Sea lamprey (*Petromyzon marinus*) control in the Lake Champlain basin: An integrated pest management approach

Conservation Biology Case Study
Molly Parren and Leah Hart
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Executive Summary

The sea lamprey (*Petromyzon marinus*) is a parasitic fish found in Lake Champlain and is considered a nuisance species due to its impacts on the lake’s fisheries. These fisheries are a priority to state and federal agencies because they provide economic stability to the surrounding basin area and are culturally valuable as an indicator of the lake’s health and therefore the region’s health.

Sea lamprey primarily target Atlantic salmon (*Salmo salar*) and lake trout (*Salvelinus namaycush*) which are cold water fish that have thin skin and small scales: characteristics that make them particularly susceptible to parasitism. These fish are also highly valued as sports fish in Lake Champlain and are economically important to the region as anglers come from all over to catch them. However, these fish, though historically native, were extirpated from the area in the late 1800s and early 1900s due to over-exploitation.

The Atlantic salmon and lake trout that we see now in Lake Champlain are stocked fish whose source populations are in Maine and New York. Stocking of salmon and trout in Lake Champlain began on a large scale in 1973 when the New York State Department of Environmental Conservation, the Vermont Department of Fish and Wildlife, and the United States Fish and Wildlife Service formed the Lake Champlain Fish and Wildlife Management Cooperative (the Cooperative) and established a lake-wide salmon and lake trout restoration program.

There are arguments as to whether the sea lamprey is native to the Lake Champlain region, or not. When control programs were first instated to lower the numbers of sea lamprey in Lake Champlain it was widely believed that sea lamprey were a non-native nuisance species. However, recent genetic studies looking at mitochondrial DNA have shown that sea lamprey
have been in Lake Champlain for thousands of years. Regardless of their status as a native species it became clear in the 1980s that wounding rates of game fish were inordinately high and that salmon and trout populations were smaller, as was the size of the fish being caught. It was then that the Cooperative decided to implement sea lamprey control in the region.

In 1990 the Cooperative began an eight year experimental sea lamprey control program based upon the control program put into action in the Great Lakes in the early 1960s. To control sea lamprey in the Great Lakes The Great Lakes Commission used a selective lampricide called Trifluoromethyl-4-nitro-cresol, sodium salt (3-trifluoromethyl-4-nitrophenol or TFM) which targets and kills larval sea lamprey in tributaries of the lakes. While this pesticide (along with another used to treat deltas- Baylucide) was approved by the EPA as an appropriate chemical to use to control sea lamprey, there is associated non-target mortality which results from the use of these lampricides. This non-target mortality was labeled as acceptable during the review of the experimental control program that took place in Lake Champlain and in 2002 a long-term control program was approved and implemented which focused heavily on the use of lampricides to control sea lamprey populations.

Sea lamprey wounding rates have dropped significantly since the implementation of this long term control program and game fish being caught are bigger and more plentiful. There have been noticeable economic responses to the decrease in wounding rates and responsive increases in sport fish populations. However, there is still a sect of people that think that using pesticides to kill lamprey is a bad idea and that the science still does not exist to prove that these chemicals will not have long-term effects on the Lake Champlain ecosystem. Several studies have been completed looking at a particular amphibian species, the mudpuppy (*Necturus maculosus*), which is known to be a non-target species sensitive to TFM. While everyone can agree that the
sea lamprey population was too high in Lake Champlain and that the use of lampricides has considerably lowered this population and this has resulted in positive economic benefits; there is still debate as to whether we really know the long term impacts TFM may have on other species which also compose the Lake Champlain ecosystem.

In order to continue the reduction of sea lamprey populations, reestablish fisheries, and move towards healthier, more efficient, and safer treatments there are several steps that need to be taken. First, chemical control of lamprey should continue so that their population level remains low. Impact to non-target species should continue to be considered by U.S. Fish and Wildlife Service. Understanding preferred habitats by sea lamprey will allow treatments to be prioritized. All the tributaries should have some kind of treatment, whether it is chemical or a barrier. Aside from having a larger, yet more directed treatment program, research should continue to evaluate different chemical treatments and durations. Additional research should look at the use of pheromones to lure and trap sea lamprey and the alteration lamprey genes, compromising lamprey reproduction. Overall an integrated pest management program will allow for continued treatment, while supplemental research will result in more efficient, safer chemical treatments. Lake and fishery health is too important to the economy and culture of the Lake Champlain basin to not make the best effort to reduce wounding rates of sea lamprey. Monitoring the long-term effect of pesticide treatments should be continued and overall lake health should be the ultimate goal. If the Atlantic salmon and trout populations could be reestablished in Lake Champlain this would be a positive indicator of a successful lake ecosystem. Currently a larger reduction of lamprey population numbers is necessary and feasible with this new suite of solutions.
Problem Definition

Lake Champlain is the sixth largest body of fresh water in the United States and is bounded on the west by the Adirondack Mountains of New York and on the east by the Green Mountains of Vermont. It flows north from Whitehall, New York to the Saint Lawrence River in Quebec (Lake Champlain Land Trust, 2012). Lake Champlain was named for Samuel de Champlain who was the first European to discover the lake in 1609. Since that discovery there have been substantial physical changes to the watershed, lake sediments, and hydrological connections within the lake. Two fish species have been extirpated, fifteen species have been added to the lake, and sixteen species have been listed as endangered, threatened, or of special concern/susceptible (Marsden and Langdon, 2011). There were several causes of these physical changes and resulting biodiversity alterations. Habitat fragmentation of rivers occurred wherein dams were constructed on most of the major rivers in the 1800s; this likely interrupted the spawning of certain fishes such as the Atlantic salmon. Habitat fragmentation of the lake was also created through the construction of several causeways between the mainland and islands, which created isolated basins. Shoreline alterations through development and draining and filling of wetlands likely increased predation and reduced spawning and larval habitats for some species. There have also been some chemical changes in the lake due to industrial runoff and pollution and, most recently, chemical treatments to target and kill larval sea lamprey in the tributaries of the lake (Marsden and Langdon, 2011).

The sea lamprey (*Petromyzon marinus*) is an eel-shaped parasitic fish with a skeleton made of cartilage rather than bone; it is also a jawless fish which has a suction disk mouth filled with small sharp, rasping teeth and a file-like tongue it uses to feed on the body fluids of fish (NYSDEC, 2012). The sea lamprey is one of thirty-one species of lamprey found worldwide and
one of four lamprey species found in the Lake Champlain Basin; the others being the Northern brook lamprey (*Ichthyomyzon fossor*) which is endangered in Vermont, the Silver lamprey (*Ichthyomyzon unicuspis*), and the American brook lamprey (*Lampetra appendix*) which is threatened in Vermont (NYSDEC, 2012; Fisheries Technical Committee, 2009). None of the other lamprey that inhabit Lake Champlain are parasitic. Sea lamprey, like salmon, are diadromous which means that they spend the early stages of their lives in streams and rivers, the middle stages of their lives in the ocean or in a large freshwater lake (such as Lake Champlain), and the final stage of their lives is spent in the same freshwater streams and rivers where they hatch when the breeding adults return to spawn and then die. The lifecycle of sea lamprey in Lake Champlain lasts on average six years (NYSDEC, 2012).

As was mentioned above, sea lamprey are a parasitic fish. But what is particularly important about sea lamprey is that they prefer to prey on fish species with small scales and thin skin: fish like the Atlantic salmon (*Salmo salar*) and the lake trout (*Salvelinus namaycush*) (NYSDEC, 2012). Sea lamprey do not always kill their hosts. Studies on the Great Lakes, where populations of sea lamprey are also extant, show a forty to sixty percent mortality rate for fish attacked by sea lamprey. However, even if a fish survives an attack it will expend more energy on healing than on growing, producing eggs, and mating so sea lamprey do impact population dynamics even without outright killing their prey (NYSDEC, 2012). The reason this is a problem, and the real reason people are trying to control the sea lamprey population is that Atlantic salmon and lake trout are important game fish in Lake Champlain and the fishing of these species is particularly important to the local economy. In fact, the New York State Department of Environmental Conservation writes on their webpage that “It has been estimated that 29.4 million dollars in economic benefits to businesses and residents of the Lake Champlain Basin are
lost due to the impacts of sea lamprey” on the sport fishing industry (NYSDEC, 2012). What is worrisome is not that people are trying to control the sea lamprey numbers in Lake Champlain, but rather the control methods pursued.

Before delving much further into the issue of sea lamprey in Lake Champlain and the resulting issue of trying to control sea lamprey, it is important to understand how this problem came to be and why sea lamprey are currently so prevalent and problematic. The first aspect to understand about sea lamprey in Lake Champlain is that their native status is still being debated today. When sea lamprey control in Lake Champlain first began in the 1990s most people believed that the sea lamprey was a non-native nuisance species that had reached Lake Champlain through the Hudson-Champlain Canal. This canal was completed in 1819 and connected Lake Champlain to the Hudson River which has natural runs of sea lamprey (Nettles, 2001).

However, recent genetic studies suggest that the population is native to Lake Champlain (Bryan et al., 2005; Waldman et al., 2006). Research using mitochondrial DNA found that the population of sea lamprey in Lake Champlain is genetically distinct from those in tributaries of the Atlantic Ocean, Lake Ontario, and Lake Superior (Waldman, et al., 2006). Significant haplotype frequency differences exist between Lake Champlain and other locales indicating that the sea lamprey population in Lake Champlain is genetically unique and had time to mutate since its colonization event (Waldman, et al., 2006). Microsatellite loci were also examined to determine the native status of sea lamprey in Lake Champlain and found that a rare allele is represented in only Lake Ontario and Lake Champlain populations. The presence of this allele indicates that these populations of sea lamprey have been separated from anadromous populations for a considerable amount of time (Bryan, et al., 2005). Together these two genetic
studies provide significant data which indicate that sea lamprey are native to Lake Champlain and likely established themselves in the Lake less than 15,000 years ago when glaciers, which covered the entire area during the Wisconsinian Age, receded (Bryan et al., 2005).

Regardless of whether sea lamprey are, in fact, native it is important to realize that when management programs were developed it was believed that sea lamprey were non-native and did not belong in the Lake Champlain ecosystem. What has occurred since then is the presentation of very convincing evidence suggesting that sea lamprey have been a part of this ecosystem for thousands of years. If there is now a problem with sea lamprey and their abundance there has been a change somewhere within the ecosystem that has caused an increase in sea lamprey numbers. What this discovery indicates is that people may be trying to control a native species which may just be overabundant due to reasons not yet identified or addressed, meaning that management plans may be completely misdirected and trying to fix a problem without finding its source.

If lamprey are native (and even if they are not) why are they so abundant in Lake Champlain and why is this such an issue? One of the possible explanations for why sea lamprey numbers are so high is due to gradual habitat transformation over time. Many people are in agreement that it is possible that through land development and resulting sedimentation in lakes and rivers people have actually provided sea lamprey with an even better larval. Larval lamprey are known as “ammocoetes” which are blind and look worm-like. Ammocoetes hatch from eggs in gravel nests in tributaries and drift downstream with the current. When these larvae locate suitable habitat, which is usually silt/sand stream bottoms and banks in slower stretches of water, they burrow in and filter-feed on algae, detritus and microscopic organisms and materials
This part of the sea lamprey’s lifecycle lasts for about three to four years in Lake Champlain.

Larval sea lamprey habitats have been increased by land development. The settling of the land, agricultural and urban development has led to increased sedimentation in tributary rivers thus providing additional suitable substrate for ammocoetes to burrow (Marsden and Langdon, 2011). Not only has habitat transformation created better habitat for larval sea lamprey but could also be providing lamprey with more food. Tributary nutrient levels have likely increased over the last hundred years, thus providing greater levels of suspended material that filtering ammocoetes can utilize for more nourishment, which in turn leads to increased growth rates and possible shortened of the length of time in the larval stage (Marsden and Langdon, 2011).

Another possible cause of sea lamprey increase is the decrease in their predators. Very little is known about freshwater predators of sea lamprey but it is thought that possible predators of larval lamprey are lake sturgeon (*Acipenser fulvescens*) and American eel (*Anguilla rostrata*) both of which declined substantially in Lake Champlain prior to the increase in sea lamprey (Marsden and Langdon, 2011). The other time in a sea lamprey’s life when it is particularly susceptible to predation is when it is a “transformer”. This is the life stage at which, sometime in the mid to late summer of their third or fourth year, ammocoetes change in both form and function. They become a smaller version of an adult sea lamprey by developing eyes and a suction disk mouth. When the sea lamprey have undergone this change they are ready to begin their next life stage as a parasite of fish and they move to deeper water (Lake Champlain) in order to seek out host fish (NYSDEC, 2012). Atlantic salmon, which were one of the two species which were extirpated in Lake Champlain, were historically present in streams in high densities during the period when sea lamprey transformers are descending toward the lake (Marsden and
Langdon, 2011). This indicates that a species which no longer naturally exists in Lake Champlain was a likely predator of sea lamprey. With its loss sea lamprey were able to thrive and multiply.

A final possible explanation for the increase in sea lamprey in Lake Champlain has to do with the final life stage of the sea lamprey when it is functioning as a parasite in Lake Champlain. The reason that sea lamprey may be so abundant currently is that we are stocking Lake Champlain with the sport fishes which fishermen like to catch but also on which sea lamprey like to prey. Before talking more about stocking of Lake Champlain it is important to understand why such stocking takes place.

The two fish species that are of greatest concern to fisheries in regards to the presence of sea lamprey in Lake Champlain are the two species that were historically extirpated: the Atlantic salmon (Salmo salar) and the lake trout (Salvelinus namaycush). Prior to the 1800s, native Atlantic salmon and lake trout were abundant in Lake Champlain. However, by the mid-1800s overfishing, pollution and damming of tributaries had eliminated native salmon from Lake Champlain and lake trout soon followed by 1900 (NYSDEC, 2012). Numerous attempts were made to restock these two species in Lake Champlain during the late 1800s and early 1900s as well as the late 1950s and 1960s but none of these stocking programs were successful. But, in 1973 when the New York State Department of Environmental Conservation, the Vermont Fish and Wildlife Department, and the United States Fish and Wildlife Service formed the Lake Champlain Fish and Wildlife Management Cooperative (the Cooperative) they also established a lake-wide salmon and lake trout restoration program (NYSDEC, 2012).

However, because the populations of these fish that were native to Lake Champlain were extirpated, fish had to be taken from elsewhere to stock the lake. The salmon that are stocked by
Vermont are originally from Sebago Lake, Maine and the domestic brood stock is being held in a Vermont hatchery (Fisheries Technical Committee, 2009). The salmon that are stocked by New York are from a brood stock established in Little Clear Pond from a variety of Atlantic salmon strains. The trout which are stocked in Lake Champlain are from several different strains, including the Finger Lakes strain, Seneca Lake strain, and progeny of feral lake trout from Lake Champlain (Fisheries Technical Committee, 2009).

Fish that are being stocked in Lake Champlain are not native (the species is, but not the strain). This brings us back to the third possibility as to why sea lamprey are currently so prevalent. It is possible that we are supplying the sea lamprey with a steady source of vulnerable food which cannot protect itself. Irrespective of whether sea lamprey are native to Lake Champlain it is clear that the fish being stocked in Lake Champlain have not evolved with sea lamprey and that current stocking rates are supporting an artificially high parasite population and maintaining an unnatural host-parasite relationship (Marsden and Langdon, 2011). If, however, sea lamprey are native (which genetic studies seem to indicate) it is likely that the native strains of salmon and trout co-evolved with them and could have developed either avoidance strategies which would have led to lower spatial overlap with sea lamprey or resistance to sea lamprey-induced mortality (Marsden and Langdon, 2011). The current stocked populations, however, do not have these adaptations, resulting in high rates of parasitism of sport fish and why a sea lamprey control program was necessary.

By 1985 it became clear to the Cooperative that the goal of restoring the salmon and trout fishery was unattainable due to the impacts of sea lamprey and it began an integrated control program to reduce sea lamprey in Lake Champlain (NYSDEC, 2012). In fact, it was estimated that the salmonid (for “Salmonidae”, the family in which both trout and salmon belong) harvest
and the number of angler trips in 1985 was only forty-five percent of the numerical targets stated in the fisheries plan adopted and implemented by the Cooperative in 1977 (Nettles, 2001). When it came time to create the control program, the Cooperative looked to the Great Lakes where a program to control sea lamprey had begun in the 1950s (Nettles, 2001).

The Great Lakes Fishery Commission first tried to control sea lamprey by constructing mechanical and electrical barriers in tributaries of the Great Lakes in an attempt to block sea lamprey spawning migrations; but these control measures were not very effective. It was not until 1958 when Triflouromethyl-4-nitro-cresol, sodium salt (3-trifluoromethyl-4-nitrophenol or TFM), a selective lampricide, was discovered and put to use that any control measures really made an impact on lamprey numbers (Nettles, 2001). While the biology behind TFM is still somewhat unknown, other than that it affects larval sea lamprey respiration, it was chosen for its effectiveness at controlling sea lamprey without significantly impacting other species after a screening of over six thousand chemicals (NYSDEC, 2012). Barriers are still used in the Great Lakes to control sea lamprey but the main method of control is the use of the lampricide, TFM.

TFM and Baylucide (2’5-dichloro-‘4-nitrosalicylanilide (3.2% granular Bayluscide)), another lampricide approved by the EPA for the control of lamprey in the Great Lakes (as well as Finger Lakes and Lake Champlain), target larval sea lamprey, killing them before they can transform into parasitic adults (NYSDEC, 2012). TFM is a liquid pesticide which is used to treat the tributaries of larger water bodies whereas Bayluscide is used to treat deltas and is manufactured in granular form which allows it to sink to the bottom of deltas where it releases its active ingredient, niclosamide, into the waters close to the burrows of larval sea lamprey (NYSDEC, 2012). TFM is closely monitored and measured as it is applied (sprayed) into streams. The amount of TFM applied is based upon chemical and physical characteristics of the
tributaries and is metered into the streams at a rate necessary to achieve up to 1.5 times the Minimum Lethal Concentration (minimum concentration of TFM predicted necessary to kill 99.9% of sea lamprey in a nine-hour period) for a period of twelve hours (Nettles, 2001; NYSDEC, 2012). Bayluscide is applied through a mechanical spreader mounted on a platform on the back of a boat; the boat moves back and forth across the delta and Bayluscide is applied evenly across the area to be treated (NYSDEC, 2012). Both kinds of treatments are used about every four years because that is the length of time sea lamprey remain in their larval stage; this timing is most effective at targeting the most larval sea lamprey.

Figure 1. Control methods on each of the Lake Champlain tributaries (NYDEC, 2012).
Based on the success of the sea lamprey control program in the Great Lakes, in which sea lamprey numbers were decreased to ten percent or less of their formal numbers (USGS, 2008), the Cooperative decided to implement a similar control program. An eight year control program of sea lamprey in Lake Champlain was implemented in September of 1990 in which thirteen streams and five deltas were treated with lampricides between 1990 and 1997 (NYSDEC, 2012). This experimental control program also established two physical barriers to bar adult sea lamprey from accessing spawning habitat (Nettles, 2001). While there are a variety of barrier types, vertical-drop barriers are the most widely used. However, the problem with barriers is that their full effect may not be realized until four to six years after the barrier is built (because larval sea lamprey already upstream of the barrier can still transform and become parasites) (NYSDEC, 2012).

At the end of the experimental program, an evaluation of the efficacy of the program was made. During this time period a limited three year interim sea lamprey control program was undertaken from 1998 to 2000 (NYSDEC, 2012). Results from the evaluation showed that:

“Sixteen of 24 TFM treatments resulted in a reduction in catch rate of sea lamprey larvae at index stations to less than 10 percent of pre-treatment levels. Treatment-zone, live-cage mortality in eight of the nine delta treatments conducted with Bayluscide exceeded 85 percent. Spawning-phase sea lamprey was monitored throughout the eight-year control program through adult trapping and by conducting nest counts in index sections of ten tributaries. There were substantial (80 to 90%) reductions in the number of animals trapped compared to pre-control levels. Nest count data revealed a reduction in the number of sea lamprey nests to 43 percent of pre-control levels” (Nettles, 2001).
This evaluation also revealed increases in both salmon and trout populations, an increase in the weight of fish, and a decrease in the number of wounds on fish. All together this led to a benefit to cost ratio of 3.5 to 1 where sea lamprey control generated benefits of approximately $29.4 million with costs of about $8.4 million, due to the increased number of boaters and anglers spending longer periods of time in the Lake Champlain area (NYSDEC, 2012).

After the evaluation of the experimental control program the Cooperative developed a Supplemental Environmental Impact Statement (SEIS) which identified an extensive, long term, integrated program as the desired approach to sea lamprey control in Lake Champlain (NYSDEC, 2012). In 2002 this SEIS was reviewed and accepted by the EPA and the current long-term control program was implemented which utilizes chemical treatments, trapping, physical barriers, and other methods of control (NYSDEC, 2012). Traps are used to capture adult sea lamprey as they move upstream in tributaries during their spawning migration, but before they can spawn. These traps are particularly useful when used in conjunction with sea lamprey barrier structures as well as in constricted stream channels where adults concentrate. Traps, however, are labor-intensive and must be maintained for the duration of the spawning run. Thus, trapping is used as a supplemental control method (except where the physical stream conditions make trapping an effective primary technique or where other techniques are not feasible or chemicals should not be spread) (NYSDEC, 2012). The objectives of this long term control program were to achieve and maintain lamprey wounding rates at or below: twenty-five (ideally ten) wounds per one-hundred lake trout, fifteen wounds (ideally five) per one-hundred landlocked salmon, and two wounds (ideally one) per one-hundred walleye (Nettles, 2001).

Following the implementation of this long term control program for sea lamprey in Lake Champlain in 2002, annual collected data shows that wounds on lake trout and landlocked
Atlantic salmon began declining in 2007. Also, sampling in the fall of 2010 found that, for the first time since the inception of the long-term control program, the management goal of fifteen wounds per one-hundred salmon had been met. The management goal of twenty-five wounds per one-hundred lake trout has still not been met but the wounding rates have improved considerably since the high of ninety-nine wounds per one-hundred trout caught in 2007 (NYSDEC, 2012). It would appear from the above data that the issue of sea lamprey in Lake Champlain has been resolved; sea lamprey wounding rates have decreased dramatically, trout and salmon populations are growing both in numbers and size, and the associated economy of the Lake Champlain basin has benefitted greatly due to the management of sea lamprey. However, while this is true, this is just one side of the story. The debate over sea lamprey control in Lake Champlain is ongoing due to opposing values on ecosystem management. There is a group of people who are still questioning how lampricides are impacting non-target species in the tributaries and deltas of Lake Champlain.

If chemical treatments were killing a significant number of organisms from a range of species the EPA would not have approved the use of TFM in tributaries; so it is obvious that TFM’s effects on non-target species are not huge. However, just because the EPA approves TFM as a pesticide in Lake Champlain tributaries this does not mean that TFM does not affect other organisms; the effects are just considered to be “acceptable”. It was discovered in Vermont that seven state-listed endangered or threatened mussel species, four state-listed endangered or threatened fish species, three other species and one amphibian that occur in one or more of the streams proposed for treatment were identified by the Department to be susceptible to chemical treatments (VTFWD, 2010). It was decided, however, that the controlled application of lampricides at the proposed concentration for each tributary would pose an acceptable risk to
non-target species (VTFWD, 2010). The species evaluated in this statement are just present-day threatened and endangered species, not species that are currently thought to be stable; however, they too are being affected. In the environmental impact statement that was written for the proposal of this long term sea lamprey control program was a section on threatened and endangered species;

“The purpose of the Endangered Species Act is to conserve ‘the ecosystem upon which endangered and threatened species depend’ and to conserve and recover listed species. Under the law, species may be listed as either ‘endangered’ or ‘threatened.’ Endangered means a species is in danger of extinction throughout all or a significant part of its range. Threatened means a species is likely to become endangered within the foreseeable future” (Nettles, 2001).

What this EIS showed was that species meeting these requirements (of threatened and endangered status) were further threatened by the presence of lampricides, but this risk was considered acceptable.

The reasoning that is given for this acceptable risk is that each year when treatments are repeated in the same tributary (every four years) individuals of these species are found dead, which means that the population is existing and still living in that tributary despite the use of lampricides. It is mostly fishery managers and biologists completing these counts who are mostly concerned with the health of the species they are focusing on (salmon and trout) and are satisfied with just knowing that other species are surviving in the presence of lampricides; not necessarily thriving. There have been some changes made to accommodate some species of concern such as the lake sturgeon (\textit{Acipenser fulvescens}) which is listed as threatened in every state in which it occurs. Lampricide treatments now primarily take place in the fall because lake sturgeon spawn
in the spring and the newly-hatched juveniles are known to be vulnerable to TFM (Emily Zollweg-Horan, personal communication)\(^1\). However, these accommodations are rare and typically few amendments are made to control plans with regards to the effects of TFM on non-target species.

After speaking to the chair of the Reptile and Amphibian Advisory Group for the Threatened and Endangered Species Committee of Vermont, Jim Andrews, it was made clear that although some research has been done in respect to non-target mortality caused by TFM, the effects on the wider ecosystem are relatively unknown (Jim Andrews, personal communication)\(^2\). While it is clear that there is a great deal of data out there about non-target mortality due to TFM (required in all Environmental Impact Statements), what biologists such as Jim argue is that this data is too simplistic and does not give a clear view of the long-term impacts of TFM. Jim Andrews believes that just focusing on the presence or absence of a species does not give an indication of the health of the population and that is what is needed to predict the future presence of a species. This leads very much to the concept of “burden of proof” in which the burden of proof has fallen upon the people who oppose lampricides rather than those who support and use them. While fisheries managers have proven to what extent one treatment kills individuals in a population (the acute affect) they have not really done the research which shows the long-term effects of exposure to lampricides on other species. In other words, we know how many individuals are killed per treatment but we do not know the impact on a population due to the loss of these individuals.

While there are several species different environmentally-conscious groups focus on, there is one amphibian species that has had a great deal written about it, this is the mudpuppy

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\(^1\) Phone Interview. April 13, 2012.
\(^2\) Phone Interview. April 16, 2012.
(Necturus maculosus). While mudpuppies are not listed as threatened or endangered in Vermont or New York, they are considered a species of concern in Vermont and a lot of controversy has arisen recently regarding whether they should be listed. The mudpuppy has become the poster-child for the movement against lampricides although several mussel species, fish species, and invertebrates are just as, if not more, affected by TFM. Data clearly shows that mudpuppies have been killed by TFM but this appears to be of little concern because in most cases mudpuppies are once again found after a second treatment. What people worry, though, is that while we know exactly how many mudpuppies will be killed by acute exposure to TFM we do not know the chronic effects because mudpuppies can live for about 25 years and will be exposed to many treatments of TFM over that time (Jim Andrews, personal communication)\(^3\). While it would appear that enough research has been completed to support the premise that TFM has a small impact on non-target species, biologists who often do this kind of research say that the information that has been garnered from these studies just scratches the surface of what needs to be known about the impacts TFM. In the case of TFM it would appear that the program was implemented before the long-term impact of TFM was fully exposed and now opponents of TFM must do the work which proves TFM as either safe or dangerous.

Again, this problem comes back to economics. Lamprey were considered a problem because they impact Lake Champlain fisheries and as such are an economic issue for the Lake Champlain basin. Because lamprey were an economic issue, a control program was put in place in which the most cost-effective strategy to manage sea lamprey numbers was to treat tributaries with the pesticide, TFM. TFM may have a far greater impact on the natural ecosystem than currently known; the research has just not been done to identify the long-term impacts of TFM use in Lake Champlain. The impact of TFM on non-target species, such as the mudpuppy, is not

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\(^3\) Phone Interview. April 16, 2012.
widely considered a problem except for within certain environmentalist and conservationist circles. Jim Andrews and others believe that the issue of lampricides is not being fully acknowledged because it is not an economic problem. TFM fixes an economic problem for a majority of stakeholders and to stop the use of lampricides to protect non-target species would not be economically-wise. There is no widely-accepted economic way to value biodiversity. People are able to currently see the positive effects of TFM, but the negative effects are much more hidden and unknown.

TFM could pose a problem to the ecosystem in the future ecologically, but not economically in the present. But it is worth pointing out that people have been in a similar position in the past. The use of DDT to control a pest species was not until later on, after the chemical compounded in the ecosystem, noticed to be threatening biodiversity of many bird species in North America. So the question is: could this be happening again? People can agree that sea lamprey are a problem for fisheries and that TFM is an effective way to lower their numbers, but at what cost? Are the negative repercussions of TFM really known? Research is ongoing; especially through University of Vermont which is located right on Lake Champlain. Hopefully people can find these answers in time to recognize any problem with TFM and be able to discontinue its use before the ecosystem incurs more damage. What needs to be remembered is that humans caused this problem. Humans depleted the lake of salmon and trout, altered the habitat to accommodate sea lamprey, and stocked the lake with non-native strains of fish and the lamprey responded. People are now once again using chemicals to treat the lake’s tributaries. Is this chemical intervention as safe as it appears?
Identification of Stakeholders

There are many people, agencies, and economies which have a stake in the issue of overabundance of sea lamprey in Lake Champlain and their control using pesticides. One reason so many people are impacted by this issue is that Lake Champlain is a large water body that borders two countries and two states, meaning that several governmental agencies must be involved to come up with a solution for any problem that impacts the Lake.

The two countries involved are Canada and the United States and the two respective federal government agencies involved in the control of this parasite in Lake Champlain are the Ministère du Développement durable, de l’Environnement et des Parcs of Canada (Quebec) and the U.S. Fish and Wildlife Service. The lake also borders two states; Vermont and New York, meaning that state agencies are also involved; the New York State Department of Environmental Conservation and Vermont Fish and Wildlife Department. Because application of pesticides to flowing waters violates provincial statutes (Bouffard, 2008) in Quebec and because Canada shares such a small portion of the Lake, focus will be put on stakeholders in Vermont and New York who are more directly involved and affected by sea lamprey and the programs implemented to control them.

The U.S. Fish and Wildlife Service along with the Vermont Fish and Wildlife Department and the New York State Department of Environmental Conservation formed the Lake Champlain Fish and Wildlife Cooperative in 1972 which is “responsible for coordinating evaluation of environmental impacts on fish and wildlife resources and formulating appropriate responses; developing a comprehensive fish and wildlife management plan for species of interstate significance; and encouraging implementation of the comprehensive plan by the agencies with primary responsibility” (Fisheries Technical Committee, 2009). It is this
Cooperative which is primarily responsible for the implementation of the long term sea lamprey control program which was created in 2002 (NYSDEC, 2012).

When we asked a fisherman from Vermont, Gerry Hartley, who fishes on Lake Champlain if he is impacted by sea lamprey he responded,

“Yes, I am personally impacted by the overabundance of sea lamprey in Lake Champlain. I am an avid Landlocked Atlantic Salmon, Brown Trout, and Steel head fisherman on Lake Champlain. The more sea lamprey present in the lake, the more sea lamprey wounds (and even sea lamprey) I see. Wounded fish are much smaller and weaker. Brown Trout and Steel head in particular seem unable to survive a hit by a sea lamprey. With the population of this parasite coming under control, we are seeing more Steel-head than ever, our Brown trout are doing very well, and the Landlocked Salmon are bigger, heavier, more energetic, and much, much healthier. I often keep the fish I catch for table-fare. Nothing beats a meal of fresh fish, unspoiled by the wrath of the parasite known as the sea lamprey” (Gerry Hartley, personal communication)⁴.

It is apparent that fishermen, like Gerry, feel that they hold a big stake in this conservation issue and they want the lamprey to be controlled in order to preserve the health of their “world-class” fishery. We were able to get Gerry to post some questions of ours on an online forum for fishermen called “Lake Champlain United” where Gerry’s feelings were reiterated again and again. Each respondent said that they felt sea lamprey were a big problem and needed to be controlled if not downright extirpated. These feelings are reflected in Gerry’s response to the question “Do you think sea lamprey should be controlled? How?” Gerry stated that,

“Yes I believe the sea lamprey in Lake Champlain need to be controlled. I wouldn’t even be opposed to outright extermination of them. They are a parasite and I feel there is no

⁴ Email Interview. April 12, 2012.
place for them in the lake. I don’t believe they serve a useful purpose in the Lake Champlain environment. The method of sea lamprey control needs to be the most effective method available. This parasite needs to be stopped” (Gerry Hartley, personal communication)\(^5\).

While fishermen are clearly impacted by the presence of sea lamprey and many, if not the majority, of them are in support of the chemical programs to control sea lamprey there are other people who are stakeholders in a very different way. These are the people and other species directly impacted by the pesticides being used to kill larval sea lamprey in the tributaries of Lake Champlain.

Emily Zollweg-Horan, a senior aquatic biologist for New York State Department of Environmental Conservation, highlighted local property holders and visitors of the lake as important stakeholders in this issue other than fishermen and the agencies involved in the actual control programs. Emily said that when rivers and deltas are treated people are told not to swim on the day of treatment or drink the water until the pesticide levels (TFM) are below a certain level (Emily Zollweg-Horan, personal communication)\(^6\). While Emily is someone who is directly involved in these control programs and a member of one of the agencies which implements these chemical treatments, she recognizes that these control programs can impact the lives of residents and vacationers alike. While Emily emphasized that the streams and deltas should be perfectly safe for people to interact with, it is just a precaution to tell people to avoid the water for the day. However, on the label for TFM-HP Sea Lamprey Larvicide there is a danger warning which states “Acute Hazards: Corrosive. Causes irreversible eye damage and skin burns. May be fatal if swallowed. Harmful if absorbed through skin or inhaled” (ChemTel, 2008). While these hazards

\(^5\) Email Interview. April 12, 2012.  
\(^6\) Phone Interview. April 13, 2012.
are likely about direct contact with this chemical rather than interaction with it once it has been seriously diluted in water (when applied in streams to kill larval sea lamprey) it is not surprising to think that some landowners on these tributaries and visitors to these areas do not want to be exposed to this chemical and are a bit wary of its use in an ecosystem they use for recreation and drinking water.

While the Lake Champlain region may occasionally lose visitors who are scared of the use of pesticides in the water body it would appear that the overall economic impact of the lampricide treatment has been positive. In 2001 the three agencies which comprise the Cooperative submitted a final environmental impact statement of their proposed long-term sea lamprey control program in Lake Champlain. In this four-hundred plus page document the agencies addressed every angle of the sea lamprey problem and their control, including an economic reasoning for the program:

“Substantial economic benefits would accrue if the proposed program is enacted. Estimated benefits and costs of the eight-year experimental sea lamprey control program indicated favorable benefit: cost ratio of 3.48:1. Continuation of sea lamprey control on Lake Champlain would be expected to generate up to an additional 1.2 million days of fishing and $42.2 million in fishing-related expenditures, as well as an estimated $59.3 million in additional water-based recreation expenditures each year” (Nettles, 2001).

From this example it would seem quite obvious that the local economies are stakeholders in this issue and they greatly benefit from the control programs.

It is worth noting, however, that it is not just people, governments and agencies, and economies which are affected by conservation issues. While it is typically the human stakeholders which are first considered and who management programs cater to; we are not the
only players and management programs often must take into account the overall environmental impact a management plan has. This is why an environmental impact statement was required when the U.S. Fish and Wildlife Service along with Vermont Fish and Wildlife Department and New York State Department of Environmental Conservation created their long-term plan for sea lamprey control. In the executive summary of this document the authors write,

“This Supplemental Environmental Impact Statement (SEIS) is written pursuant to the National Environmental Policy Act (NEPA) requirements regarding implementation of a long-term sea lamprey control program for Lake Champlain. This proposed program will be subject to the NEPA public review and comment process before federal funding and federal personnel will be committed to the project” (Nettles, 2001).

NEPA writes on their own web page that:

“The National Environmental Policy Act (NEPA) requires federal agencies to integrate environmental values into their decision making processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. To meet NEPA requirements federal agencies prepare a detailed statement known as an Environmental Impact Statement (EIS). EPA reviews and comments on EISs prepared by other federal agencies, maintains a national filing system for all EISs, and assures that its own actions comply with NEPA” (EPA, 2012).

This system not only indicates the Environmental Protection Agency as yet another stakeholder but also illuminates the fact that people are also accepting the environment as a stakeholder.

The EIS submitted by the agencies responsible for the long-term sea lamprey control program was required to cover the impacts the use of pesticides would have on other organisms sharing the streams and deltas with sea lamprey which were to be treated with chemicals. While
it is obvious that this EIS was accepted and the program was allowed to be implemented (it is eleven years later and the program is in action) it is still worth recognizing the impacts these chemicals have on non-target species. This is especially true because while the program has been implemented many people are still pushing for an amendment of the plan which reduces the use of chemicals and the impacts on endangered and threatened non-target species.

It is worth noting here that while these environmental impact statements are required and it is acknowledged that the environment is a stakeholder, in a lot of ways the environment is the stakeholder with the least consideration in these kinds of management plans. There are still a lot of unknowns involved with the use of lampricides and while there has been research completed about the impacts of these chemicals on non-target species, there is still a lot more to understand. The environment is a stakeholder and while it cannot speak for itself it is still important to recognize all ecological processed affected by human interference (such as treating water with pesticides) and to fully acknowledge the environment as the stakeholder within this controversial conservation issue.

There have been cases of citizen groups trying to fight the use of lampricides in their local tributaries as a way to speak for the environment as a stakeholder. The Poultney River Committee did just that in 1996 when it tried to appeal to the Vermont Water Resources Board to disallow the permitting of lampricide use in Poultney River (Nettles, 2001). In this case the group did not successfully halt the use of pesticides in their local water body, which was listed as a Natural Area by the Nature Conservancy; however, this case does emphasize community groups as yet another stake holder in this issue and as a group who is against the use of lampricides.
It is not just community groups, however, that are opposed to the use of lampricides. Jim Andrews is in charge of the Vermont Reptile and Amphibian Atlas project and is also the chair of the Reptile and Amphibian Scientific Advisory Group for the Threatened and Endangered Species Committee and is very much opposed to the use of lampricides in the tributaries of Lake Champlain. While different people have different reasons for being opposed to the use of lampricides in Lake Champlain, Jim is worries about the mudpuppy (*Necturus maculosus*), a species of salamander native to both New York and Vermont, and a species of special concern in Vermont. Mudpuppies are known to be one of the species impacted by TFM. Jim Andrews worries that there is the possibility that certain populations which occur in tributaries treated by TFM could be extirpate as there was already an occurrence in one river called Lewis Creek (Jim Andrews interview April 16, 2012). Jim represents the group of scientists and government workers who do not focus on fisheries, but rather focus on the other native species occurring in the Lake Champlain Basin and who are worried that the impacts lampricide has on native species is not being taken seriously enough. Mike Winslow, a staff biologist for Lake Champlain Committee and member of the Alternative Sea Lamprey Control Work Group, echoes these concerns. While less concerned about the use of lampricides in Lake Champlain tributaries, Mike is concerned that agencies are downplaying the effects TFM can have on native species (Mike Winslow, personal communication).7

It is not surprising that people who study organisms other than fish, and more specifically, sport fish, are concerned that the impacts lampricide have on other species is not being taken seriously. The mudpuppy does not have a key economic role in the Lake Champlain Region, and the lake trout does. Is it surprising that government agencies are more concerned with having lake trout in Lake Champlain rather than mudpuppies? After speaking with Jim Andrews and

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7 Phone/Email Interview. April 16, 2012.
Mike Winslow it is clear that there are people who take the place of human stakeholders for the environment; there are people who are only involved because they care about the ecosystem. However, there are just so many stakeholders in this issue that it is hard to take everyone’s opinion into account. In a lot of ways, people like Jim Andrews are the ones who are not being heard. The issue of sea lamprey and their control in Lake Champlain affects many people, species, and economies and that is why it is such a complicated and emotional problem. The sheer number of stakeholders in this conservation issue is enough to explain why it has been in contention for decades and will likely remain so for a while longer.

**Governmental Issues**

*Federal Requirements:*

Before the use of any pesticide, such as TFM or Bayluscide, is permitted the sponsor (in this case: the Cooperative, composed of the USFWS, VTFWD, and NYDEC) must first obtain approval of the Environmental Protection Agency (EPA). The EPA has a specific set of guidelines, regulations, and data requirements that must be approved in order to attain approval for the use of a pesticide. Some of these mandates are: the sponsor must demonstrate that use of the pesticide has no long-term effect on the environment or non-target organisms (although it has noted earlier in this document that the science conducted to do this has been minimal), does not leave persistent residues, does not break down into other toxic substances, does not pose a health hazard to applicators, and does not have unanticipated long-term effects on human or animal life (Nettles, 2001). In the United States TFM has the EPA registration number 6704-45 and Bayluscide carries the EPA registration number 6704-91 (3.3% granular lampricide) (Nettles, 2001).
It is not just the pesticides that need to be approved by the EPA, but also the management plan and this is why management plans have Environmental Impact Statements (EIS). The cooperative wrote an initial EIS for their experimental sea lamprey control program in the 1990s and followed that with a Final Environmental Impact Statement in 2001 which was for the proposed long-term management plan of sea lamprey in Lake Champlain. Both of these Statements were accepted and approved by the EPA and this is why federal personnel and funding have been able to go to the project.

The U.S. Fish and Wildlife Service (The Service) is authorized by 16 U.S.C. Section 661-666 (Fish and Wildlife Coordination Act) to provide assistance to federal, state, and other agencies in development, protection, rearing, and stocking of fish and wildlife and controlling losses thereof. Further authority to control sea lamprey in Lake Champlain was specifically granted to the Service through Section 304 (c) paragraph (2) of the Lake Champlain Special Designation Act of 1990 (P. L. 101-596): “To accomplish the purposes of paragraph (1), the Director of the United States Fish and Wildlife Service is authorized to carry out activities related to - (A) controlling sea lampreys and other nonindigenous aquatic animal nuisances;... ”(Nettles, 2001).

State-level Control

However, while the U.S. Fish and Wildlife Service, which is a federal government agency within the United States Department of the Interior, is primarily responsible for the lampricide treatments in Lake Champlain, the two state agencies are just as involved and therefore the governments of the two states play a big role in determining what management plans are feasible. In New York, the New York Department of Environmental Conservation is given the authority to manage fish and wildlife resources via Articles 11 and 13 of the
Environmental Conservation Law (ECL) (Nettles, 2001). The Vermont Fish and Wildlife Department is given the authority to control sea lamprey in Vermont waters of Lake Champlain in Subchapter 2, Section 4081 and Subchapter 3, Section 4081 and Subchapter 3, Section 4138 of Title 10 of Vermont Fish and Wildlife Laws and Regulations (Nettles, 2001).

While both Vermont and New York require the Cooperative to complete many permit applications; there are a few main criteria that must be met for either state government to allow the use of a pesticide such as TFM. In New York, compliance with New York State Environmental Quality Review Act (SEQRA) is required in which the sponsoring or approving governmental body must identify and mitigate the significant environmental impacts of the activity it is proposing or permitting (NYDEC, 2012). In Vermont, many of the permits required to use TFM in tributaries of Lake Champlain were issued by the Vermont Department of Environmental Conservation.

Separate from the generic licensing and permitting, required at both the state and federal level when proposing the use of TFM in Lake Champlain, is protection of threatened and endangered species. Both Vermont and New York have their own laws pertaining to threatened and endangered species which had to be taken into account when creating the long-term management plan for sea lamprey in Lake Champlain. Authority for protection of endangered species of plants and animals in Vermont is provided in Vermont Fish and Wildlife Laws and Regulations (Nettles, 2001). New York’s Environmental Conservation Law provides regulations pertaining to rare, threatened, and endangered species in New York, managed by NYSDEC. And finally, under the Endangered Species Act of 1973 statutory protection is afforded to endangered and threatened wildlife at the national level and administration and enforcement of this Act is the responsibility of the U.S. Department of Interior, Fish and Wildlife Service (Nettles, 2001). This
is applicable because there had to be significant proof that TFM was not threatening the extant populations of threatened and endangered species which share tributaries with sea lamprey and would likely be exposed to chemical treatments.

Brad Young of U.S. Fish and Wildlife commented that eleven months out of the year are dedicated to applying for pesticide and treatment permits\(^8\). Each year Young and his team of six full time employees must reapply to state, federal, and provincial departments to receive permission to treat Lake Champlain with chemicals. This is a tedious and arduous process but because lampricide treatments have been persisting for over a decade in Lake Champlain, these treatments are generally granted every year.

\(^8\) Phone interview. April, 17 2012.
Application for a permit to use pesticides in Vermont.
Development of Solutions to the Problem

a. Parameterizing the solution:

In order to ensure the health of Lake Champlain and that sea lamprey presence is at a tolerable level, adjustments must be implemented in lamprey management. Before new research and any drastic changes commence, it is first imperative to define the aspects of the problem that need to be addressed. The basis of the problem has two main layers. The primary problem is the overabundance of sea lamprey in the fresh waters of Lake Champlain and the second problem is the treatment with chemical pesticides 3-trifluoro-methyl-4-nitrophenol (TFM) and 2’5-dichloro-‘4-nitrosalicylanilide (3.2% granular Bayluscide) to kill lamprey in their larval stage. The potential problem of adding chemicals into an aquatic ecosystem is more difficult to understand. Lamprey population problems are measured in wounding rates on sport fish and population control is marked in the reduction of these rates; however, pesticide impacts on an ecosystem scale are also of concern although less quantifiable. The solution arrives twofold: minimize the amount of pesticides entering the lake through sea lamprey control efforts while decreasing the size of the lamprey population so as to not endanger fishery repopulation efforts, fishing culture, and the economic benefits stemming from the popularity of fishing.

The chemical input of Lake Champlain has been minor in comparison to other lakes and waterways around North America because there is less large industry, but there has been a general lack of research as well (Mardsen and Langdon, 2011). However, since the experimental program of chemical lampricide treatments began in 1990, potentially caustic chemicals have entered the lake (Marsden, 2010). Pesticides are applied in tributaries where lampreys conduct their larval stage. Lake Champlain has eleven major tributaries that drain from 2,252 to 3,500 km$^2$ and many other streams that provide perfect habitats for lamprey to spawn (Mardsen and
Langdon, 2011). These chemicals are not only killing lamprey larvae but endangering sensitive non target species of fish and mussels. Studies have not been conducted on all species prone to lampricide poisoning, but some laboratory studies have proven that sensitive fish include the catfish family, *Ictaluridae*, juvenile white sturgeon, and adult mudpuppies (Boogard, et al, 2003). Even more important to note is that the full effect of these chemicals on non-target species was not researched prior to treating lampreys in Lake Champlain’s tributaries. Ecosystem level effects of killing non-target species is impossible to assume because the species interactions within Lake Champlain are under studied.

The culture and economic benefits supporting the stocked fish industry outweighs a majority of stockholder’s trepidation of disturbing an ecosystem with lethal chemical compounds. In an interview with University of Vermont Professor, Ellen Marsden, she stated, “I am a strong advocate for native species restoration” (Marsden, 2012). On the other side of the lake New York State Department of Environmental Conservation (NYSDEC) Bureau of fisheries Chief Douglas remarks that Lake Champlain is a very important fishery to NYSDEC District 5: in 2005 almost 70% of NYSDEC fishery staff’s time was dedicated to Lake Champlain sea lamprey control (NYSDEC, 2007). Ideally, the lake would regain native fish populations on “foundations of self-sustaining stocks, supplemented by judicious stocking of hatchery-reared fish” in order to provide “wholesome food, recreation, cultural heritage, employment and income, and a healthy aquatic ecosystem” (Great Lakes Fishery Commission, 1997). However, these populations are not recovering on their own. Coldwater fisheries annual stocking includes 68,000-90,000 lake trout, 78,000 steelhead, 68,000 brown trout, 240,000 Atlantic salmon smolts⁹, and 450,000 Atlantic salmon fry (Marsden and Langdon, 2012). If people decide they are dedicated to the fishing heritage and the intrinsic value of native fisheries, they must also not become complacent

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⁹ Sub-adult salmon.
with chemical treatments and lose sight of the harm lampricides may have on the ecosystem. 

Since the first European settler saw Lake Champlain in 1609, the lake has been forever changing. A balance must be met by maximizing ammocoete mortality while simultaneously making strides to minimize fatality of non-target species (McDonald and Kolar, 2007).

U.S. Fish and Wildlife Control Coordinator, Brad Young, said that his ideal goal would be to see Lake Champlain with “co-adapted species” (Young, 2012). This is the crux of the issue: if sport fish stocks could reach a level of sustainability where they were naturally reproducing, annual stocking was no longer necessary, and lamprey no longer harmed fish at such high rates then it would be easier to address the sea lamprey problem. However, there are challenges of acclimating reintroduced species of salmon and trout into Lake Champlain. Parasitism by sea lamprey is an additional burden to overcome to ensure a healthy population of sport fish.

Lampricide treatments have reduced the wounding rate to a more manageable level, therefore current management strategies should look toward efficient treatments and alternatives to chemicals. While sea lamprey populations are manageable and chemical impacts are considered minimal, this is an important time to take a step back and evaluate the two decades of lampricide treatment.

Management innovations should include more efficient treatments that decrease the chemical input. Additional research should evaluate ways in which the ecosystem is impacted by chemical treatments and also try to understand how the lake ecosystem functions as a whole. This is no time for drastic, hasty chemical treatments as suggested by some frustrated anglers looking to eradicate lampreys. Rather, it is a time to slow down and consider the next step: one not with the highest lamprey lethality, but highest lamprey management effectiveness and regard for the entire ecosystem.
b. **Identification and evaluation of potential solutions:**

There are many ways in which sea lamprey presence can be controlled and chemical treatments can be offset. The following is the set of solutions applicable to sea lamprey control and treatment:

*Continue with current lampricide treatments and accept a higher wounding rate*

Continuing with current dosages, durations, and chemicals suggests that present efforts are acceptable at combating high sea lamprey populations. It is important for present applications to continue in order to suppress the lamprey population below current wounding rates. On the other hand, perhaps current wounding rates could be accepted and the immediate desire to use lampricides quelled. Perhaps the wounding rate now is an appropriate rate and a continuation of treatment every four years on tributaries in the fall is a good course of action. It is important to see the possibility of stagnation in treatment measures to recognize the need for innovation. Sometimes when management projects are working well enough a sense of complacency overwhelms stakeholders and any momentum slows to accept this relative success as the norm. Also, people’s primary focus may shift to restoration of fisheries if sea lamprey are not the major problem in reestablishing fish populations. However, because there is a department within the U.S. Fish and Wildlife Service dedicated to sea lamprey control, innovation should be encouraged in the management plan.
Introduce a species into Lake Champlain that will increase predation pressures on the lamprey

Little information is known about sea lamprey predators in fresh water; however, perhaps the reason why there is an abundance of lamprey is because ammocoete predation has declined (Marsden and Langdon, 2012). In laboratory experiments both lake sturgeon and American eel have captured American brook lamprey ammocoetes (Perlmutter, 1951). The lake sturgeon is endangered in Vermont and threatened in New York (Marsden and Langdon, 2012), thus stocking the lake with additional predatory fish that are also low in abundance could address two problems within the lake ecosystem. In reports from the NYSDEC, lake sturgeon have also been susceptible to lamprey wounding. Therefore, there is a risk of increasing the parasitic adult lamprey prey base while attempting to combat the lamprey at its larval stage before it even reaches the capability of being parasitic.

Lampricide treatments with longer exposures at lower concentrations

Lampricides are spread with the goal of killing 99.9% of lamprey larvae (Young, personal communication\textsuperscript{10}). Treatments currently last for nine hours, after tests on-site achieve the appropriate amount of concentration to kill larvae within that nine hour window (Young and Chipman, 2010). However, to account for the lag time from application to contact with the lamprey and attenuation\textsuperscript{11}, lampricide treatments need twelve hours to reach the nine hour minimum. When sensitive non-target species may be vulnerable, a less potent <1.5xMLC\textsuperscript{12} concentration is used; as a result the lethality to sea lamprey also diminishes when the baseline instances of lethality drop under nine hours (Young and Chipman, 2010). Therefore, the U.S. Fish and Wildlife Service and Vermont Fish and Wildlife Department recommend a fourteen

\textsuperscript{10} Phone interview, April 17, 2012. \\
\textsuperscript{11} A gradual loss of concentration (lampricide) through a medium (the water) \\
\textsuperscript{12} MLC: Minimum lethal concentration; SMLC: Stream minimum lethal concentration
hour treatment when using less concentrated lampricides (Young and Chipman, 2010). Stream flow must also be considered. Attenuation occurs more in slow moving streams because the chemical block is spread out slowly over time. Therefore, the state and federal fishery management agencies request that under smaller concentrations, such as 1.0xMLC, as is allowed in the Winooski River, the duration of the treatment be expanded to fourteen hours.

The major goal is to decrease the amount of chemicals entering the Lake Champlain Basin. Adjusting the chemical treatment for each tributary is a rational idea; however, extending the treatment of less concentrated lampricides should be researched further. Is it rational to consider that these lower concentrations will continue to kill lamprey but have a reduced effect on non-target species? If a tributary is host to endangered or threatened species why would decreasing the concentration levels, only to treat the river for more hours, ensure that non-target species are not under the same threat if a quicker and higher concentration were to be implemented? A better understanding of tributary ecosystems is necessary to answer these questions.

*Identify original natal stream of adult lamprey*

The Great Lakes fishery is trying to create a cost-effective way to track the streams and tributaries where a majority of larval growth occurs and prioritize lampricide treatments (Carrol *et al.*, 2006). Otoliths, calcareous structures located in the inner ear of the teleost fish and used for hearing and balance, act as a natural tag. Otolith microchemistry data has been used in past fishery management problems such as tracking migration pathways and reconstructing habitat use (Campana 1999; Thresher, 199). Otoliths would be helpful in determining which tributaries were hosting highest larval density because their elemental composition reflects the chemical and
physical environment the fish has inhabited. This has been an effective technique in
discriminating between Great Lakes and larger tributaries, but more work needs to be
accomplished in order to differentiate between individual streams (Carrol, et al., 2006).

Sea lamprey control could become more efficient if majoring natal tributaries are
recognized. Chemicals could be spread in the areas of highest sea lamprey maturation. Further
research is needed to understand how inter-annual variability and physiological effects influence
the otolith. The Lake Champlain Sea Lamprey Alternative Control Work Group has otolith
microchemistry analysis as their primary research venture to see if this technique can be refined
to work within the Lake Champlain basin. Not only does this microelement analysis streamline
the pesticide application process, but it provides more information about the sea lamprey’s life
history in general. Apart from their parasitic nature as adults on susceptible sport fish and where
the larva spawns, little is known about the sea lamprey. More insight into how the sea lamprey
chooses acceptable habitats may display greater biological and chemical interactions within the
broader lake ecosystem. It is in the best interest of Lake Champlain patrons to understand all
layers of the sea lamprey overabundance and not commit to the use of caustic chemicals without
considering lampricide’s widespread impacts.

Commercial use of sea lamprey

Sea lamprey have been fished commercially in Europe and can be found on fish markets
alongside smoked eel, yellow perch, brown trout, Arctic char, and Atlantic salmon in Stockholm,
Sweden, for example (Korcheis, 2004). Lamprey have a long history atop the plates in Medieval
times, the colonial era within the United States, and had a brief stint in a Canadian canning
company in the 1980’s. Although it is not on the map for most Vermonters and New Yorkers,
trends do come and go. Needless to say, this is not a very practical implication, as fishermen are more concerned in catching large, prized coldwater fish and less in harvesting a parasitic vertebrate species.

Sea lamprey could also be used for biological and scientific experimentation. The unique features of sea lamprey and their abundance could allow for research on neurological and spinal cord regeneration, locomotion, eyes, kidneys, blood research, and hormones (Korcheis, 2004). However, companies trying to collect lamprey for research have been limited in the past by the population size in Maine rivers and had to seek additional imports from Nova Scotia and the Great Lakes (Korcheis, 2004). If the need for lab specimens is great enough perhaps a sea lamprey fishing industry in Lake Champlain would be viable. Especially if other parts of the world may lack lampreys due to polluted bodies of water, the healthy specimens of Lake Champlain may be in demand.

Pheromones to reduce lamprey populations

The Great Lakes Fishery Commission identified the use of pheromones, as a way to regulate sea lamprey reproduction and migration (Li et al., 2007). There are three pathways that pheromones can be used to help lamprey management. First, lampreys could be redistributed to habitats where they cannot reproduce or can be easily removed and killed. For example, they could be attracted to a tributary with poor qualities for egg and larval survival, that may be treated with pesticides soon or in a location conducive to trap placement (Li et al., 2007). During mating season, two compounds, 3-keto-petromyzonol sulfate (3kPZS), a cue that influences behavior, and 3-keto-allocholic acid (3kACA), a cue that likely promotes sexual maturation, have been discovered in laboratory trials (Siefkes and Wingfield). Second, pheromones could

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13 Chemical cues used for communication and interaction between individuals in a species
extend the trapping period if females could be lured in utilizing spermiated males as bait, for example. Finally, pheromones could be used to disrupt mating strategies. Lampreys use pheromones as sexual cues designed to select the most viable mate. Therefore, pheromones could be used to confound mating cues or even to attract females to sterilized males (Li et al., 2007). Few studies have been conducted with sea lamprey in the past, but there are places in the Great Lakes Region that view tactical pheromone usage as a gateway to safe, effective lamprey management (Young, 2012).

Dr. Weiming Li from Michigan State is working on mapping the sea lamprey genome. With money from an $18 million grant awarded to Washington State from the National Institutes of Health, Li plans to better understand the basic genetic makeup that may affect migration, mating, or responses to danger (Siefkes and Wingfield). With this information a) the use of pheromones can be better implemented b) any unknown genetic weakness can be targeted to reduce lamprey population. For example, information now suggests that lampreys use the odor from dead lampreys as an alarm cue (Siefkes and Wingfield). Scientists could possibly use this defense mechanism to deter lamprey from spawning in certain tributaries while concentrating them in other waterways.

**Better designs for barriers, traps, and fishways**

Physical barriers impeding lamprey have been used since the 1940’s in the Great Lakes to capture sea lamprey, but are mainly employed today to collect data from lamprey and to conduct the sterile male release program (McLaughlan *et al.*, 2007). Barriers, traps and fishways have had a range of results, for example, catch efficiencies have varied from 23-79% (Great Lakes Fishery Commission 2001b). The Great Lakes Fishery Commission has a goal of decreasing its
chemical input by 50% while also trying to make physical impediments in tributaries have less of an impact on non-target species. There is concern that barriers also inhibit other spawning species and traps catch and kill. Some fish can avoid fishways by utilizing jumping pools to migrate; however, only jumping fish benefit from this consideration (McLaughlan et al., 2007). Therefore, the Great Lakes Research Commission has listed several research needs to make the addition to tributaries more effective in controlling lamprey populations, yet less intrusive to native species:

1. Predicting timing and magnitude of runs for sea lamprey and non-target species
2. Frequency and consequences of early and late season movements by sea lampreys
3. Sea lamprey migration and dispersal patterns
4. Passage needs for non-target fishes
5. Behavior of sea lamprey and non-target species at barriers, traps, and fishways
6. Hydraulic, hydrological, and biological criteria for barriers
7. Attractors and distracters for sea lamprey and non-target species
8. Funnel and trap configurations
9. Innovative and new designs of barriers, traps and fishways
10. Spillway design
11. Effectiveness of blocking and trapping sea lampreys
12. Effectiveness of non-target fish passage
13. Traditional and personal knowledge about movements of sea lamprey and non-target species in streams (McLaughlan et al., 2007)

With greater research in these areas, barriers, traps, and fishways could help decrease the amount of pesticides spread in the water and associated impacts on non-target species.

*Map habitats preferred by sea lamprey*

Young mentioned that his research team in the U.S. Fish and Wildlife Service was interested in mapping out the habitats within Lake Champlain to better understand sea lamprey’s preferred locations within the lake. If the U.S. Fish and Wildlife understood where sea lamprey are most likely to spawn and thrive, pesticides could be directed more efficiently and in reduced dosages. Approximately $550,000 is spent on a yearly average within a four year treatment.
period on chemical lamprey control (Young, personal communication\textsuperscript{14}). To streamline chemical treatments would have a great economic and environmental benefit. It is important to remember that lampricide treatments have been persisting for over two decades and a majority of stakeholders support this treatment. As long as salmon and trout populations are being stocked and are not adapting to sea lampreys, lampricides will continue to be employed. Long term impacts of chemical treatments are difficult to predict, therefore minimizing their use now will only mitigate future negative repercussions.

Ensure all tributaries are treated

Currently there are 266 tributaries that are part of the Lake Champlain watershed and provide an excellent habitat for lampreys to spawn (Marsden and Langdon, 2011). Each summer Brad Young oversees a group of federal workers who measure larval abundance and distribution within each of the tributaries and ranks these streams and rivers by larval density (Young, 2012). After the tributaries have been prioritized, chemical treatments are spread in the fall to the tributaries nurturing the most larvae. Currently there are two major tributaries that are not being treated. Young explained that due to more rigid laws about applying pesticides in Canadian waters, barriers instead of pesticides are the best defense against high density spawning lamprey. One New York barrier on a tributary called Beaver Brook showed great success: lamprey were unable to migrate upstream and a U.S. Fish and Wildlife employee was tasked with removing the lamprey while throwing the non-target species back into the river. The U.S. Fish and Wildlife would like to emulate the Beaver Brook project and develop a dam on a river in Quebec; however, they are having a difficult time finding a contractor to pick up the work. This is frustrating for Young because the funds are available, yet the project is still on hold.

\textsuperscript{14} Phone interview, April 16, 2012.
Deltas on the Saranac and Plattsburgh Rivers have been shown in recent research to be areas of high larval density. Sedimentation that develops at the mouths of tributaries creates an environment conducive to nest survival and fragile larval development. A new chemical treatment is experimenting with crystal forms of niclosamide. The chemical is released in river deltas and sinks to the bottom, targeting the larvae buried beneath the sediment layer. Again, the density of larval lamprey should be estimated before it is decided whether to treat river deltas with lampricides. If pesticides are going to be used in Lake Champlain it is important that the areas with the highest density are targeted, while keeping the lives of non-target species as a paramount parameter. When areas of high density go untreated the sea lamprey population will continue to decimate sport fish populations. Responsible chemical implementation depends on strategic and comprehensive management.

*Adjustments in the chemical treatment*

The Great Lakes Fishery Commission lays out parameters for new research regarding lampricides evaluating treatment effectiveness, non-target effects, modes of toxic action, and lampricide development:
<table>
<thead>
<tr>
<th>Title</th>
<th>R/TA</th>
<th>Status</th>
<th>Location</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepare lampricide analytical standards for field use</td>
<td>TA</td>
<td>O</td>
<td>HBBS</td>
<td>1</td>
</tr>
<tr>
<td>Evaluate TFM samples for physical, chemical and toxicological properties</td>
<td>TA</td>
<td>O</td>
<td>HBBS</td>
<td>1</td>
</tr>
<tr>
<td>Do static and flow-through toxicity tests yield the same toxicity information?</td>
<td>R</td>
<td>P</td>
<td>HBBS</td>
<td>2</td>
</tr>
<tr>
<td>Effect of groundwater inflow on distribution of lampricide and on survival of sea lamprey larvae during a stream treatment</td>
<td>R</td>
<td>P</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Study of issues related to stream pH and lampricide treatments</td>
<td>R</td>
<td>O</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Lampricide toxicity to juvenile mudpuppies</td>
<td>TA</td>
<td>O</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Evaluation of an extended duration lampricide block as an alternative treatment strategy</td>
<td>R</td>
<td>P</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Avoidance of young-of-year lake sturgeon (<em>Acipenser fulvescens</em>) to Bayluscide 3.2% granular sea lamprey larvicide</td>
<td>R</td>
<td>P</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Re-evaluate accuracy of lower pH/lower alkalinity range of pH/alkalinity sea lamprey minimum lethal prediction model as a tool to define target treatment levels for effectively controlling larval sea lampreys with the lampricides TFM and niclosamide</td>
<td>TA</td>
<td>P</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Relative toxicity of the lampricides TFM and niclosamide to newly transformed and larval sea lamprey (<em>Petromyzon marinus</em>)</td>
<td>TA</td>
<td>O</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Residue levels of the lampricides TFM and niclosamide in moribund sea lamprey larvae following exposures to TFM and a TFM/1% niclosamide combination</td>
<td>R</td>
<td>P</td>
<td>UMESC</td>
<td>4</td>
</tr>
<tr>
<td>Dissipation of TFM and niclosamide following stream treatments</td>
<td>R</td>
<td>P</td>
<td>UMESC</td>
<td>4</td>
</tr>
<tr>
<td>Development of a glucuronyl transferase assay to assess the sensitivity of the lampricide TFM to nontarget species of concern</td>
<td>R</td>
<td>P</td>
<td>UMESC</td>
<td>4</td>
</tr>
<tr>
<td>Toxicity of the lampricides TFM and niclosamide to American eels (<em>Anguilla rostrata</em>)</td>
<td>TA</td>
<td>P</td>
<td>UMESC</td>
<td>5</td>
</tr>
<tr>
<td>Estimating treatment effectiveness using in-situ caged larval sea lampreys during lampricide control operations</td>
<td>TA</td>
<td>P</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Re-evaluation of the TFM pH/alkalinity sea lamprey minimum lethal prediction model using an improved statistical design</td>
<td>R</td>
<td>P</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Acute toxicity of TFM and a 99%TFM:1% niclosamide mixture to the northern brook lamprey (<em>Ichthyomyzon fossor</em>), American brook lamprey (<em>Lampetra appendicula</em>), and sea lamprey (<em>Petromyzon marinus</em>)</td>
<td>TA</td>
<td>C</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Acute toxicity of TFM and a 99%TFM:1% niclosamide mixture to the giant floater (<em>Pyganodon grandis</em>), fragile paper shell (<em>Leptodea fragilis</em>), and pink heelsplitter (<em>Potamilus alatus</em>) unionid mussels and sea lamprey (<em>Petromyzon marinus</em>) larvae</td>
<td>TA</td>
<td>C</td>
<td>UMESC</td>
<td>3</td>
</tr>
<tr>
<td>Relative toxicity of larval and adult <em>Halipius sp.</em> to the lampricide TFM as a surrogate for the endangered Hungerford’s crawling water beetle (<em>Brychius hungerfordii</em>)</td>
<td>TA</td>
<td>O</td>
<td>UMESC</td>
<td>3</td>
</tr>
</tbody>
</table>

Contact 1: K. Slagt, kslaght@usgs.gov
Contact 2: Bill Swink, wswink@usgs.gov
Contact 3: Mike Boogaard, MBoogaard@usgs.gov
Contact 4: Terry Hubert, THubert@usgs.gov
Contact 5: Jane Rivera, JRivera@usgs.gov

Table 1. Recent and current research projects on sea lamprey chemical treatments.
In some places, lamprey are an indicator species for healthy aquatic systems. Across the Atlantic Ocean, Scotland’s populations of brook, river, and sea lamprey are on the decline. Lampreys have been extirpated from much of their native breeding grounds across all of Europe and people fear that Scotland may also lose their lamprey (Kelbie, 2005). Why are the Scottish so intent on restoring lamprey populations? Science and Policy Adviser at Scottish Natural Heritage, Dr. Colin Bean, claims, “their presence is an indication of the health of the river: they rely on clean, undisturbed river systems and they affect the complex food web by feeding on a variety of species,” (Kelbie, 2005). Lake Champlain and its tributaries are clean enough to harbor lamprey, and to jeopardize relatively healthy waters with rampant chemical applications could be short-sighted. However, in the case of the sea lamprey, a species in overabundance is just as clear of an indicator as a species lacking population viability as a suggestion of an ecosystem out of balance.

Sterilization of male sea lamprey

Reducing or preventing the ability of lamprey to produce offspring is a population management strategy. Male sea lamprey are bisazir-injected for 48 hours then sit in lake water for 48 more hours to ensure that they are alive after sterilization. Eventually, after sterilizing the male sea lamprey, males will still attract females to their nests and sterility can persist through mating. The goal is to increase the ratio of sterile to non-sterile males (Nettles et al., 2001). Embryo survival in individual streams should be reduced and each year class will gradually diminish. Eventually with less successful breeding the number of lamprey will be reduced as will the damage rate to sport fish (Bergstedt and Twohey, M.B, 2007).
Stop stocking Atlantic salmon and lake trout

The state and federal governments are keen on establishing native populations of fish in Lake Champlain. However, one way to stop lampricide wounds to these sport fish would be to stop stocking. If fish that are susceptible to parasitism by sea lamprey are no longer stocked, sea lamprey populations will decrease and chemicals would no longer need to be spread in the Lake Champlain tributaries. No longer would there be a necessity to risk disrupting an entire ecosystem in order to regain fish populations that have been unable to naturally exist in the lake for centuries. The long term conservation goal for Lake Champlain must be evaluated. What is a healthy lake? Does it have all the species that lived in its waters historically? Is it free of chemicals? What is more important, the ecosystem or individual species that bring in economic support to lakeside communities? Can we have both? Young said that with every $1.00 spent on lampricide treatments, the surrounding waterfront towns will get back $3.80 in revenue from added tourism (Young, personal communication\textsuperscript{15}). Thus, due to economic and cultural heritage, giving up on stocking sport fish is a difficult solution to sell.

Stock more sport fish

More Atlantic salmon and lake trout could be reintroduced to Lake Champlain each year. Perhaps the current stocking rates are too low for fisheries to establish viable populations. The healthiest fish would be the individuals to avoid effects of predation and to reach reproductive capabilities. Gradually the fish population would increase in numbers and tolerance. These are assumptions. Realistically, more fish would just equate to more lamprey. This has become obvious as lampreys were not a concern before repopulation of fisheries, but lamprey populations were able to expand with higher numbers of hosts.

\textsuperscript{15} Phone interview, April 16, 2012
c. **Identification of feasible solutions:**

Several of these proposed solutions will not adequately address the problem of sea lamprey control within Lake Champlain due to cost, stakeholder values, or reality of more feasible ideas. The reality of these ideas is based on technical, economic, social and environmental implications and the following do not meet these baselines:

- **Continue current lamprey treatments:** There are more efficient and safer methods to use chemicals; the use of chemicals should always be under debate. Not changing the treatments implies that the current wounding rates are acceptable, cost is feasible over the long-term, there are no environmental impacts on individual species and lake dynamics, and that all treatment options have been examined. These assumptions are false. A major step in altering the sea lamprey presence and treatment involves more research on treatments and their impacts.

- **Introduce a species into the Lake Champlain that will increase predation pressures on the lamprey:** Introducing more sturgeon will add a larger prey base for the parasitic lamprey. In addition, lake sturgeon have already proven to have a difficult time surviving on their own in Lake Champlain (Marsden and Langdon, 2012).

- **Commercial use of sea lamprey:** There has been very little consideration of fishing lamprey in Lake Champlain and, in addition, there is no industry set up to accomplish lamprey fishing. If lamprey were prized in Vermont, New York, or the global sphere there is no doubt they would be hunted.
• Target all tributaries. Although it is important for sea lamprey treatment to be consistent throughout the lake and not leave any gaping holes, the focus should not be on treating all tributaries, but treating the highest densities of sea lamprey.

• Stop stocking Atlantic salmon and lake trout: Admittedly, all problems concerning sea lamprey would dissipate if sport fish were not present. However, the goal of state and federal wildlife departments is to restore the fisheries. Minimizing the impact of parasitism has become another obstacle in meeting the end goal: sustainable Atlantic salmon and lake trout community (Young, personal communication\textsuperscript{16}). The addition and continuation of a sport fishing industry in Lake Champlain has proven to be a high priority for recreationalists and members of the local economy benefitting from tourist dollars.

• Stock more sport fish: This will only intensify the problem and increase spending on both stocking programs and, in turn, lampricide treatments.

• Sterilization of male sea lamprey: Affecting the ability of sea lamprey to produce viable offspring could be a method to limit lampricide usage. The aspects to consider are the ease of sterilization, environmental impact of spreading sterilization agents into the water, and economic rationale. If it were to reduce lamprey numbers this could be a worthwhile program, but there is no guarantee. Young admitted that this idea is entirely too expensive and dangerous. The risk of putting chemicals strong enough to permanently sterilize a species into the water with non-target species is entirely too high to warrant experimentation (Young, 2012).

\textsuperscript{16} Phone interview, April 16, 2012
The following are solutions that should be considered for decreasing lamprey parasitism and increasing environmental accountability.

- Target all high-larval producing tributaries: Assumptions on the most successful spawning territories can be made with research done by Marsden at University of Vermont using otolith microchemistry to pinpoint the genetic origin of adult sea lamprey. Even if a tributary nurtures a high density of offspring, it is important to understand if these larvae are reaching parasitic adulthood and a reproductive stage. Prioritizing streams could be based on larvae’s capability to survive in the greater lake ecosystem: the place where lampreys are parasitic and thus considered a problem.

- Map habitats preferred by sea lamprey: Understanding suitability of aquatic habitats for sea lamprey will allow researchers to hone in on specific areas in Lake Champlain that may contain high numbers of larvae or adult parasites. Treatment could be more effective, less presumptuous, and more environmentally-sustainable.

- Adjustments in the chemical treatment: More research must be conducted on the efficacy, timing, and non-target impacts of chemical treatments. At the beginning of the 1990’s TFM was the only chemical used in lampricides treatments. However, in 2001 a combination of TFM and niclosamide was used; their combined effect allowed for a lower chemical concentration to do the job of TFM alone (Young, personal communication17). There is no reason to rule out further innovation in pesticides.

- Better designs for barriers, traps, and fishways: Better physical barriers can be erected in tributaries that host endangered species such as the brook lamprey or mudpuppy as an alternative to chemical treatments. Research in to better designs that capture lamprey but

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17 Phone interview. April 16, 2012.
exclude other species (through the use of doors, people monitoring the traps and throwing non-targets up or down stream of the trap, etc.) would help maximize lamprey exclusion in major tributaries, while maintaining an ecocentric perspective.

- Pheromones to reduce lamprey populations: Pheromones are dependent on the lamprey coming to biologists; therefore this treatment depends on knowledge of lamprey tendencies. Young explains that even though pheromones attract 80% of parasitic adult lamprey in the trap, the 20% remaining are virulent enough to rebound. Every four years a stream is treated and about 85% of the larvae (who are anywhere from year one to four in their larval life phase) are killed; four generations are decimated in one treatment (Young, personal communication\textsuperscript{18}). However, even if pheromones are relatively effective, this treatment waits until lamprey reach their parasitic adult life. Therefore, pheromones are only effective when used in an integrated pest management strategy: use of pheromones to attract adults alongside chemical treatment of larval lamprey. For example, pheromones can be helpful when a barrier is washed out in a flooding event. Female lamprey will be attracted to “pots” filled with pheromone-producing male sea lamprey. Luring massive amounts of parasitic lamprey to desired locations would provide easier management implementation.

- Lampricide treatments with longer exposures at lower concentrations: Currently, U.S. Fish and Wildlife biologists are conducting research on extended lampricide treatments. These treatments are looking to extend nine to twelve hours treatments to upwards of twenty hours but with lower minimum concentration levels at MCL x 1.0. (Young, personal interview\textsuperscript{19}).

\textsuperscript{18} Personal interview, April 17, 2012.
\textsuperscript{19} Phone interview, April 17, 2012.
• Accept a higher wounding rate: An interview with Lake Champlain Committee staff scientist, Mike Winslow, suggested that the target wounding rates fishery managers are trying to maintain are unrealistically low (Winslow, personal communication20). Lake Champlain is attempting to reach wounding rates comparable to those in the Great Lakes; however Winslow states that because Lake Champlain has so many tributaries in relation to the Great Lakes, wounding rates will inevitably be higher. Admittedly, Young states that ideal wounding rates are not exact; they are an index estimating the maximum damage lampreys have on sport fish without affecting fish population dynamics (Young, personal communication21). Are lampreys the sole reason why fisheries are not rebounding in Lake Champlain? Will raising the wounding rates further have an impact on the fisheries or will more chemical treatments threaten additional native non-target species than will be saved?

d. Identification of best solutions:

Sea lampreys are impeding efforts to reestablish self-perpetuating stocks of Atlantic salmon and lake trout in Lake Champlain. The U.S. Fish and Wildlife Service, under the supervision of Lamprey Control Advisor, Bradley Young, has been requested by the states of Vermont and New York to control the sea lamprey populations so that the lake’s fisheries can return to an era when sport fish were available catch. Unfortunately, fish populations are not able to reproduce on their own without additional stocks of adults and fry each year. In addition, lampricide is spread in four year cycles in the Lake Champlain tributaries with the goal of killing 99.9% of larval lamprey and ensuring that they do not reach a parasitic phase. Not enough

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20 Phone interview April 15, 2012.
21 Phone interview, April 16, 2012.
lamprey are killed and biologists are demanding more efficient, effective treatments to reach a
sport fish wounding rate acceptable for fish to a) build a reproductive base population and b)
please recreational fishermen. Meanwhile, other stakeholders\(^ {22}\) are concerned with the
environmental impacts and insist that new headway in the lamprey control project must strive to
minimize negative impacts on non-target species as well as the lake’s ecosystem function.

On April 19\(^ {\text{th}}\) there was a forum at the University of Vermont attempting to answer the
question of sea lamprey origin (Parren, personal communication\(^ {23}\)). Although sea lamprey have
been noticeable in Lake Champlain waters for decades, debates on how to treat this nuisance
species are still challenged. If lampreys are a native species, biologists insist on giving them an
equal share of the lake, but if lampreys are invasive, people would philosophically feel better
about killing the maximum amount of lamprey possible. In order to form a direction for future
solutions, it is important to fully understand the sea lamprey’s origin in order to justify and
rationalize treatments.

There is no doubt that Lake Champlain has been altered ever since its first encounter with
European settlers in the 19\(^ {\text{th}}\) century. Now that people inhabit the shores along the lake in
Vermont, New York, and Quebec, Canada it is important that humans be able to use the lake in a
way that will indefinitely promote native populations and a self-regulating ecosystem. Sea
lamprey control has seen success since the lampricide treatments began over two decades ago,
but there is still room for greater efficiency, a healthier lake, and more successful fisheries. The
way to achieve better management treatments is through integrated pest management systems\(^ {24}\)
as well as improvements in chemical treatments. It is apparent that chemicals should continue to

\(^ {22}\) Including the Nature Conservancy, private landowners, and biologists, for example
\(^ {23}\) Email contact, April 16, 2012.
\(^ {24}\) This does not rely on one specific solution but many
be used to suppress lamprey populations while also aiming to attain more efficient and less intrusive treatments.

Research projects must be continued across the board. Under Ellen Marsden and the University of Vermont in collaboration with Vermont Fish and Wildlife and the U.S. Fish and Wildlife, persistent research on achieving sustainable fisheries, mitigating impacts of lampricide treatment, and understanding the greater lake ecology should be prioritized. The more the lake and the subtle interactions within this system are considered, the better we can address problems. This is not a time for haste and reckless chemical applications. Lamprey populations have diminished enough under the past two decades of treatments that now, time should be allotted to understanding greater ecosystem effects. It is not imperative to treat every stream with fierce efficiency, rather, time to evaluate how the impact on non-target species is reverberating throughout the lake’s ecosystem. There are too many unknowns and people should not yet feel at ease with the current lampricide management techniques.

Chemical treatments can be improved by additional research in the following ways:

1. Ensuring the safety of TFM and niclosamide. Currently they are considered very safe due to their short half-life. Within six to twelve hours of TFM/niclosamide treatment 90-99% of the chemical no longer remained in catfish and rainbow trout being tested (Vue, et al., 2011). Nonetheless, fragile non-target species may still be at risk. Mudpuppies are being killed, but what does the decline of this species mean for the health of the entire ecosystem? Perhaps there are different chemical treatment options that would target sea lamprey and spare non-target and endangered species.
2. Treating locations that contribute the most to the parasitic lamprey population. Mapping suitable habitats, marking ranges of adults from their larval stage, and treating the tributaries that are of highest importance.

3. Additional use of barriers and traps to decrease chemical use. Barriers can catch spawning lamprey before they can even lay eggs.

4. Continue research on the use of pheromones to lure sea lamprey into concentrated populations. If humans can control the location of adult lampreys, chemical treatments will be in fewer tributaries and additional trapping methods may be able to be implemented in place of lampricides.

The end goal for every person who has a stake in Lake Champlain is to see a healthy ecosystem. The future of large, numerous Atlantic salmon and lake trout that can reproduce naturally and provide sport, food, and an irreplaceable aesthetic quality are being undermined and physically destroyed by the presence of the sea lamprey. Sea lamprey, regardless of their genetic origin, are considered the villain undermining the beauty and function of a vigorous Lake Champlain. Lamprey are voracious parasites and pose a direct threat to people and fish because of their difficulty to control. These parasites turn people away from Lake Champlain instead of drawing valuable dollars to waterfront towns and additional money to federal and state Fish and Wildlife Services who rely on fishing licenses as part of their budget. Without sea lamprey people could enjoy the lake and its natural beauty. These people would become stewards of the land and a standard of a clean and prosperous lake would be enforced. Sea lamprey stand in between a people and their culture, a better economy, and ideals of natural beauty. As a result, an innovation in management protocols is needed. Research focused on long term ecosystem
effects of pesticide use should be a priority and ultimately reducing chemical treatments should be the end goal.

**Ease of Implementation**

The multifaceted management approach including directed, minimized lampricide use, barriers and traps, pheromones, and understanding lampreys’ preferred habitat will be necessary to combat this nuisance specie and pursue innovative new management ideas. In order for wounding rates to decrease to a level that allows for enough fish to reach reproductive stages and help build a self-sustaining population, treatments need to become more efficient. Implementing a plan that requires continued strategic lampricide treatments, broadens research on effective chemical treatments, and monitors ecosystem health is what a majority of stakeholders would like to see happen.

Rose Paul, director of Science and Stewardship for the Vermont Chapter of The Nature Conservancy told me that finding an alternative to chemical lamprey controls, “for a conservation organization is a hopeless issue” (Rose Paul, personal communication25). By Young’s estimates, the average number of objections by land owners on Lake Champlain or its tributaries to the treatment of tributaries with pesticides amounts to ten out of 10,000. Environmental organizations are a voice for the non-target species and the overall lake ecosystem and only a small minority are vocal against chemical treatments. For environmentalists it is unsettling that pesticides are entering the watershed annually, and the burden of proof is put on conservationists to prove these chemicals dangerous. However, as continued research is being conducted, the benefits (economic, social, and environmental) appear to outweigh the harm of any chemical treatments.

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25 Phone interview April 18, 2012.
Lampricide treatments need to continue in combination with thoughtful research into their long term effects. If lampricide treatments were to stop now, the two decades of treatments to reduce the wounding rates could be lost. Lamprey populations could rise again and management would go back to where it began in 1990 within a matter of years. Therefore to maintain the progress made in the last two decades, lampricide treatments must persist while more research is conducted. Ultimately, a reduction of pesticides and more efficient application would be ideal to save money and reduce the amount of non-target species put at risk. Although applying lampricides is expensive, control of this nuisance species encourages more people to visit the lake and spend money. Therefore, the only opposition to lampricides is the small minority of environmentalists. Controlling sea lamprey is important enough to citizens, fishery managers, and fishermen that research and control has enough support to expand until wounding rates are attained and fish populations are strong.

Controlling sea lamprey is a project with momentum. There is a Sea Lamprey Control Department in the U.S. Fish and Wildlife Service and grants and federal funding are available annually to help Lake Champlain see more successful sport fish populations. Researchers from universities surrounding both Lake Champlain and the Great Lakes are poised to discover new treatments. This additional research and new innovative management strategies are underway, marking the first step in a ecosystem-level lamprey control program in Lake Champlain.
Step by Step Implementation

Fortunately, sea lamprey treatment has seen success since lampricides were implemented in 1990. Therefore, there is already momentum for continued progress and an established direction for treatment improvement. After two decades of research, treatments, application for permits to use chemicals in the lake, etc. the dedication to lamprey control is well established. The Lake Champlain Management Cooperative is committed to controlling nuisance species in order to ensure key sport fish species are given every opportunity to reestablish self-sustaining populations. In order to continue reducing wounding rates on fish new strategies should be pursued.

The first step in implementing new solutions is to continue chemical treatments on Lake Champlain’s tributaries and maintain barriers and traps already in place. It is important that current treatments persist while more efficient, safe, and affordable treatments are considered. There are many different levels of research that should be considered. First, research on the effects of lampricides on not only non-target species, but the ecosystem as a whole, should be conducted. How is the death of mudpuppies reverberating through an entire ecosystem? What other negative impacts are going unnoticed? Second, research on pesticide alternatives should be considered. Mapping the sea lamprey genome will give an insight into how pheromones and other hormonal cues could confound lamprey reproduction and life cycle.

Next, treatments should assume greater efficiency. Two studies should be completed in order to understand how to capitalize on lamprey’s lifecycles. Tributaries that produce the most adult lampreys need to be prioritized for treatments and productive natal streams can be traced by tracking genetics (Marsden, 2012). Suitable lamprey habitats should be better understood and mapped out in order to prioritize treatments. Honing in on key lamprey spawning grounds and
understanding preferred habitats will ensure that each treatment will have a substantial effect on overall population numbers and that chemical treatments can be avoided in low priority tributaries.

Experimentation with new treatments follows once treatment areas are prioritized. This includes the use of pheromones in luring female lampreys into traps or altering genes so that sea lamprey are unable to reproduce. Alongside with developing treatment methods that avoid the use of chemicals is also understanding more about chemical treatments in general. Research to establish the maximum concentration for lethality and treatment duration should continue as maximum efficiency has not yet been obtained. Current treatment is effective, but still can improve with additional research and experimental trials.

While all of these adjustments to treatments are being made research on TFM/niclosamide safety in aquatic ecosystems should be continued. Also, new chemicals should be considered in case there is a more safe and effective pesticide available. Research on lamprey population numbers and effects of lampricides on non-target species should continue to ensure the healthiest lake ecosystem possible. The last step in this integrated pest management strategy is to continue to pursue effective chemical alternatives and monitor the lake’s ecosystem and fishery health.
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