INNOVATIVE SOLUTIONS IN THE CONTROL OF INVASIVE SPECIES: LESSONS FROM THE SEA LAMPREY

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INVASIVE SPECIES AND THE DESTRUCTION THEY BRING

Chairman Barrasso and Mr. Carper, thank you for inviting me to appear before this committee to discuss innovative solutions to invasive species. My name is David Ullrich. I am the chair of the Canada-U.S. Great Lakes Fishery Commission. The Commission knows a great deal about invasive species. The commission was established in 1954 by the Canadian and U.S. Convention on Great Lakes Fisheries primarily as a response to one of the most injurious invaders to ever enter the Great Lakes system: the sea lamprey. I am also the executive director of the Great Lakes and St. Lawrence Cities Initiative, which coordinates the actions of more than 120 Canadian and U.S. mayors to advance the protection and restoration of the resources. Both the commission and the initiative are highly involved in invasive species prevention and management because of the severe economic and ecological damage such species cause.

The Great Lakes and St. Lawrence River Region is an economic powerhouse for the United States and Canada. The region contains 84% of the North American's surface freshwater and is home to 100 million Canadians and Americans, 40 million of whom rely on the resource for drinking water. The region is the third largest economy in the world with $5.8 trillion annually in economic activity.[1] The fishery alone generates more than $7 billion each year[2] and the system is a vibrant transportation corridor that moves goods in and out of the North American heartland. Moreover, the Great Lakes and the St. Lawrence River are unrivaled in natural beauty, which enhances property values and the quality of life, and attracts millions of tourists.

Unfortunately, the Great Lakes are under assault from invasive species. Invasive species are non-native animals and plants, both aquatic and terrestrial, that enter new environments, become established, and spread. Today, the lakes harbor more than 185 non-native species.[3] Invasive species generally enter new ecosystems accidentally, find the new environments to be accommodating for reproduction, have ample food, and have few or no predators that keep them in check. Invaders have entered the Great Lakes through the discharge of ship ballast water, the trade of live organisms for food and pets, the release of live baitfish, canals and waterways, and the movement of pleasure crafts between watersheds.

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Most affected by invasive species are sport, commercial and tribal fishers; water treatment and power generation plants; manufacturing; and tourism. Collectively, hundreds of thousands of people are employed in these industries. Although quantification of the costs of invasive species is difficult, what we do know is sobering. Worldwide, invasive species cause more than $1.4 trillion in damage annually; damage costs range from $14 to $137 billion annually in the U.S., depending on species considered and assumptions.[4] In the United States, invasive species costs the sportfishing industry more than $5 billion annually and zebra and quagga mussels cause a conservative $1 billion per year in damage mitigation. [5] Invasive species inflict $5.4 billion in annual damages to the Great Lakes alone.[6] Aptly, Ricciardi et al, in a 2011 study,[7] likened biological invasions to natural disasters like floods, earthquakes, and disease epidemics (and, thus, they argued, should be treated with the same response and preparedness). Ricciardi adds that invasive species inflict a cost on an order of magnitude higher than natural disasters.[8] At least 40% of the species on the threatened or endangered list are on the list because of invasive species.[9]

The history of aquatic invasions has shown that people are left with few options to control a species once the species enters an ecosystem and spreads. Physical removal of terrestrial invasive species is cumbersome and disruptive. Control of aquatic invaders is difficult given the paucity of selective control techniques. Thus, prevention is paramount. Nevertheless, in cases where invasive species are present or looming, innovative solutions using technology and ingenuity can make a difference. The highly successful sea lamprey control program provides us with positive examples.

SEA LAMPREY CONTROL IN THE GREAT LAKES: INNOVATION AND SUCCESS

Sea lampreys are primitive eel-like fishes native to the Atlantic Ocean (figure 1).[10] Sea lampreys attach to fish with their suction cup mouth then dig their teeth into flesh for grip (figure 2). Once securely attached, sea lampreys rasp through the fish's scales and skin with their sharp tongue. Sea lampreys feed on the fish's body fluids by secreting an enzyme that prevents blood from clotting, similar to how a leech feeds off its host (figure 3A and 3B).

The first recorded observation of a sea lamprey in the Great Lakes was in 1835 in Lake Ontario. Niagara Falls served as a natural barrier, confining sea lampreys to Lake Ontario and preventing them from entering the remaining four Great Lakes. However, in the late 1880s and early 1900s, improvements to the Welland Canal, which bypasses Niagara Falls and provides a shipping connection between lakes Ontario and Erie, allowed sea lampreys access to the rest of the Great Lakes. Within just a short time, sea lampreys spread throughout the system: into Lake Erie by 1921, lakes Michigan and Huron by 1936 and 1937, and Lake Superior by 1938.[11]

Sea lampreys were able to thrive once they invaded the Great Lakes because of the availability of excellent spawning and larval habitat, an abundance of host fish, a lack of predators, and their high reproductive potential—a single female can produce as many as 100,000 eggs.

In their native Atlantic Ocean, thanks to co-evolution with fish there, sea lampreys are parasites that typically do not kill their host. In the Great Lakes, where no such co-evolutionary link exists, sea lampreys act as predators, with each individual capable of killing up to 40 pounds of fish over its 12-18 month feeding period. Host fish in the Great Lakes are often unable to survive sea lamprey parasitism, either dying directly from an attack or from infections in the wound after an attack. Host fish that survive attacks often suffer from weight loss and a decline in health and condition.

Sea lampreys prey on most species of large Great Lakes fish such as lake trout, brown trout, lake sturgeon, whitefish, ciscos, burbot, walleye, catfish, and Pacific salmonids including Chinook and coho salmon and rainbow trout/steelhead. Sea lampreys wreaked staggering damage on the Great Lakes ecosystem. By the 1960s, harvest of lake trout, a keystone species, had fallen by 99% from the average catch of the 1930s (figure 4). Basin wide, sea lampreys killed more than 100 million pounds of fish annually—a stunning amount of fish, especially when compared to the pre-invasion lake trout harvest of lake trout of 17 million pounds annually in the upper lakes.

Because of sea lamprey, the fishery that once sustained native fishers, fueled lucrative commercial operations, and attracted millions of anglers who simply enjoyed the outdoors, was devastated. Sea lampreys changed a way of life in the Great Lakes basin. The problem was so severe, the governments of Canada and the United States were largely motivated by the sea lamprey's devastation when they agreed to the 1954 Convention on Great Lakes Fisheries. The convention created my organization, the Great Lakes Fishery Commission, and, among other duties, gave it the responsibility to control the sea lamprey. I discuss the Commission as a unique governance arrangement below.

Since the convention began operating in 1956, the Commission has delivered a sea lamprey control program, in cooperation with the Department of Fisheries and Oceans Canada, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, the U.S. Army Corps of Engineers, and state agencies. Through sound science and the use of innovative techniques, which I will describe below, the Commission has successfully reduced sea lamprey populations by 90% in most areas of the Great Lakes, which is consistent with the fishery management needs of our state, provincial, federal, and tribal partners. (Figure 5 illustrates sea lamprey abundance in each lake compared to pre-control abundance levels and target levels.)

This significant reduction in sea lamprey populations has reduced fish loss in the Great Lakes from approximately 100 million pounds annually to around 10 million pounds annually (figure 6). Although 10 million pounds is still a lot of fish, that amount is an order of magnitude lower than the 100 million pounds lost annually to lamprey in the past. The 90 million pounds saved from sea lamprey predation is 90 million pounds of fish that have the chance to grow old enough to reproduce, to be caught by humans, or to lead a natural life.

The $7 billion Great Lakes fishery would not exist as we know it today without sea lamprey control. Moreover, the states, the province of Ontario, the tribes, federal agencies, and the millions of people who depend on the fishery for jobs, recreation, and subsistence, also depend on sea lamprey control for that economic success. The fishery is also an important part of our history and culture.

How did the Commission and its partners achieve the remarkable level of sea lamprey control? Through innovation, persistence, technology, and a sustained, binational commitment.

The Beginnings: Understanding the Sea Lamprey

Sea lampreys bypassed Niagara Falls through the Welland canal around 1920 and by the middle part of that decade, fishers and scientists alike were beginning to realize they had severe problem on their hands. Walter Koelz and John Van Oosten, two pre-eminent scientists with the Bureau of Commercial Fisheries, noted the international nature of the problem and pleaded with commercial fishers as early as 1927 to report sea lamprey sightings so that the fishery managers would have a grasp of the degree of the problem. Their "wanted dead or alive posters," which they sent throughout the region, recognized the multi-jurisdictional nature of sea lamprey (they swim across borders with wild abandon after all) and also sounded the alarm about the impending invasion.

Early scientific literature catalogued the spread of sea lamprey and recorded the economic impact on the region's fishers. Just as state and federal biologists were observing more and more sea lamprey, commercial fishers were reporting dwindling catches. Worse still, the fish that were caught were so full of lamprey wounds they resembled Swiss cheese. While biologists and fishers were marking the spread and effects with growing trepidation, scientists were warning that control techniques were lacking.

The earliest innovations in sea lamprey control began in 1944 when state and federal conservation officials in northern Michigan constructed a mechanical weir on the Ocqueoc River to try and block sea lamprey migration. These officials later added electricity to the barrier to try to enhance its effectiveness. "Angry mobs" of local fishers used spears and pitchforks on the Ocqueoc to lend a hand. These early attempts at control, which also included work in other states like Wisconsin, and in Ontario, were only somewhat effective. The mechanical weirs still allowed considerable numbers of sea lampreys to pass and electrical barriers tended to short out, leaving the river unimpeded. Moreover, the electrical barriers killed large amounts of desirable fish. Sea lampreys continued to spread and as they did, it became apparent that the physical and mechanical approaches were not even slowing the invasion, let alone leading to control.

Researchers like Koelz, for years, had been stressing the need for better science so that sea lamprey control could be more targeted than crude electrical or mechanical weirs. As he said in 1927: "The problems that confront other fisheries confront the conservationist on the Great Lakes—we want to know more about the life histories of our species; we want adequate statistics; in short, we want to know everything about them . . . or no fish will remain for us to investigate." Koelz knew that a scientific understanding of the sea lamprey's life cycle would be the key to developing innovative control techniques. He was right.

With a growing amount of information about the pattern of invasion, Congressional interest led to the passage of legislation in 1946 authorizing funds for the Bureau of Commercial Fisheries to conduct the necessary scientific assessments that would lead to a detailed understanding of the sea lamprey life cycle. The State of Michigan supplemented those funds.

A biologist named Vernon Applegate was a pioneer in this era with his scientific work to study and publish the sea lamprey life history, with the purpose of discovering ways in which sea lamprey could be vulnerable.[12] The sea lamprey life cycle is unique, so it gave Applegate and his peers much to work with. Sea lampreys spend the first three to four years (some more than 10 years)[13] of their life living as larvae in stream beds. They are small and wormlike in this stage and they filter feed on detritus that drifts past. Applegate determined that larval sea lampreys inhabit approximately 500 Great Lakes tributaries throughout the basin. In the spring, after that larval phase, lampreys metamorphose into the lethal adult—they develop eyes, grow the suction cup mouth ringed with sharp teeth and a rasping tongue, and out-migrate to the open lake. Lampreys, during this metamorphic stage, are called "transformers." Once in the lake, they feed by attaching to fish with the suction cup mouth, bore a hole through the scales and skin, and consume blood and body fluids. Each lamprey will move from fish to fish while it feeds, usually destroying approximately forty pounds of fish. After about a year to eighteen months in the open lake, sea lampreys migrate into streams to spawn once and die. This deep understanding of the sea lamprey life cycle would (and continues to) result in many creative, innovative ideas for control.

Also in 1946, after several years of trying out different things to control sea lamprey, scientists and managers convened the Great Lakes Sea Lamprey Conference as a place to discuss the sea lamprey life history, present any ideas for how that life history could be exploited, and recommend control techniques. Innovation was the theme of the day. Many techniques, like mechanical weirs, electrical barriers, and out-migrating-larvae-removing sieves, were at one time considered innovative, but after field-testing and evaluation, were deemed ineffective. The group looked at everything from physical removal using hoop nets and commercial trawlers to dredging and concluded that a pesticide to kill larval sea lamprey would be the most viable solution.

One major hurdle to the use of a pesticide was the inopportune fact that nothing selective to sea lamprey existed. Any known pesticide that would be used, in other words, would not discriminate, potentially causing considerable loss to desired fish populations. Although Applegate was realistic enough to know that a pesticide was the best bet (most other techniques had already failed after all), in 1949, he nevertheless concluded that an integrated approach to sea lamprey, which would add barriers, traps, and electricity to the use of a selective pesticide when discovered, would be the best approach. Applegate's method was what later would be called "integrated pest management;" this adaptive, innovative approach has prevailed throughout the history of the sea lamprey control program.

The Selective Lampricide

Efforts to discover a pesticide selective to sea lamprey began in 1950 when a graduate student from the University of Michigan—Philip Sawyer—began his experiments at an old Coast Guard station in Michigan that had been appropriated for scientific research. Sawyer, who was working through a fellowship with the Bureau of Commercial Fisheries, tested various compounds to determine what would kill lamprey and what would not harm fish. It was a tedious process. Over the next two years, Sawyer would zero in on a class of compounds that showed some promise, but a lack of funding for the field tests brought the search for a selective pesticide to a halt.

Only after Sawyer's dissertation demonstrated the clear potential of certain chemicals did the testing resume in 1953. Three years later, in early 1956, a technician named Cliff Kortman, working at the biological station, screened chemical number 5209 and simply wrote "special" in the results section of the report slip. It was special. The chemical was 3-trifluoromethyl-4-nitrophenol, or TFM, and it killed lamprey at low concentrations while not harming fish. Around this time, a second compound, called '5-dichloro-4'-nitrosalicylanilide, or niclosamide, was found to be a cost-effective way to supplement the use of TFM.[14] The two lampricides—deserving of that name, as they are pesticides selective to lamprey—would work in tandem.

Field tests in 1957 and 1958 with TFM (and derivatives of it) would demonstrate its effectiveness in the field. All told, during the seven or eight years of active search for a selective pesticide, scientists painstakingly screened nearly 10,000 compounds.[15] There was no shortage of determination to find the right lampricide.

The period 1958 through 1961 was a tense one for sea lamprey control agents. Although TFM proved effective in the laboratory and in limited field tests, its success on a management scale was not assured. When the data from the first large-scale round of steam treatments was published in 1965, the success was amazing: TFM had reduced sea lamprey population by 82% in the places where it was applied with minimal loss of non-target fish. Fishery managers exhaled.

Although the lampricide is selective to lamprey, the concentration at which it should be applied would prove to be critical. Some insecticides, for instance, remain selective even when 1000-times the amount needed to kill an insect is used. For lampricides, the selectivity ranges from only two to ten times the amount needed to kill a lamprey.[16] Thus, non-target fish like trout and walleye could be harmed if too much lampricide were to be used; not much room for error exists. During the early days of the lampricide program, the application was not precise, and fish kills were common. Sea lamprey control experts were at a loss as to why one treatment would work so well while another might not.

Unraveling the way in which lampricides work depended on two things: understanding how lampreys physically metabolize the chemical and understanding how stream chemistry itself affects the toxicity of lampricides. After much testing, scientists discovered that a stream's pH has an inverse relationship with TFM toxicity and that high stream alkalinity would exacerbate that pH/TFM relationship.[17] In other words, specific stream conditions, which could change rapidly from something as simple as a rain shower, would prove to be important—the lower the pH, the higher the toxicity of TFM and vice versa. Thus, to get the selectivity of TFM right, sea lamprey control crews would have to conduct on-site chemistry assays. That research into how lampricides work in lamprey and in streams, coupled with decades of data from thousands of stream treatments, led to vast improvements in the selective use of the lampricide, along with considerable cost savings. Currently, thanks to innovations in the manner in which lampricides are applied, non-target fish kills are extremely rare despite thousands of treatments.

Today, sixty years after the first lampricide field tests, lampricides remain the workhorse of the sea lamprey control program. Their discovery and ever-refined use through adaptive management came about because of an innovative culture that took root in the 1940s. That culture depended on science, encouraged creative thinking, valued innovation, learned from failure, and created the atmosphere to continually seek improvement. That innovative culture continues today as the Commission and its partners consider whether sea lampreys have developed a tolerance to lampricides and whether biological traits can be exploited. Such an understanding will lead to the development of the next generation of lampricides that are even more selective than the ones used today.

Barriers and Traps

As noted above, before the discovery and use of lampricides, fishery managers relied on barriers and weirs that were purpose-built for sea lamprey suppression, with mixed results. Barriers in general are quite effective at blocking sea lampreys as they migrate to reach their spawning grounds. Lampreys do not jump like trout and salmon, so even a small obstruction can be effective in limiting their range. The Great Lakes region contains thousands of dams and obstructions that block fish (including sea lamprey) migration. These dams were built for purposes other than sea lamprey control, such as for hydropower, flood management, pipeline protection, logging, industry, and the creation of private fishing holes.[18] Such barriers are not selective for sea lamprey but they do serve a useful purpose in the sea lamprey battle.

In 1971, the Commission revisited the idea of barriers as a specific control technique. The Commission reasoned that barriers built for sea lamprey control could be minimally intrusive, complementary to lampricides, and save considerable amounts of money.[19] With a sea lamprey barrier near the mouth of a stream, that stream would not require a lampricide treatment above the barrier.

To be effective in controlling lamprey, barriers do not have to be tall—a drop as short at 45 centimeters (about the height of a coffee table) would be sufficient.[20] Such short drop would present little obstacle for jumping fish, and other fish passage devices would accommodate non-jumping fish.

The new wave of better, more innovative barrier construction began in 1975. Eventually, approximately 75 sea lamprey barriers would be constructed between 1975 and 2017. Barriers remain extremely cost effective. For every $5 million spent on barriers, the Commission each year saves $500,000 in lampricide costs and $22 million worth of fish. Spread over the 50-year life span of a barrier, that $5 million investment saves more than $25 million in lampricide costs and $1.1 billion worth of fish.

Another benefit of barriers is the ability to integrate sea lamprey traps into the design or to simply place traps along the barrier face. Combining barriers and traps makes sense: sea lampreys, as they migrate upstream to spawn, are persistent, and when they hit an obstruction, they try to feel their way around it. In doing so, they might mistake an opening of a trap for passage around the barrier. Because a single female sea lamprey can produce up to 100,000 eggs, trapping spawners goes a long way to limit reproduction.

Barrier designs have evolved since the 1970s and continue to push the envelope of innovation. The Commission has experimented with a new generation of barriers equipped with electricity as a deterrent to migration, but the success has been limited. On the other hand, electricity, coupled with new trapping designs that apply lessons from eel ladders (lampreys swim like eels), have shown promise in helping to guide sea lampreys into traps. The Commission has experimented, also, with barriers that increase the velocity of a river to take advantage of a sea lamprey’s poor swimming ability, but also with limited success. More promising are simple small structures, made from stop logs, that can be altered as river conditions change, or larger structures that can be raised (through inflation of air bladders) during the spawning run and lowered on the river bottom for the rest of the year.

Sterile-male-release and Granular Bayluscide

In 1937, a scientist by the name of Edward Knipling was the first to suggest that sterilization could be an effective technique to minimize or even eradicate insect populations.[21] Knipling's work would come to fruition in the mid-1950s with the successful use of sterilization to eradicate screwworms from the West Indies. From that point forward, sterilization has been an integral part of insect control worldwide.

In 1970, a biologist named Lee Hansen, working in the sea lamprey control program, suggested to the Commission that we could learn a lot from insect control; he proposed the Commission consider whether sterilized sea lampreys, released into streams, could reduce spawning without the use of barriers or lampricides. The risk of further loss of fish through the release of sterilized spawners was considered non-existent because once sea lampreys reach their spawning phase, they are physically incapable of feeding, as their digestive systems have shut down. At that point in their lives, sea lampreys have only reproduction in mind.

The Commission embraced Hansen's proposal in 1970 and launched a major investigation into whether sterilization could be an effective control method.[22] Between 1971 and 1991, the investigation led to the development of an effective sea lamprey sterilant (no such sterilant existed hitherto) after many compounds were tested. This search for a sterilant was certainly reminiscent of the massive search for a lampricide that took place in the 1950s. By 1991, the Commission also had identified sites where sterilization could be tested, conducted studies on the best practices for release of sterilized lampreys, determined that sterile males would be more effective than sterile females, and procured the equipment to sterilize sea lampreys. (On that last point, given the highly unique nature of the program, the equipment would be for a single user in the world and would have to be invented.) In 1991, the Commission launched sterile-male-release-technique (or SMRT) as a sea lamprey control method.

The SMRT works by putting enough sterilized male lampreys into a river to outnumber the fertile males. The sterile males successfully spawn with females, and lamprey eggs are fertilized. However, the sterilant used causes the eggs to produce non-viable larvae. Thus, both the males and the females think the spawning was successful when, in fact, it was not.

While the work was progressing to develop SMRT, major water quality improvements in the Great Lakes—thanks in part to the Great Lakes Water Quality Agreement and the Clean Water Act—had vastly improved fish habitat. The rebound in fisheries and fish health was astounding by the 1980s and 1990s.[23] But just as valuable fish like trout and salmon found the water quality improvements to be beneficial, so too did the sea lamprey. Nowhere was this more obvious than in the St. Marys River, an immense connecting channel between Lake Superior and Lake Huron that also happens to contain some of the best sea lamprey habitat in the entire Great Lakes basin. As the quality of the St. Marys River improved, sea lampreys spiked in that region and swam into Lakes Michigan and Huron like an invading army. At one point, the problem of lampreys from the St. Marys River was so severe, federal, state, tribal, and provincial fishery agencies stopped stocking fish in Lake Huron until the lamprey problem could be resolved.

The main issue was size—the St. Marys River is 25 times larger than any river ever treated with lampricide and, as such the use of TFM would have been neither affordable nor effective. Moreover, as an active shipping corridor, barriers would not have been remotely possible.

Through painstaking assessment work, the Commission and its partners determined that sea lamprey larvae were not evenly distributed throughout the St. Marys River, rather, are concentrated in "hot spots." As such, the entire river does not need to be treated with lampricide. Instead, the strategy has been to treat just the hot spots with a granular version of the lampricide niclosamide (called granular Bayluscide). Granular Bayluscide would sink to the bottom of the St. Marys River, dissolve slowly (much like time-release cold medication) just above the substrate, and kill the sea lamprey larvae living there.[24]

Given the size of the river, however, and given the entire system could not be treated (just the hot spots), granular Bayluscide alone would not be sufficient, most thought, to manage populations on the St. Marys River. The Commission determined that granular Bayluscide should be combined with the SMRT to implement a two-pronged approach to sea lamprey suppression. This innovative approach, thus, combined a new formulation of the lampricide and a new sterilization technique. Certainly, this approach was the epitome of integrated pest management.

Starting in 1987, the St. Marys River was the test site for the SMRT. In 1997, SMRT became the major sea lamprey control technique on the river and in 1999, granular Bayluscide was added to the mix. The first applications of granular Bayluscide were done by helicopter in 1999 (an off-season crop duster did the job) and the results of those two approaches, although less dramatic and apparent than with conventional TFM treatments in typical Great Lakes streams, was apparent within a decade. Fish stocking resumed in Lake Huron and sea lamprey populations, by 2016, were at 30 and 20 year lows in Lakes Huron and Michigan, respectively, which supported a combined fishery worth more than $1 billion annually.

An assessment of the novel techniques for the St. Marys River, however, yielded some surprising results: the granular Bayluscide applications were likely responsible for the reduction in sea lamprey abundances while the SMRT could not be evaluated for its contribution to control.[25] In other words, while the innovative Bayluscide worked, the effectiveness of SMRT was not able to be determined. As such, the Commission, in the late-2000s, invested in boats capable of delivering granular Bayluscide to the lamprey hot spots, and put the SMRT in abeyance in 2011. SMRT funds were re-directed to more cost-effective methods.

As the Commission learned with the crude mechanical and electrical weirs of the 1940s and 1950s, innovation does not always work out as predicted. However, as the Commission also learned over time, previous techniques that do not always work as planned can lead to better innovation. Just as barriers improved because of the knowledge gained from disappointments, the SMRT—because of the considerable work that went into its development—remains a viable control method in inland lakes and places of low sea lamprey density, particularly where lampricides and barriers would prove to be less desirable or effective. As always, the Commission takes full advantage of knowledge gained from every innovative technique it develops.

The Future of Innovation: Pheromones, Genomics, Barriers, and Traps

As the Commission says in its strategic vision, “The probability of reaching [sea lamprey] 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.”[26] In other words, 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 dividend of investments in research and development will likely 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.

Why does the Commission devote resources and attention to innovation? Because innovation has brought us to where we are today and innovation will allow us to keep up with ever-shifting challenges, both from sea lamprey as they try to expand their range and by society as it shifts its values. For instance, the Commission is quite aware that it has been granted a social license to use lampricides in the Great Lakes and that such a license comes with expectations. Moreover, the Commission is aware that society is becoming less tolerant of dams and obstructions in rivers, particularly as older, more obsolete structures deteriorate and, thus, become more costly to maintain. Society, indeed, demands the minimal, most judicious use of pesticides and favors rivers that flow more freely. Although the Commission anticipates barriers and lampricides will continue to be essential elements of the sea lamprey control program, we are also optimistic that innovative technologies can usher in a new era of control that continues to fulfill Vernon Applegate's vision for an integrated pest management program.

The future of control will certainly lie in a deep understanding of what makes a sea lamprey tick. Just as work in the 1940s and 1950s to understand the sea lamprey's life cycle led to the discovery of lampricides and other techniques, work conducted over the decades, and continuing today, will further unlock sea lamprey biology and identify specific traits that can be exploited for control. Several approaches are emerging as particularly promising:

The sea lamprey genome: During the past decade, sequencing the genome of a species has gone from a monumental, expensive, multi-year endeavor involving massive computing power, to a quick and cheap process that almost can be done on a home computer. Genetic technologies could help in the control of harmful fish, including sea lamprey.

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.[27] This monumental achievement will allow scientists, for years to come, to 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.

One example of how genetic technologies could help control sea lampreys is through a technique called "gene knockdown." Gene knockdown could manipulate sea lamprey development, such as focusing on fertility genes (rendering sea lampreys sterile) or producing only males or females. Such genetic technologies are already yielding success in other species and in fishery management in other parts of the world.

Pheromones and alarm cues: Sea lampreys have an extremely well-developed sense of smell; their nose is half the size of their brain and loaded with receptors that allow them to detect pheromones and other odors (particularly those selective to lamprey) over large distances and in minute concentrations. 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. Lampreys, it was discovered, require a sex pheromone to locate each other for reproduction. Such a need turns out to be a tremendous weakness in the lamprey's life history and one that can be manipulated. 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.

The use of pheromones and other cues has actually long been considered as having a high potential for control. Research since the 1990s, supported by the Commission and later supplemented by the Great Lakes Restoration Initiative, has led to the discovery of several pheromones and alarm cues that affect sea lamprey behavior. Such research into the use of pheromones and cues in a *vertebrate* species is unprecedented.[28] In 2016, the U.S. Environmental Protection Agency approved the use of a Commission-developed pheromone (called 3KPZS) as a biopesticide for sea lamprey control. This approval paves the way for the development of other pheromones and cues in sea lamprey control. The Great Lakes Restoration Initiative has provided funds to move the pheromone program from the laboratory into the field. The Commission is hopeful that within ten to fifteen years, pheromones and alarm cues will be used throughout the basin as an integral complement to lampricides, barriers, and traps.

Acoustic telemetry: Many Great Lakes fishes, such as sea lamprey and lake trout, migrate throughout their lives to feed and reproduce. Until recently, scientists could only guess at fish movement. Starting in 2010, with funds seeded by the Great Lakes Restoration Initiative, the Commission has developed a Great Lakes Acoustic Telemetry Observation System, a network of innovative technology that tracks the precise movement of fish, aids in the recovery of native species, and helps us better understand the sea lamprey.

The acoustic telemetry network consists of nearly 2000 receivers – small, data-logging computers – that are anchored near the bottom of the lakes. To date, more than 30 species of fish (and 6000 individual fish) have been tagged with transmitters that broadcast a series of "pings" into the surrounding water. The receivers "listen" for tagged fish and the transmitter's unique ID code is saved with the date and time. Tens of millions of pings have been recorded. With each ping, researchers learn more about fish movements, migration patterns, habitat use, and survival. Receivers have been placed in key areas of the Great Lakes to help investigate specific research questions—for instance, walleye movement patterns in Lake Huron and the Huron-Erie corridor and lake trout spawning around Drummond Island, Lake Huron. Any scientist with the right tags can take advantage of this network. As the network grows the information and, perhaps, linkages among projects, grows as well. The Great Lakes network is now connected to the massive Ocean Tracking Network and the telemetry network in Lake Champlain.

Related to sea lamprey control, the project has shown that large populations of sea lampreys are hiding in the St. Marys River—existing in places where conventional assessment methods have been unable to detect. Through the acoustic telemetry project, researchers were able to collect better data on the size and location of the sea lamprey population in the St. Marys River. These data showed that the population in the river was much larger than previously thought, which allowed the commission to increase the efficiency of its sea lamprey control program and to redirect $500,000 annually to improve control throughout the Great Lakes

Connectivity and smart sea lamprey barriers and traps: 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 because it also addresses the removal of parasitic juveniles before they enter the lakes to feed on fish.

The vast majority of barriers in the Great Lakes basin were neither constructed for sea lamprey control nor are owned by the Commission and, thus, are out of our hands. However, without those barriers, sea lamprey control would cost tens of millions of dollars more each year, if it even would be possible. The Commission is concerned that with the general trend towards dam removal, the sea lamprey range will expand, millions more fish will be killed each year, and control will become prohibitively costly. And yet, the Commission strongly supports measures taken by public and private interests to remove barriers to fish passage, as fish need rivers and barriers prevent connectivity between streams and the Great Lakes. Just as barriers protect the fishery from the deadly sea lamprey, they also impede fishery rehabilitation by keeping fish from their spawning grounds or from feeding habitat.

This "barrier schizophrenia" is not unique to the Great Lakes basin. Fishery managers all over the planet are challenged by how to block bad things like sea lamprey and pass good things like trout, salmon, walleye, and sturgeon. The Great Lakes Fishery Commission believes that smart barriers, with the use of innovative technologies, can solve this problem and, as such, launched in 2016 an innovative initiative called FishPass.

FishPass seeks to identify smart technologies that can sort a mixed assemblage of fish. Just as municipal recycling facilities separate glass, plastic, and newspaper from a single stream (and kicks out nonrecyclables like foam and tires), the Commission believes technology can sort fish that congregate at an obstruction like a dam or a barrier. Recently, and in consultation with a wide range of government and non-government experts, the Commission selected a dam in northern Michigan as a site to test innovative fish passage/lamprey blocking technology. Over the next few years, scientists, biologists, and engineers will work with fishery managers at all orders of government at this test site to identify and install promising technology, evaluate the effectiveness of the technology, and make recommendations for future use, if appropriate. If this project proves successful, it could solve one of the greatest fishery management challenges of our time.

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.

INNOVATIONS IN GOVERNANCE

Most of this testimony has focused on innovations in science and technology in the control of the sea lamprey. I would be remiss if I did failed to note that the sea lamprey control program would not be the success it is without the innovative governance arrangement in place since 1954. Governance is important, and what is achieved is often a reflection of how people go about achieving it.

Sea lampreys swim across borders with wild abandon and spawn throughout the Great Lakes basin. As they spread in the 1920s through the 1950s, they posed a considerable threat to fishery management because containing and controlling the species required a level of cooperation across borders that was absent and certainly not at all in the culture at the time. In 1942, for instance, a Canadian-U.S. International Board of Inquiry noted that fishery collapse and sea lamprey spread was largely due to a parochial, jurisdictionally based approach to management.[29] Cooperation across borders was nonexistent and the fishery suffered because of that. Moreover, the lamprey invasion proved far too large a problem for any one jurisdiction to handle.[30]

By the 1950s, the sea lamprey problem, as noted above, was intolerable, and Canada and the United States agreed to the Convention on Great Lakes Fisheries of 1954.[31] The convention created the bi-national Great Lakes Fishery Commission, consisting of prime-ministerial and presidential appointees from both nations, who would lead fishery science, cross-border cooperation, and, importantly, sea lamprey control. This governance arrangement, which included an on-the-ground, bi-national, border-blind program, was unique in the Great Lakes basin and greeted with both applause from those who wanted the lamprey to be addressed and trepidation by those who were concerned about the Commission over-reaching its authority.

This testimony has described in detail the importance of the Commission’s science program in developing innovative sea lamprey control techniques. The Commission also has played an integral role in helping the state, tribal, provincial, and federal fishery jurisdictions work well together on the Great Lakes. It is one of the best examples of sound science and good policy working together for the benefit of the Great Lakes. This success in fostering collaboration is largely due to the fact that the convention explicitly prohibits jurisdictions from interfering in the Commission’s authority but also explicitly prohibits the Commission from intruding in the other jurisdictions’ authority. The convention acknowledged that cooperation would be necessary to achieve sound fishery management. Among other things, the Commission works closely with the other jurisdictions to ensure sea lamprey suppression is consistent with their fishery management programs. For instance, the states, the tribes, and the Province of Ontario depend on the Commission to control sea lamprey at levels that allow them to stock fish and issue fish harvest regulations.

In addition to the science and cross-border collaboration mandate found in the Convention on Great Lakes Fisheries, the governance arrangement is also unique in that is puts a specific agency—the Commission—in charge of controlling an invader. Responsibility (and, thus, accountability) for sea lamprey control is unambiguous. This authority stands in sharp contrast to other invasive species that are widely dispersed; where responsibility to act is either vague or, like the pre-convention situation, too diffuse to make a difference.

CONCLUSION

The sea lamprey control program is widely viewed as one of the world's best examples of an alleviated environmental disaster. Sea lamprey populations have been reduced by more than 90% in most parts of the Great Lakes, which saves tens of millions of pounds of fish each year, supports 75,000 jobs, and contributes to a $7 billion fishery that is the envy of the world. This control program has been possible through innovation, science, technology, and the courage to try new things. It is important to note that had the Commission stopped innovating in 1957 with the discovery of TFM, it could not afford—either in monetary or social-license terms—to control sea lampreys in the Great Lakes basin.

The sea lamprey has taught some tough lessons, which we would be well-served to heed as we consider other threats like Asian carp and zebra mussels:

- A single invasive species can cause significant, permanent damage to the economic and ecological health of a region. We are fortunate that sea lampreys can be controlled, but sea lampreys remain a permanent, destructive element in the Great Lakes basin. Most—if not all—fishery management decisions made by federal, state, tribal, and provincial agencies must forever account for sea lampreys.

- Control of invasive species, if possible, is expensive and ongoing. The commission has spent more than $450 million (actual; cumulative) since 1956 controlling sea lampreys. This total amount over sixty years, while large, is still just a small percentage of the annual $7 billion value of the fishery. This figure does not include the immeasurable damage to the ecology of the Great Lakes basin.

- Prevention is key; eradication is not possible. The Great Lakes fishery will forever contend with sea lampreys.

- Citizens shoulder the costs and consequences of invasive species, and programs to manage invasive species are costly and often borne by taxpayers.

The sea lamprey control program, though, has also taught us the value of innovation. As chairman of the Great Lakes Fishery Commission, I can tell you the future looks bright. I am confident in two things: first, not all of the innovative tools under development will lead to viable control techniques but second, the only way we will find the new tools to keep us ahead of this noxious predator will be through innovation.

I thank the committee for holding this important hearing and for allowing the Great Lakes Fishery Commission to tell this exciting, hopeful story.

NOTES

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Figure 1: Parasitic sea lamprey (actual size: approximately 60cm). Drawing: Paul Vecsei.

Figure 2: Sea lamprey mouth (shown approximately actual size). Photo: Ted Lawrence, GLFC

Figures 3A and 3B: Sea lamprey (A) attached to a Great Lakes lake trout and (B) mouth and wound on a Great Lakes salmon. Photos: Marc Gaden, GLFC.

A

B

Figure 4: Decline of lake trout after sea lamprey enter the Great Lakes. Diagram: Marc Gaden, GLFC.

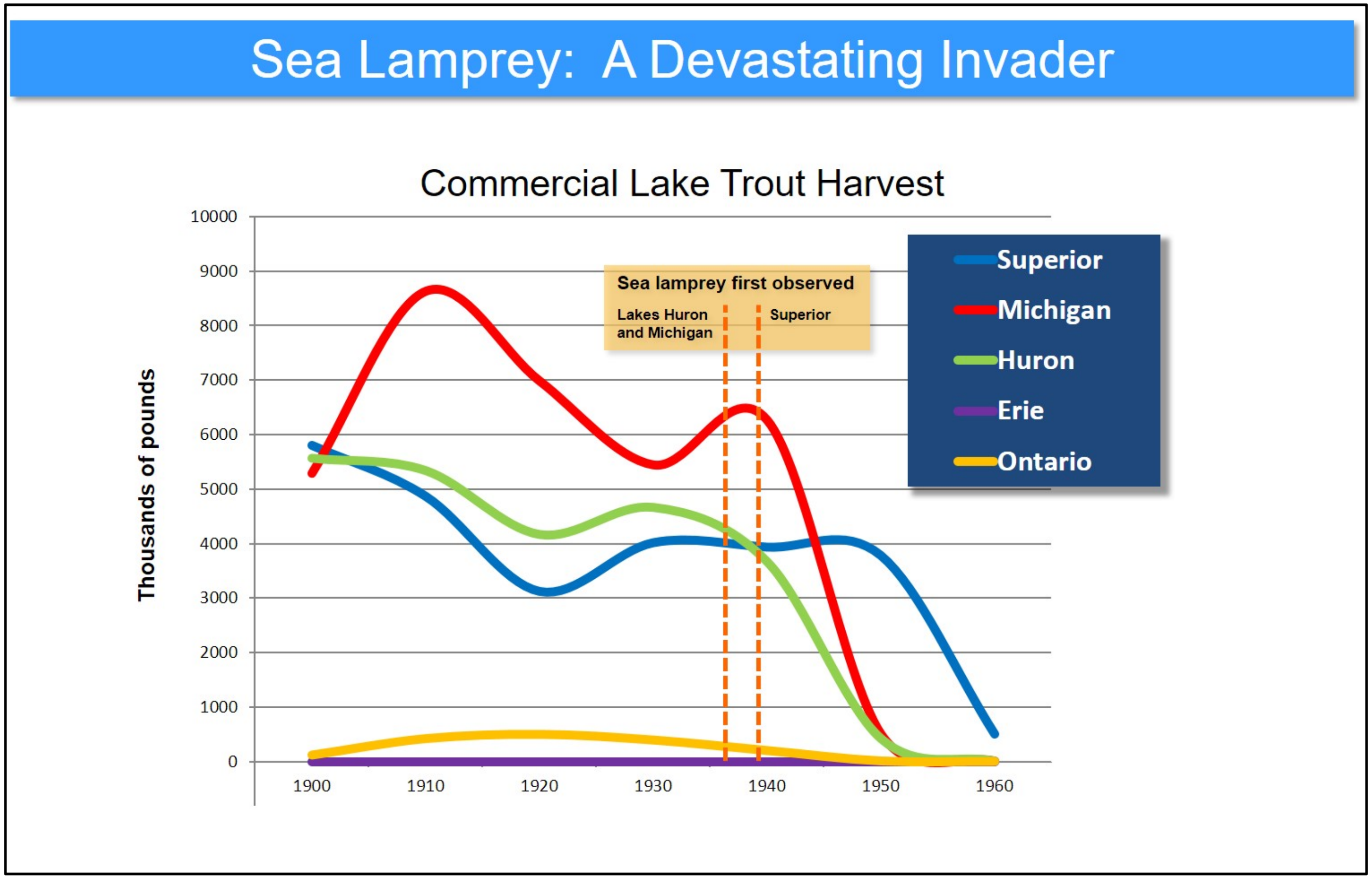

Figure 5: Sea lamprey abundance by lake compared to abundance target range. Diagram: Michael Siefkes and Marc Gaden, GLFC.

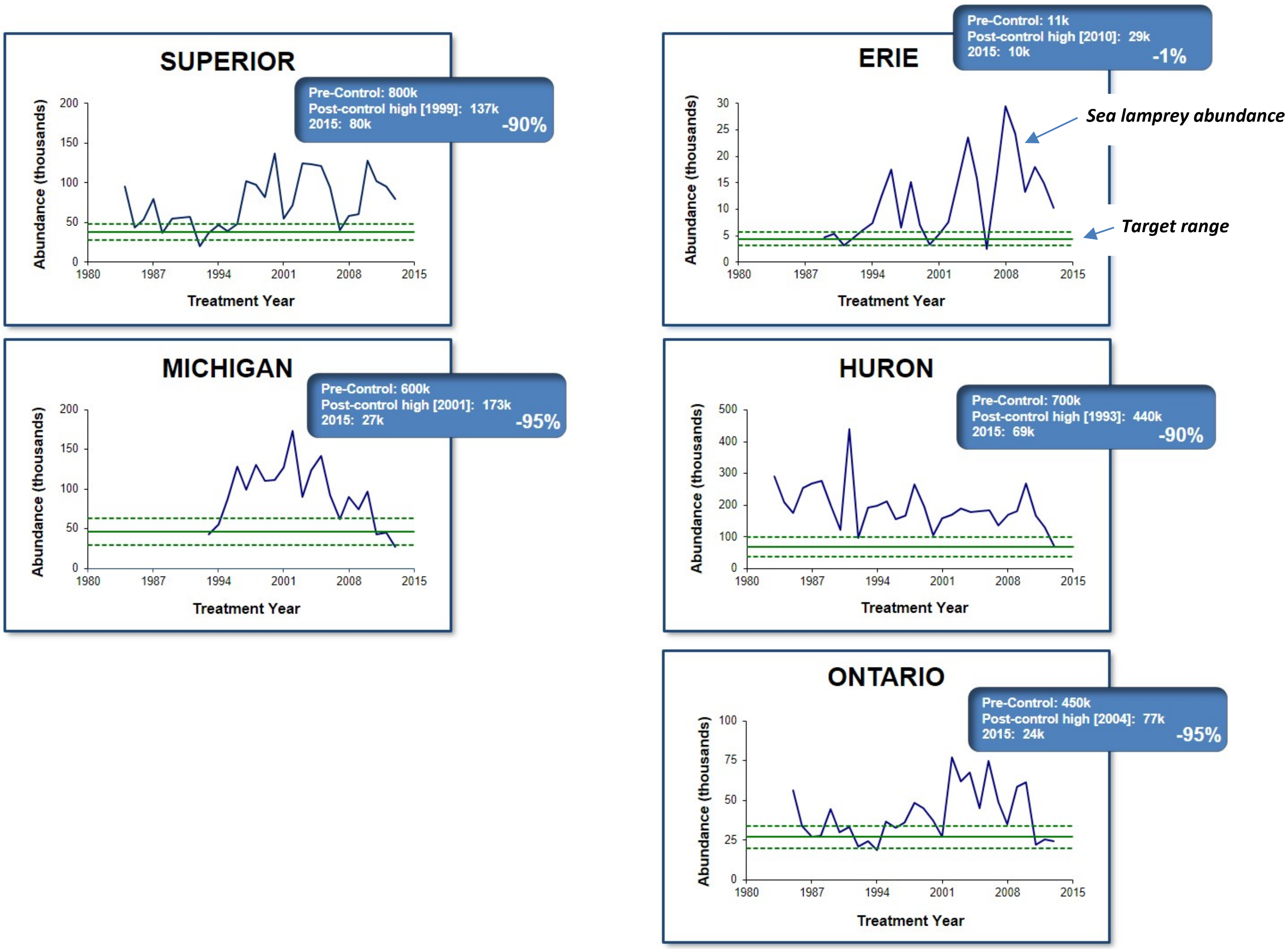

Figure 6: Millions of pounds of Great Lakes fish lost to sea lamprey. Diagram: Marc Gaden, GLFC.

1957-2017: Sea lamprey populations have been reduced by more than 90%. The result is a savings of more than 90 million pounds of Great Lakes fish per year that otherwise would have been killed by sea lamprey.