guide sea lampreys to areas that can be treated effectively with lampricides or into traps (i.e. pull). Alarm cues, by contrast, may be used to prevent sea lampreys from entering streams or areas that are difficult to treat or trap (i.e. push). Using both types of signals in concert as "push-pull" techniques could provide synergistic benefits beyond the use of a single signal.

Interrupting the migration of sea lampreys – either as downstream-migrating parasitic juveniles that have recently metamorphosed from larvae or as upstream-migrating adults – by diversifying and improving the network of **barriers and traps** is another strategy that could improve sea lamprey control. This strategy is attractive not only because it involves blocking adults from thousands of miles of suitable reproductive habitat, but it also addresses the removal of parasitic juveniles before they enter the lakes to feed on fish.

As the issue of restoring the natural flow of aquatic systems gains momentum, the commission and its partners are committed to developing a cohesive process for proposing, evaluating, and implementing **barrier construction and removal** projects. The commission believes such projects must incorporate designs to stop invasive species, protect species at risk, prevent the movement of contaminants and disease, facilitate the passage of native migratory species, and improve recreation. Improvements in barrier design and trapping will help the commission meet these objectives.

When will this happen?

Innovation never stops at the Great Lakes Fishery Commission. The commission and its partners have created an ambitious vision for the future of sea lamprey control that may take decades to achieve – but the potential payoff of any one of these techniques could be huge. Thanks to the commission's science program and the Great Lakes Restoration Initiative, major advances in new control methods have occurred. As soon as new techniques have been field-tested and proven to be effective, they will be deployed in the field.

Pheromone field trials, Ocqueoc River, Michigan.

A female lamprey is attracted to an area that is baited with male pheromone washings.

Photos: GLFC, A. Miehls