Chapter 10. Cost-benefit Analysis and Regulatory Restrictions of Pest Management Programs

by Terrance D. Hubert

> “If there is good information on the cost of carp damage and on the cost and effectiveness of control techniques, it should be straightforward to work out which techniques to use, and how much to spend on them to maximize the benefits of control relative to costs. Unfortunately, good information is not always available on either costs of damage or in the effectiveness of control techniques.”
>
> Bomford and Tilzey (1997) in “Controlling Carp”

In analyzing the costs and benefits associated with development of a pest control program, financial and other components need to be considered. As noted by Bomford and Tilzey (1997), this can be a challenging task because some of the information required to provide an accurate assessment is not readily available. Aside from the direct financial costs associated with, for example, piscicide registration or barrier construction, there are components that can be difficult to measure that must be considered. Among these are the potential risks associated with the use of piscicides, such as impacts on nontarget organisms and environmental persistence (Carp Control Coordinating Group 2000). This chapter examines some of the factors that should be included in a cost-benefit analysis for a pest control program.

10.1 Costs

Costs associated with subcomponents of an integrated pest management program, such as barrier construction, pheromone trapping systems, and pesticide development and registration, have finite costs that can be challenging to estimate. As noted in Chapter 8, Dent (1995*d*) described costs of an integrated pest management program including salaries, overhead, travel, running costs, and consumables. For example, in registration of a piscicide, there are not only costs associated with registration, but also registration maintenance and regulatory affairs, product manufacturing, costs for the pesticide application (personnel, materials, transportation, lodging, etc.), costs for public outreach, and program insurance (to cover instances of liability from misuse of the piscicide). All of these costs vary and depend on the size and scope of the program.

The GLFC's program for integrated management of sea lamprey assesses these costs annually and makes projections for a 3-year period. Table 10-1 illustrates the components and estimated total cost of $13.2 million for 2000 (GLFC 1998). Cost estimates for each component listed in this table are provided by task forces assigned to each component. Members of each task force meet biannually to discuss proposed work in that area/component and to determine labor and materials requirements, associated costs, and miscellaneous expenses. A proposed budget for that component is then submitted to the Sea Lamprey Integration Committee with recommendations and priorities for proposed work. The Sea Lamprey Integration Committee then acts on those recommendations and determines a final proposed budget that is submitted to the Commissioners for approval.

Table 10-1. Estimated program requirements for sea lamprey control in the Great Lakes for Fiscal Year 2000 (Great Lakes Fishery Commission 1998). "Base" refers to the critical funding requests necessary to carry out the program. "Full" refers to the amounts needed if all requests were fully funded.

	Program cost ($)	
Component	**Base**	**Full**
Lampricide control		
Schedule treatment	3,305,100	4,001,800
Total chemical purchase	3,247,500	6,503,500
Assessment		
Adult	831,300	1,189,800
Larval	2,405,200	2,947,100
Alternative control		
Barriers	721,500	2,227,900
Sterile male	591,200	801,600
Internal research	999,500	1,108,700
Agent administration	585,200	817,900
Alternative control research	646,700	2,898,200
Integrated management of sea lamprey protocol	79,600	79,600
Total cost	13,231,700	22,517,100

The New South Wales, Australia, National Parks and Wildlife Service examined the costs associated with the eradication of the plague minnow that posed a serious threat to threatened species, such as the green and golden bell frog (*Litoria aurea*; National Parks and Wildlife Service 2002). In their assessment, they considered costs associated with drafting a proposal to declare the plague minnow as noxious, education and awareness tools, environmental assessment advice, habitat surveys, targeted control measures, monitoring, participation in broad-scale river health programs, plague minnow dispersal factors, plague minnow impacts on frogs, and chemical control procedures. Table 10-2 details the total estimated cost of $200,000 associated with these factors. In this instance, the plan was laid out over a 5-year period, and each factor was assigned a number rating criticality to the overall program.

Table 10-2. Estimated costs for the removal of the plague minnow from New South Wales waterways (National Parks and Wildlife Service 2002).

Action	Priority	Estimated cost per year ($) 1	2	3	4	5	Total cost
Declare species as noxious	1	3,500	0	0	0	0	3,500
Education and awareness tools	1	5,000	5,000	0	0	0	10,000
Environmental assessment advice	1	350		0	0	0	350
Survey for habitats free from species	1	1,000	1,000	0	0	0	2,000
Conduct targeted control	1	6,000	5,000	0	0	0	11,000
Monitor control sites	1	2,000	8,500	10,000	7,500		27,500
Initiate broad scale river health programs	1	0	0	0	0	0	0
Identify factors limiting dispersal	2	0	17,000	17,000	17,000	0	51,000
Assess impacts on frogs	2	0	11,000	7,000	12,000	0	30,000
Chemical control trials	2	0	22,000	0	0	0	22,000
Coordinate plan	high	10,500	10,500	7,000	7,000	7,000	42,000
Total cost		23,850	80,000	41,000	43,500	7,000	199,350

10.2 Benefits

Discussion of the benefits associated with pest control programs must provide a balanced assessment between the positive outcomes associated with control and the risks associated with its implementation. Some benefits of pest control are easily measured, such as the restoration of a popular game fish and the re-establishment of the recreational and commercial fishing associated with the restoration. An example of a successful control program with easily measured benefits is the Sea Lamprey Control Program in the Great Lakes (Lamsa et al. 1980). Introduction of the parasitic sea lamprey had a devastating impact on the commercial and recreational fishing industries. Once sea lamprey were under control and fish populations rebounded, commercial and recreational fishing industries likewise rebounded and are today valued at an estimated $4 billion annually. The benefit of the Sea Lamprey Control Program is estimated at approximately $13 for every dollar invested (G. Christie, GLFC, personal communication).

In contrast, estimating the benefits of protecting or restoring a threatened or endangered species are difficult. Furthermore, calculating a real cost of the impact of an invasive species on lost biodiversity and its consequence to ecosystem-level health is difficult. At best, one can only evaluate the impact of various control options on the ecosystem. This was the approach used by the U.S. Fish and Wildlife Service in their assessment of a tilapia removal project for the Virgin River in Nevada and Arizona (U.S. Fish and Wildlife Service 2002). The Service proposed treatment of portions of the Virgin River System using a combination of the piscicide rotenone, detoxification, and barriers to exclude tilapia. The assessment provided a qualitative evaluation of various alternative actions to the piscicide/detoxification/barrier approach. Alternatives considered were piscicide/barrier (no detoxification), barriers in the irrigation system, piscicide alone, mechanical removal, barriers in the mainstream, and no action. The piscicide/barrier approach was rejected because without detoxification there would be no control over the extent of the area affected by rotenone. Barriers in the irrigation system were rejected because there would be insufficient time to construct barriers that would not impede the irrigation system. Piscicide treatments alone would have to be conducted on an annual basis that was considered to be cost prohibitive and logistically difficult with limited staff. Eradication of tilapia would not occur with mechanical removal because of the morphology of the river and the ability of tilapia to avoid capture equipment. Finally, barriers in the mainstream were rejected because ideal sites were not available. The analysis focused on the impacts of the proposed control strategy versus taking no action on resources, such as soils, air quality, water, vegetation, aquatic organisms, and wildlife. The approach of using rotenone/detoxification/barriers would be expected to have no effect on air quality and only slight temporary disturbances to soils, vegetation, and wildlife. Water resources would be negatively impacted during the treatment, but detoxification of rotenone would limit the impacts to the treatment area. Aquatic organisms would be safeguarded because of the elimination of tilapia. The U.S. Fish and Wildlife Service concluded that if no action was taken it is likely that aquatic organisms, wildlife, and submerged aquatic vegetation composition would change or decline with time once tilapia were established.

The New York State Department of Environmental Conservation, the Vermont Department of Fish and Wildlife, and the U.S. Fish and Wildlife Service together formed a group to manage fisheries and wildlife in Lake Champlain. One of the responsibilities of the Lake Champlain Fish and Wildlife Management Cooperative (Cooperative) is to control sea lamprey. An experimental program of sea lamprey control was initiated by the Cooperative in 1990 and continued for 8 years (Lake Champlain Fish and Wildlife Management Cooperative 1999). During this period, the Cooperative conducted a detailed cost-benefit analysis of the program (Gilbert 1999). Table 10-3 lists the factors that were considered in the analysis. Among the cost factors considered were costs to landowners resulting from sea lamprey control operations, infrastructure costs because of increased demands for lake access for fishing, and state and federal costs for sea lamprey control. Benefits were values given to the program by anglers and user/non-user groups.

Costs to landowners were items such as temporary loss of water use during control operations and physical damage to the landowner's property resulting from activities like assessment and control operations and cleanup of dead sea lamprey. Inconvenience costs were factors like having to carry potable water from a source remote from the area being treated. Infrastructure costs were items related to the development, renovation, and expansion of structures for public fishing, such as docks and boat ramps. State and federal costs centered in the Sea Lamprey Control Program and included actual expenses for staff salaries, postage, public notices, equipment rentals or purchases, barrier construction and maintenance, chemical costs, etc.

Table 10-3. Cost and benefit factors considered by the Lake Champlain Management Cooperative in assessing the value of sea lamprey control on Lake Champlain from 1990 to 1997 (modified from Gilbert 1999).

Costs	Benefits
Landowner costs loss of water-based activities, drinking water purchase, cost of water for non-drinking purposes, cost of physical damage to landowner's property, inconvenience costs	Angler values willingness to pay for sea lamprey control
Infrastructure costs development of public fishing-related infrastructure	User/non-user values willingness to pay for sea lamprey control
State and Federal costs Sea lamprey control treatment, assessment, propagation	

Benefits of the Lake Champlain sea lamprey control effort focused on two areas, angler values and user/non-user values. Angler values and user/non-user values placed on sea lamprey control were considered to be the maximum amount that people in these categories were willing to pay if the program was to be discontinued. Anglers, who purchased fishing licenses in the states of Vermont and New York and user/non-users within a 56 km radius of the lake, were surveyed in 1991 and again in 1997 to determine the willingness to pay for sea lamprey control. Surveys in the user/non-user groups were limited to heads of households with telephones. Nonheads of households and heads of households without telephones were not surveyed.

Gilbert (1999) estimated that the 1991 benefit was \$1,805,268 and increased to \$8,625,314 in 1997. Over the 8-year period, the total benefit realized from sea lamprey control was estimated to be \$29,379,211. Costs for the control program over the period were \$8,447,011. The total estimated benefit realized and the cost of the control program were converted to 1990 dollars. The benefit-cost ratio was estimated to be \$3.48 for every dollar spent in the program.

Unlike the Cooperative's assessment of the costs and benefits of sea lamprey control, an assessment for the restoration of threatened and endangered species in Arizona watersheds is a daunting task. Since it is difficult to quantitatively assess the value of restoration of an endangered species, it may be more appropriate to determine the maximum economic impact that might result from such an effort. In contrast to the desired higher values of the ratio of benefit to cost when restoring a sport fishery, restoration of threatened and endangered species in Arizona watersheds would focus on the economic impacts associated with the effort, with ratios below one being more desirable for endangered species restoration. Table 10-3 lists some possible factors for consideration. For example, assessment of impacts could incorporate surveys to assess the impacts of the restoration effort on local angling. Cost assessments would be based on the costs to conduct the eradication program, costs to educate the public on the need to carry out the restoration, and costs to provide alternative fishing opportunities for anglers.

10.3 Regulatory Restrictions

Piscicides present a situation of special concern to the EPA because the use involves application of the chemical to a body of water. The potential for the piscicide to move into groundwater is greater than with a pesticide applied to soil. Also, if the piscicide is to be applied to a flowing body of water, the risk of contact with humans and wildlife becomes greater because of the potential for the piscicide to cover great distances. Consequently, the EPA scrutinizes the proposed methods and locations of application for the potential to translocate into groundwater or to end up in crops irrigated with water from treated streams. It is likely that restrictions will be placed on the registration. Almost certainly, registration restrictions would include reference to application by certified applicators and use of water for irrigation of crops or watering livestock.

Biological and physical controls would also be subjected to regulatory restrictions. For example, biopesticides would be subjected to regulatory restrictions, although the level of the restrictions may be somewhat relaxed compared to chemical piscicides because biopesticides are naturally occurring substances. A pheromone used in fish control may be expected to undergo more scrutiny than insect pheromones, largely because no vertebrate pheromones have been registered and consequently the EPA is venturing into new territory. Genetic technology is subjected to regulatory oversight. An example of such regulation is the incorporation of genes in plants that produce thiurengensin, the toxin produced by *Bacillus thirurengensis*. Use of this technology is regulated by the EPA. Incorporation of a gene to produce some desired effect in fish, such as daughterless offspring, can also be expected to undergo similar oversight. Physical controls also face regulatory oversight. Placement of barriers, capture devices, or drawdowns have the potential to alter habitat. State natural resource agencies would probably regulate such controls to ensure proper design, placement, and operation.

Chapter 11. Case Study of Integrated Pest Management: Control of Sea Lamprey in the Great Lakes

by Cynthia S. Kolar, Michael A. Boogaard, and Terrance D. Hubert

11.1 Background

Now that the necessary elements for the development of taxon-specific piscicides and integrated pest management programs have been presented, we turn to a case study of a successful fish control program. Arguably the most successful program for the control of nonnative fishes in the United States is the Sea Lamprey Control Program, which is administered by the GLFC to control sea lamprey in the Great Lakes. Although the focus of this report is on the control of nonnative fishes in the Gila River basin, a close examination of the development and evolution of the multifaceted and highly respected Sea Lamprey Control Program can provide insight into the development and implementation of such programs. As in the current interest in controlling undesired fishes in the Gila River basin, the Sea Lamprey Control Program began with the search and development of a taxon-specific piscicide.

The sea lamprey, a primitive and jawless fish that is parasitic in its adult life stage to other fishes, is native to the Atlantic Ocean and ascends streams and rivers on the Atlantic Coast of Europe and the United States to spawn. After hatching, larval sea lampreys (ammocetes) remain in the sediments for several years where they ingest detritus before they metamorphose (transform) into adult lampreys and migrate downstream to the Atlantic Ocean where they grow rapidly by preying on marine fishes before they ascend rivers to spawn.

Although they may have been native to Lake Ontario, sea lampreys were first found above the Welland Canal in 1921, after modification to the canal in 1919 (Christie 1974). From Lake Erie, sea lampreys were able to invade the remaining Great Lakes and were able to complete their life cycle in the fresh waters of the Great Lakes basin. By the 1940s, sea lamprey had become abundant in all of the upper Great Lakes and had contributed to severe reductions in the lake trout, whitefish, and cisco populations in the Great Lakes. It has been estimated that during its parasitic stage, each sea lamprey can kill more than 18 kg of fish (GLFC 1985). Commercial catch of lake trout declined from 6,800,000 kg before invasion by the sea lamprey to about only 136,000 kg in the early 1960s. Motivated by the resulting collapse of commercial fisheries in the Great Lakes, the governments of the United States and Canada created the GLFC by bilateral agreement in 1954 to protect the fisheries resources of the Great Lakes basin.

The GLFC quickly sponsored research to identify a taxon-specific piscicide that could be used to control sea lamprey at their most vulnerable life stage. A chemical was found and a chemical control program was implemented. The wounding rates (fresh wounds and scars from previous sea lamprey attachment) of lake trout began to decline, survival increased, and lake trout populations supplemented by intensive stocking began to rebound (Figure 11-1). Since the first chemical treatments in the 1950s, sea lamprey control measures have been taken every year to protect the fisheries resources of the Great Lakes. Through time, however, it became apparent that eradication of the sea lamprey in the upper Great Lakes was impossible and that a long-term control program would be necessary. In response to increasing concern about adding chemicals to the environment, the GLFC began searching for other control methods to add to the Sea Lamprey Control Program to reduce reliance on chemical treatment to effect management of sea lamprey populations. Integrated management of sea lamprey has resulted in a sustained 90% decrease in the abundance of sea lamprey compared to their peak in the 1960s (Figure 11-1).

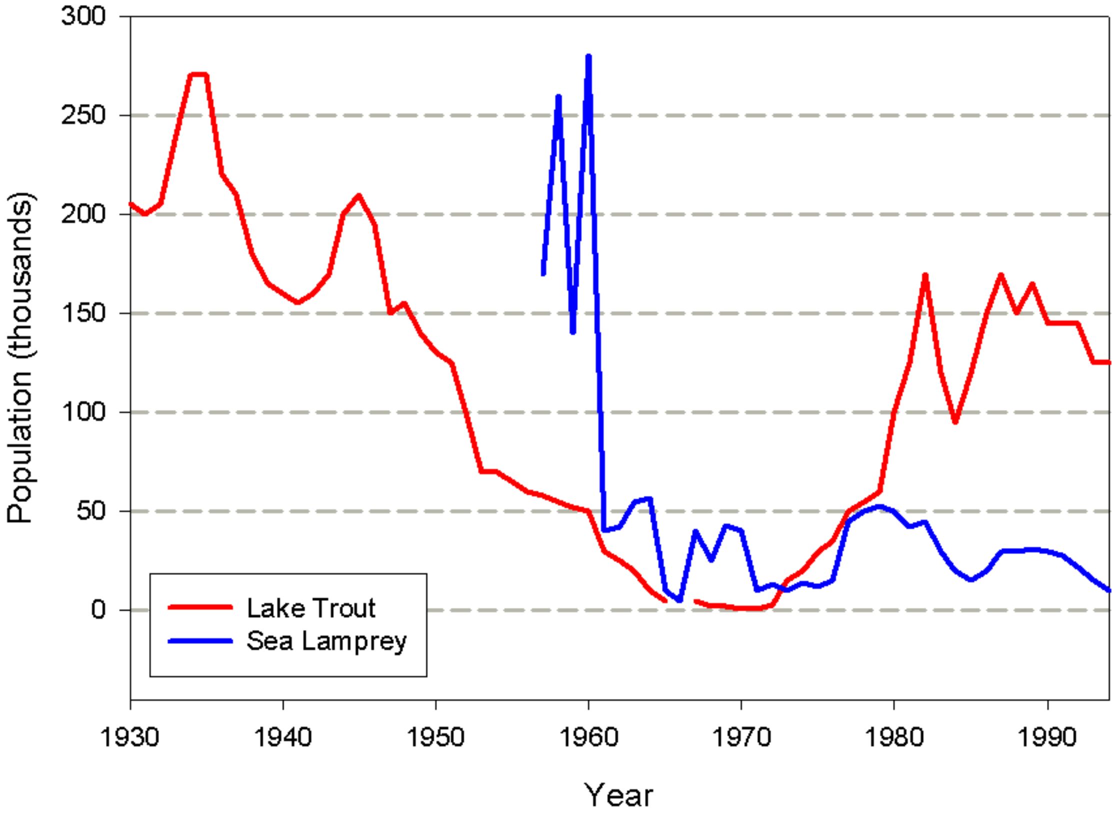

Figure 11-1. Abundance of lake trout (1930-1996, no data collected in 1966) and sea lamprey (1956-1996) in Lake Superior. Lake trout were declining significantly before control of sea lampreys began in the early 1960s (from the Great Lakes Fishery Commission).

The remainder of this case study will detail the development and evolution of the Sea Lamprey Control Program in the Great Lakes from development of a treatment strategy to active ingredient and formulation development, application methods, chemical production, and the current strategy of integrated pest management.

11.2 Developing a Treatment Strategy

Selecting Critical Life Stage for Control

Development of control measures began by examining the life history of the sea lamprey to identify the most appropriate life stage on which to attempt control. The life history of the sea lamprey consists of two major stages: a nonparasitic, stream-dwelling, larval phase and a parasitic, lake-inhabiting juvenile/adult phase. Because larval lamprey remain burrowed in the sediments of streams and rivers for 4 to 7 years (National Research Council of Canada 1985), the control program quickly focused on this life stage. Initially, physical barriers, followed by electrical barriers, were constructed in hundreds of tributaries of the Great Lakes to prevent adults from ascending them to spawn. Barriers, however, could not be constructed on all tributaries with suitable habitat and where constructed were ineffective during seasonal floods and when adult sea lamprey were migrating. Therefore, these early barriers proved to be largely unsuccessful for sea lamprey control.

The use of selective lampricides was considered appropriate since sea lamprey larvae are found in sediments for such a lengthy time and because several year classes could be eliminated with a single stream treatment. Identification of unique aspects of the physiology and life history of the sea lamprey allowed the development of perhaps the most successful chemical control program for invasive aquatic species in existence today.

Selecting Candidate Chemicals and Toxicity Screening

The search for a selective lampricide was initiated while this initial barrier system was still in use. In the process of screening more than 6,000 chemicals, it was found that the sea lamprey was particularly susceptible to nitrophenols, and eventually TFM was found to provide the best selectivity for sea lamprey (Applegate et al. 1958, 1961). The screening of control chemicals continued, and in 1963 Bayluscide® was also found to be highly toxic to sea lamprey (Howell et al. 1964). Because it is also less selective to nontarget organisms, it is currently used as an additive toxicant or economic synergist with TFM to reduce the amount of TFM required and consequently, the cost of treatments.

Safety Considerations

Before TFM or Bayluscide® could be applied to streams, however, its use was tested for safety and approved by governmental agencies responsible for regulating its use including the EPA and Health Canada. Before 1970, the primary focus of data submitted to register a pesticide was on human safety. In 1970, the registration of pesticides became a responsibility of the new EPA, and environmental safety was added to the focus. Consequently, additional data for registration of the lampricides had to be developed to ensure all aspects of human and environmental safety were addressed. At various stages in the history of the lampricides, missing, inadequate, or outdated data have jeopardized the registrations of the chemicals. Re-registration was begun in 1992 and culminated with the publication of the EPA reregistration eligibility decision on the lampricides in November 1999. Additional studies to test product chemistry and acute toxicology of the specific formulation were finished in 2003. These challenges have been met, and today a wealth of data on the effects of the lampricides and lampricide formulations on humans and the environment are on file at the EPA. In all, 86 studies were conducted in the areas of genotoxicity, mammalian toxicology, wildlife toxicology, residue chemistry, and environmental fate. The cost to complete these re-registration studies was approximately $5.5 million. In 2003, the EPA concluded that the lampricides pose no unreasonable risk to the general population or the environment when applied at concentrations necessary to control sea lampreys.

11.3 Active Ingredient Development

The decision to develop a chemical was based not only on selectivity toward sea lamprey, but also on consideration of the chemical's properties, ease of handling in the field, effectiveness at low concentrations, and cost. Of the chemicals tested, TFM ranked the best (Applegate et al. 1961). At the time of its discovery, TFM was marketed as an herbicide (Applegate et al. 1961). Laboratory and field tests were initiated to provide data from which treatment procedures could be developed and to provide data on the toxicity of TFM to nontarget organisms and human exposure data. Data from these tests were submitted to U.S. Department of Agriculture, the agency responsible for pesticide registration at that time, and a registration was granted on August 21, 1964 (Schnick 1972). Early formulations of TFM consisted of either dimethyl formamide and water or polyethylene glycol and water. Today, TFM is registered as an isopropanol and water formulation. The need to block sea lamprey escape routes into small feeder streams off main tributaries led to the development in the 1980s of a bar formulation of TFM.

At the time of its discovery, niclosamide was produced by Bayer AG in Leverkusen, Germany, and was registered and marketed under the name Bayluscide®. It was first commercially available as a 70% wettable powder (WP) for controlling freshwater snails. Subsequent laboratory and field testing of niclosamide took about 5 years and led to the registration of a 5% granular formulation in 1968 (USDA 1968). Both formulations were subsequently used in sea lamprey control. Today, there are three formulations of niclosamide registered as lampricides. The 70% WP is still in use, but the 5% granular was replaced with a 3.2% granular formulation. Recently, a 20% emulsifiable concentrate has been developed and registered.

11.4 History of Lampricide Formulation Development

The first liquid formulation of the lampricide TFM was developed by the Progressive Color and Chemical Company of New York (Moffitt 1958), although another source credited Farbwerke Hoechst Chemical Company of Germany as the developer (Anonymous 1959). The formulation was a sodium salt dissolved in dimethyl formamide (DMF) under the name Lampricid® 2770 and consisted of about 35% active ingredient. The first field testing of the formulation was conducted on the Mosquito River (Lake Superior), Michigan, in May 1958 (Moffitt 1958). The DMF formulation was used in sea lamprey control operations for almost 30 years before concerns over the safety of the solvent carrier surfaced in the mid-1980s. In 1987, while investigating the use of the herbicide Sonar, the EPA noted that DMF could be broken down into monomethyl formamide (MMF). This degradate has been shown to have adverse effects on reproduction and is a teratogen (Daugherty et al. 1987). As a result, the registration of the DMF formulation of TFM was cancelled in 1989. The manufacturer replaced DMF with polyehylene glycol (PEG) as the carrier solvent in the formulation for the 1988 field season. It became apparent early on that the PEG formulation was not the answer. Applicators noted that the new PEG formulation turned to a paste or gel when agitated under cold conditions (Meyer 1989). This made the formulation difficult to apply resulting in inconsistent applications and ineffective treatments, and it was abandoned after one treatment season. The next year Hoechst Chemical Company replaced PEG with isopropanol as the carrier solvent. The resulting isopropanol formulation, containing about 36% active ingredient, was much less viscous under cold conditions than its previous counterpart that allowed easier and more consistent applications (Hubley 1990).

The original bar formulation contained about 23% TFM, incorporated into two non-ionic polyol surfactants, Pluronic® F38 and F68 produced by BASF Wyandotte Corporation, Wyandotte, Michigan. Field trials of the bar in 1981 were relatively successful (Gilderhus 1985). The bar dissolved at a near constant rate over a period of 8 to 10 hours although there was concern over its brittleness as it tended to break apart during handling and transport. To counter this problem, a matrix surfactant, Tetronic® 1508, was added to the formulation. The resulting bar held together well yet still maintained a consistent dissolution and this formulation was registered for use by the EPA in 1986. In 1992, BASF Wyandotte Corporation informed the registrant, the U.S. Fish and Wildlife Service, that it would no longer be producing the matrix surfactant Tetronic® 1508. The GLFC purchased the remaining stocks of Tetronic® 1508 to assure an ample supply of TFM bars for several years. In the interim, the UMESC was charged with developing a replacement formulation. Several replacement matrix surfactants were provided by BASF and tested at UMESC for possible incorporation into a new bar formulation. Of the matrix surfactants assayed, Plurafac® A-39 was found to provide the best replacement for Tetronic® 1508, and registration of the newest TFM bar formulation by the EPA was completed in 2002.

The original granular bottom-release formulation containing 5% Bayluscide® had been used in sea lamprey control operations since 1969 as an assessment method for larval sea lampreys in lentic areas. The formulation yielded a considerable amount of dust when it was applied, which posed a hazard to the applicator and the surrounding environment from pesticide drift. To eliminate this problem, a new granular formulation was developed using the "Wurster Process," which is used in the production of timed-release medications. Sand was coated with a mixture of the active ingredient dissolved in nontoxic surfactants to enhance solubility, after which a klucel and ethyl cellulose top coating was applied. The resulting granule contained 3.2% Bayluscide®, 22% coating materials, and 75% sand. Field trials of the new granule in 1991 resulted in an estimated 94% kill of larval sea lampreys in lentic areas. Also, dust generated during application was virtually eliminated. The new 3.2% granular Bayluscide® formulation was registered and approved for use by the EPA in 1995.

11.5 Application Methods

Lampricide Treatment of the Ford River: Typical Lampricide Treatment Case Study

The Ford River, located in Delta, Menominee, and Dickinson counties of Michigan's Upper Peninsula, is a large, dendritic system that has been treated on average, every 2 years to control larval sea lampreys since its first treatment in 1964 and requires extensive effort from numerous personnel. This case study highlights lampricide applications conducted in 2000 and 2002 and includes many of the steps and procedures involved.

Before treatment operations were initiated, an assessment of the river was conducted to identify the upstream limit of larval sea lamprey infestation and to assess the size and age structure of the larval population. The size and age data are used to predict the numbers of larvae that have potential to metamorphose into the parasitic life stage in the coming year and is an important factor in determining when treatment of the river is warranted. Assessment procedures were also conducted on all tributaries of the main branch to determine presence of larvae and the extent, and upstream limit of infestation. The assessment data were used to identify initial upstream application points on the main branch and all tributaries that required treatment. Once assessment operations were completed and all necessary larval population data established, treatment operations were scheduled.

Upon arrival at the river, treatment personnel were dispatched to all the reaches of the main branch and its tributaries to collect water quality data (total alkalinity, pH, temperature, and dissolved oxygen). Other personnel determined total stream discharge and conducted dye studies with fluorecein or rhodamine dyes to estimate stream hydrology. Stream-side bioassays were conducted with larval sea lamprey captured from the river to determine the minimum lampricide concentration required for successful treatment. These data, coupled with data from previous treatments, were used by treatment managers to determine target lampricide concentrations, application rates, when to initiate the treatment, and where to locate booster application sites to counter lampricide loss as the chemical block moved downstream. This pre-treatment work was conducted over a 4- to 5-day period.

Several studies have shown that the lampricide is greatly influenced by chemical and physical properties of water, in particular pH and alkalinity (Le Maire 1961, Kanayama 1963, Dawson et al. 1975, Marking and Olson 1975, Dawson et al. 1977, Bills et al. 1988). The lampricide is selectively toxic only when applied at concentrations at or slightly above the minimum lethal concentration (MLC) required to kill 100% of larval sea lamprey. Minimum lethal concentrations of TFM to larval sea lamprey can vary from 0.3 mg/L in water of low pH (6.5) and low alkalinity (30 mg/L as $CaCO_3$) to 36.0 mg/L in water of high pH (9.5) and high alkalinity (260 mg/L as $CaCO_3$) for a 12-hour exposure (Klar and Schleen 2000). Bills et al. (2003) describe how alkalinity and pH are used to determine treatment MLC values.

Treatment operations were initiated and the lampricide TFM was applied to the mainstream at the initial application point for 12 hours to achieve a 9-hour block of chemical at the target MLC concentration. Applications to tributaries were timed so that the arrival of lampricide at the convergence with the main branch coincided with the main treatment block. In the 2000 treatment, the upper reaches of the river and all tributaries received TFM alone while the lower reach received a combination of TFM + 1% Bayluscide®. Figure 11-2 shows the 2000 treatment of the Ford River and its tributaries indicating the approximate locations of all lampricide application points. In 2000, a total of 176 km of stream was treated. Average stream discharge was 3.1 m^3/sec (historically low) in the main branch of the Ford River. Travel time for the lampricide block was 8 days from the initial application point to the river mouth. A total of 48 personnel and 3,400 staff hours was required to complete the treatment. Lampricide concentrations were targeted at 4.1 mg TFM/L in the upper reaches of the river and 3.1 mg TFM/L + 31 µg Bayluscide®/L in the lower portion and were based on water quality data and pre-treatment stream-side bioassays. Total lampricide (based on active ingredient) applied to the river in 2000 was 2,113.7 kg of Lampricid® (TFM), 22.7 kg of TFM Bars, and 7.4 kg of Bayluscide® at a cost of $136,975.

Post-treatment larval assessment of the river in 2001 indicated that some larvae survived treatment in the main branch most likely the result of the low discharge treatment in 2000. The size and age data of the remaining larval population indicated that a significant number may metamorphose within the next 2 years, and the river was scheduled for treatment again in 2002. The lampricide treatment of the Ford River in 2002 was limited to the main branch. A total of 104.6 km of the main branch was treated at an average of 12.7 m^3/sec discharge. As in 2000, only the lower portion of the river received a combination of TFM + 1% Bayluscide® while the upper reaches received TFM alone. One crew of 17 personnel totaling 1,800 staff hours was required to complete the treatment. Target lampricide concentrations were 2.8 mg TFM/L in the upper reaches of the river and 2.2 mg TFM/L + 22 µg Bayluscide®/L in the lower portion. Total lampricide (based on active ingredient) applied to the Ford River in 2002 was 1,600 kg TFM and 12.8 kg Bayluscide® at a cost of $100,700.

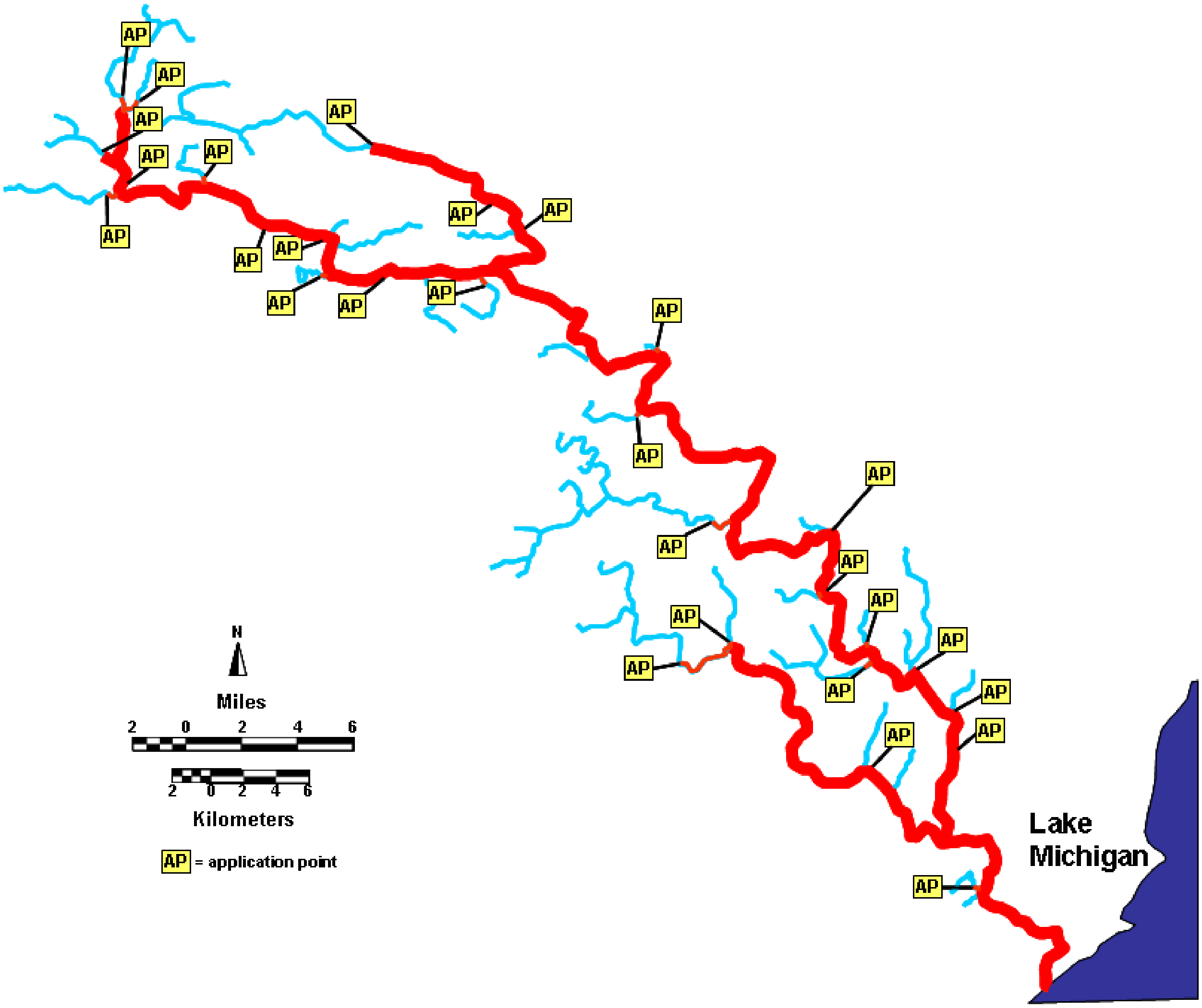

Figure 11-2. Lampricide treatment plan for the Ford River, Upper Peninsula of Michigan, in 2000. Red areas detail treated areas of the watershed. AP = Application Point

St. Marys River: Case Study of the Chemical Treatment of a Large, Open River System

The largest single application of the granular Bayluscide® in the history of the Sea Lamprey Control Program occurred on the St. Marys River in 1999. The St. Marys River flows from Lake Superior to Lake Huron and is the largest producer of sea lampreys in the Great Lakes basin. Before 1999, populations of sea lampreys in northern Lakes Huron and Michigan remained unchecked, and a vast majority of these parasites originated from the St. Marys River (Figure 11-3). In most sea lamprey control applications in which Bayluscide® or TFM is used, application can be achieved by mixing a wettable powder or liquid formulation with water from the river that is being treated. This works well because river flow transports the chemical to the areas sea lamprey inhabit, and large volumes of the chemical are consequently not required. A different approach was required to treat the St. Marys River, a large, fast flowing river. In this case, application of TFM in combination with the wettable powder formulation of Bayluscide®

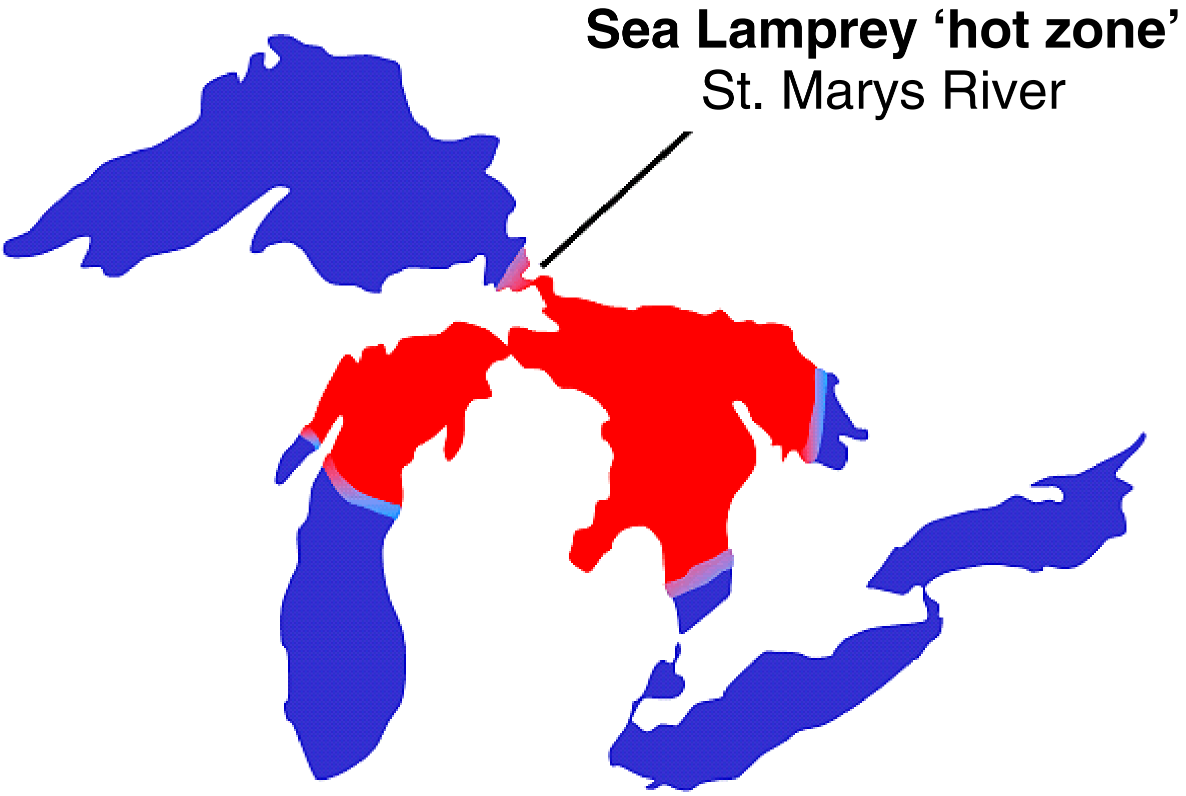

Figure 11-3. Map of the zone of influence by parasitic sea lampreys produced from the St. Marys River.

would have required a tremendous amount of both chemicals to achieve the required toxicity. Instead, the treatment used a new formulation of Bayluscide®, a 3.2% granular formulation that uses timed-release microencapsulation technology (Schleen and Klar 1999). This formulation was aerially applied to zones in the St. Marys River that contained sea lamprey larvae. The formulation is designed so that the chemical is not released until it reaches the river bed where the larvae are burrowed, thus creating a zone of chemical in the first few centimeters of water above the lamprey beds. An extensive assessment of the river for larval sea lamprey abundance was conducted before the application. Areas containing the largest concentrations of larvae were mapped using Global Positioning System (GPS) technology and targeted for treatment (Figure 11-4). Treatment of the river was conducted in summer 1999 by aerial application using a helicopter equipped with a broadcast spreader system (Figure 11-5) similar to the one described by Selbig (1974). A total of 132,679 kg of the granular formulation was applied to 759 ha over a 9-day period. Post-treatment assessment indicated that the granular treatment was successful at removing 88% of the larvae from the treated areas of the St. Marys River (Schleen and Klar 1999).

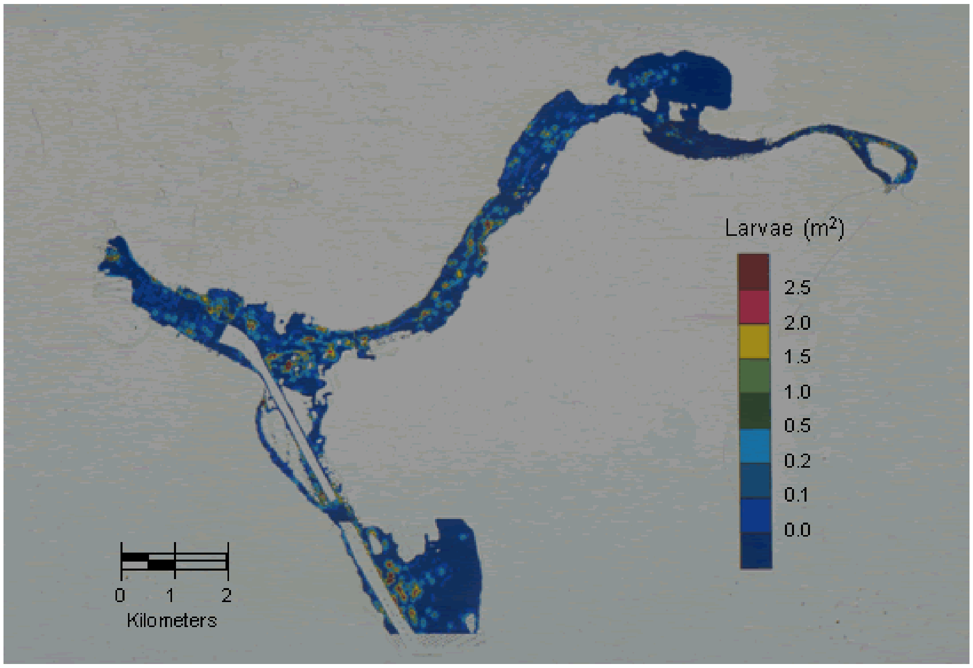

Figure 11-4. Map of the St. Marys River showing the areas in which high abundances of larval sea lamprey were detected before treatment in 1999.

Figure 11-5. Aerial application with Bayluscide® 3.2% Granular Sea Lamprey Larvicide for sea lamprey control on the St. Marys River in 1999.

11.6 Production

As noted, both lampricides were commercially available before their efficacy in sea lamprey control was known. The TFM was being manufactured by Hoechst AG in Frankfurt, Germany, and niclosamide was being produced by Bayer AG in Leverkusen, Germany. Both manufacturers still play a role in the production of these chemicals today. The representative for Hoechst AG in the United States is Clariant LSM (America), Inc. A liquid formulation of TFM is now also produced by Kinetics Industries, Flushing, New York. The TFM Bar is manufactured by Bell Laboratories, Madison, Wisconsin.

Niclosamide is manufactured by Bayer AG as the ethanolamine salt, Bayluscide®, and its use for snail control represents a large market for the company. Bayluscide® purchased for sea lamprey control is sent to ProServ, Inc., Memphis, Tennessee, where it is formulated into Bayluscide® 70% WP and Bayluscide® 20% Emulsifiable Concentrate and to The Coating Place, Verona, Wisconsin, where it is formulated into Bayluscide® 3.2% Granular Sea Lamprey Larvicide (Table 6-1).

Purchase of the lampricides was formerly done on an annual basis: typically between 32,000 and 36,000 kg of TFM and 4,500 to 9,000 kg of Bayluscide®. The GLFC recently has arranged to purchase the chemicals in larger quantities and for the production to be done over a 4-year period. For example, in 2001 the GLFC purchased 154,000 kg of TFM to be produced over the next 4 years (Sea Lamprey Integration Committee 2001). In this way, a cost savings is realized.

Each of these products have unique labels that describe the requirements for legal application of the products. The lampricides are classified as restricted-use pesticides, which means that they may only be applied for control of sea lamprey, are for use only in tributaries to the Great Lakes, and may only be applied by certified, trained applicators. Use of the chemicals in a manner not consistent with the label is a violation of Federal Law. The labels contain information on potential hazards, precautionary statements, directions for use, disposal, and first aid and contact information in the event of accidental exposure (Appendix F). Labels have changed over the years as information on the lampricides improved and application techniques have been refined. One item that sets the labels for the lampricides apart from most other pesticides is that they reference a detailed manual for application of the chemicals (Klar and Schleen 2000). This detailed treatment manual has received praise from the EPA for its attention to detail and has been held up as an example for other pesticide manufacturers to follow (T. Steeger, EPA, personal communication).

At the writing of this report, registration of the lampricides has fully entered the phase of registration maintenance. Submission of all data to fulfill the remaining EPA requirements is complete. Fees to maintain registrations are paid on an annual basis, and use of the lampricides and research being conducted on the lampricides is monitored to accumulate any information regarding unreasonable adverse effects that may be uncovered. This information is reported promptly to the EPA so that adjustment to the use restrictions, if necessary, can be made.

11.7 Integrated Pest Management

The sea lamprey control and research programs of the GLFC and its agents, the U.S. Fish and Wildlife Service, the U.S. Geological Survey, and the Canadian Department of Fisheries and Oceans, have been highly successful in revitalizing the Great Lakes fisheries using selective fish toxicants (Figure 11-1). Chemical control of sea lamprey continues to be an integral factor maintaining sea lamprey populations in the Great Lakes at acceptable levels. Since the inception of the chemical control program, however, continual improvement of the efficacy and safety of the treatments to control agents and nontarget species has remained a primary goal of the GLFC. This dedication is evidenced by the evolution of the active ingredients, formulations, treatment methods, and continued investment in research to further fine-tune treatments. However, after many years of chemical treatments to control sea lamprey, it was acknowledged that complete eradication of the sea lamprey was not possible. In the meantime, public opinion regarding the release of chemicals in the environment had swayed, and the GLFC realized that a more comprehensive control program was needed.

Physical barriers, both electrical and mechanical, have long been used to prevent adult sea lampreys from reaching spawning grounds. Many of these early barriers were not completely effective and impaired the movement of desirable fishes. In 1988, a binational task force concluded that new barriers could be designed and placed below sea lamprey spawning grounds that could simultaneously stop the movement of sea lampreys while allowing the movement of desirable fishes. Since then, the GLFC has facilitated and provided funding for the construction of several types of sea lamprey barriers: low-head, adjustable-crest, and electrical. Low-head barriers are the most common physical barrier for sea lamprey control in the Great Lakes. These barriers create a 0.6- to 1.2-m drop that stops sea lampreys from continuing upstream. Construction of an associated jumping pool below the barrier or incorporation of a fishway allows most migratory salmonids and other fish to pass easily. Adjustable-crest barriers are similar to low-head barriers with jumping pools to aid nontarget fish species passage but contain air bladders that can be inflated to raise the crest only during the sea lamprey spawning runs. Thus, the waterway can remain unobstructed most of the year, allowing free passage of all fishes. When inflated, adult sea lamprey cannot pass. Electrical barriers using gradient-field, direct current electric power to deter sea lamprey movement do not impede water flow. These barriers allow the free movement of all fishes except during the sea lamprey spawning run when they are electrified, thereby stopping the upstream movement of all fish including sea lampreys or diverting them to traps for sorting. Additional physical and electrical barriers have been approved for funding by the GLFC each year and will continue to be funded in the future.

Another portion of the integrated pest management approach of the Sea Lamprey Control Program includes the trapping and removal of adult sea lamprey during the spawning run. For example, in the St. Marys River, traps have been designed and installed to capture adult sea lamprey during spawning runs. Some of these traps are amazingly efficient, removing up to 70% of the estimated spawning run of sea lampreys (Mike Twohey, U.S. Fish and Wildlife Service, personal communication). Additional traps with improved designs are continuing to be installed in the Great Lakes.

In 1991, after 20 years of research and development, the GLFC began a sterile male sea lamprey release program. It was hypothesized that the abundance of sea lamprey could be reduced if sterilized male sea lampreys competed successfully with fertile males to mate with females. Each year, sea lamprey control agents capture approximately 25,000 male sea lampreys in strategically placed traps, sterilize them using a chemical called bisazir (not regulated by the EPA), and then release them into select Great Lakes streams.

In 1992, the GLFC established the objective of achieving a 50% reduction in the quantity of lampricides applied annually by 2000 (GLFC 1992). The GLFC hoped to accomplish this by developing improved formulations of the lampricides, developing more efficient application techniques, and by integrating other control methods into the program. By 2000, the annual quantity of lampricide applied to Great Lakes tributaries has been reduced by approximately 30% (GLFC 2001). In order to meet the goal of further reductions in the amount of lampricides used, the GLFC continues to seek new methods of controlling sea lamprey. One experimental program focuses on the use of pheromones released by sea lamprey as attractants to enhance trapping and removal of adults or possibly to lure spawning adults into streams unsuitable for reproduction (Vrieze and Sorensen 2001, Li et al. 2002).

Since the early 1960s when the abundance of sea lamprey peaked in the Great Lakes, the GLFC has integrated a variety of methods to control this harmful invasive species. Today, commercially and recreationally important fish populations are again abundant in the Great Lakes. The rebound of these fisheries can be directly attributed to the research, management, and regulatory programs of the state, provincial, federal, and international resource agencies involved in administering and implementing the Sea Lamprey Control Program. There are unique circumstances, however, that have facilitated the development of this program that would be difficult to duplicate elsewhere. The first, and most important factor was the identification of a vulnerable life stage of the sea lamprey on which to focus control efforts. Few species have such a vulnerable life stage to exploit for control. A second has been the sustained public support for the Sea Lamprey Control Program. The Great Lakes historically supported an important commercial and recreational fishery that was being destroyed by the invasion of sea lampreys. The urgency to control sea lamprey was also aided by the fact that sea lampreys are parasitic, eel-like, blood-sucking fishes. It is not a difficult sell to the public that these fishes need to be controlled—even at the sustained cost of $13 million annually—to save an economically important fishery.

As evidenced in the development and evolution of the Sea Lamprey Control Program in the Great Lakes, successful fish control programs start with an analysis of the life history of the species to be controlled in the context of the ecosystem in which the control strategy is to be realized. Critical life stages and habitats must be identified, control tools developed, regulatory requirements met, and an integrated control program developed on the basis of the type and scope of control desired. This is an evolving process whereby new formulations, new methods of application, and innovative integrated management techniques must continually be developed and refined to help improve the success of a fishery management program. In addition, a suitable answer for controlling a species in one ecosystem may need to be modified for the same species elsewhere.

Chapter 12. Feasibility of Pursuing Development of Taxon-specific Piscicides for Managing Nonnative Fishes in the Southwestern United States

by Verdel K. Dawson

The success of the pesticide industry has been based on the fact that some organisms are more sensitive than others to certain chemicals. Selectivity has most often been achieved between phylogenetically diverse groups, such as insects and plants. Although demonstrating chemical selectivity is more difficult on closely related organisms, the piscicide TFM is an example of a chemical used to selectively remove one species (sea lamprey, class Agnatha) from the same subphylum as others in the ecosystem (mostly class Osteichthyes). The liver of the sea lamprey is not as adept at forming the glucuronide conjugate of TFM as that of more derived species of fish. Therefore, lampreys cannot metabolize and eliminate the chemical efficiently and are more sensitive to TFM (Lech and Statham 1975). Generally, differential sensitivity to chemicals is insufficient among organisms from the same family to allow effective selectivity. Closely related species have similar rates of uptake of chemicals and organ systems for metabolizing and eliminating those chemicals (see Chapter 3), so there is less selectivity. An exception is the candidate piscicide, Squoxin, a chemical that shows significant selectivity for the northern pikeminnow while not harming other cyprinids (Tarr 1985). Another example is the proposed carpicide, GD-174 that has been shown in laboratory studies to kill common carp without affecting other cyprinids (Marking 1974). GD-174, however, has not been shown to be effective in field trials (Gilderhus and Burress 1983).

It is not likely that either of the approved selective piscicides (TFM and Bayluscide®) would be effective for controlling nonnative fishes in the southwestern United States because the native and nonnative fish communities are different from most areas where selective piscicides are being used. The so called “silver bullet” of selective piscicides does not presently exist for nuisance nonnative fishes in the southwestern United States, and the prospects for the development of such a tool are limited. Given the present state of knowledge concerning structure-toxicity relationships of chemicals (see Chapter 7), development of the ideal selective toxicant for eliminating invasive nonnative species in that region would probably be time-consuming and cost-prohibitive. It is estimated that development and registration of a new toxicant would require 8 to 10 years and cost \$35 to \$50 million (American Crop Protection Association 2001). Even if a chemical could be developed that is selectively toxic to target organisms, it would be difficult to obtain the data needed to pass the EPA’s ever-expanding label requirements for demonstrating nonpersistence and safety to nontarget organisms in a timely manner (Meyer and Schnick 1976; see Chapter 8). Therefore, reclamation projects on streams in the southwestern United States would probably require the use of one of the four piscicides currently registered for use by the EPA: antimycin, rotenone, TFM, and Bayluscide®. Antimycin and rotenone are registered for general use on a nationwide basis (Appendix F). TFM and Bayluscide® are registered as restricted-use lampricides with primary use in tributaries to the Great Lakes (Appendix F).

Ideally, a piscicide would be selectively toxic to the invasive species while not harming the native species. Toxicity tests of each of the four registered piscicides against the native and nonnative species of concern under similar water quality and exposure conditions would be required to assess the potential for selective removal of the nonnative species in the Gila River basin. Data on the toxicity of the piscicides to nonnative species of concern are available, but little is known about their toxicities to native species (Table 12-1). All of the available toxicity data (96-hour LC_{50} values and 95% confidence intervals presented in Table 12-1) were obtained from toxicity tests conducted at 12°C in standard reconstituted water. Data for a related surrogate species is given if no information was available for any native fish species of concern in the Gila River basin.

In the near future, successful management of nonnative fishes using piscicides in the southwestern United States probably lies in the use of currently registered piscicides–particularly rotenone and antimycin. General piscicides have been used for selective control of certain species because of habitat preferences (Smith 1950). For example, Greenbank (1940) reported on the use of rotenone for selective removal of chubs from shoal areas of a lake without harming brook trout in the open water of the lake. He also demonstrated selective removal of warmwater fishes from two thermally stratified lakes without harming coolwater fishes (see Chapter 5). In addition, mixtures of currently registered piscicides may have potential for use as selective toxicants (see Chapter 7). Unfortunately, the typically shallow waters of the southwestern United States do not allow the segregation of fishes by thermal stratification. There are situations, however, where native and nonnative fishes are geographically separated within lakes or stream reaches. Some of these situations have been identified (see Chapter 2) and more could be discovered through intensive surveys. Successful treatments that utilize geographical separation may require the use of physical barriers and/or detoxification stations during chemical applications.

Large-scale eradication of nonnative fishes has also previously been accomplished with chemicals. For example, common carp were eradicated from about 20 impoundments in Tasmania with rotenone in the 1970s. As a result, Tasmania gained 20 years of freedom from common carp (Sanger and Koehn 1997). Fortunately, common carp had not escaped into natural river systems before the successful treatments. This example demonstrates that eradication is possible and is worthwhile when the problem is contained and detected at an early stage. Piscicides continue to play an important role in the reclamation of waters because of the growing need for intensive management of fishes to meet increasing demands on shrinking water resources. Selective exploitation, unwise stocking of native or nonnative fishes, and alterations in water quality contribute to the suppression and exclusion of desirable fishes by undesirable fishes (Lennon et al. 1970).

Table 12-1. Toxicity (96-hour LC_{50} values and 95% confidence intervals) at 12°C of the piscicides antimycin, rotenone 5% liquid, TFM, and Bayluscide® to selected native and nonnative fishes of the southwestern United States. Bracketed values indicate data were taken from surrogate species. No data available as indicated by a dash.

Species	Antimycin[a] (µg/L)	Rotenone 5% liquid[b] (µg/L)	TFM[c] (mg/L)	Bayluscide®[d] (mg/L)
Native species				
Loach minnow [Fathead minnow]	[0.21]	[142]	[1.7]	[0.1]
Spikedace	–	–	–	–
Roundtail chub[e]	–	–	–	–
Gila chub	–	–	–	–
Longfin dace [Northern redbelly dace]	[0.18]	–	–	–
Speckled dace [Northern redbelly dace]	[0.18]	–	–	–
Sonora sucker [White sucker]	–	[68]	[1.4]	[0.08]
Desert sucker [White sucker]	–	[68]	[1.4]	[0.08]
Razorback sucker [White sucker]	–	[68]	[1.4]	[0.08]
Gila topminnow	–	–	–	–
Desert pupfish	–	–	–	–
Nonnative species				
Red shiner	–	–	–	–
Common carp	0.35 (0.30-0.40)	50.0 (41.1-60.8)	1.25 (1.00-1.56)	0.139 (0.134-0.145)
Channel catfish	9.00 (7.30-11.6)	164 (138-196)	1.00 (0.803-1.25)	0.082 (0.077-0.088)
Flathead catfish [Channel catfish]	[9]	[164]	[1]	0.043 (0.040-0.046)
Black bullhead	45.0 (38.8-52.2)	389 (298-507)	0.85 (0.74-0.98)	0.088 (0.078-0.098)

Table 12-1. Continued

Species	**Antimycin[a] (µg/L)**	**Rotenone 5% liquid[b] (µg/L)**	**TFM[c] (mg/L)**	**Bayluscide®[d] (mg/L)**
Brown bullhead [Black bullhead]	[45]	[389]	[0.85]	0.056 (0.049-0.064)
Smallmouth bass	0.04 (0.03-0.05)	79.0 (70.7-88.2)	6.30 (5.63-7.04)	0.060 (0.048-0.074)
Largemouth bass	0.14 (0.09-0.20)	142 (115-176)	2.19 (1.82-2.63)	0.062 (0.050-0.076)
Green sunfish	0.20 (0.15-0.24)	141 (114-174)	3.33 (2.79-3.96)	0.100 (0.094-0.107)
Bluegill sunfish	0.14 (0.11-0.17)	141 (133-149)	6.23 (5.50-7.05)	0.094 (0.083-0.107)

[a] 98% active ingredient; data taken from Berger et al. (1969)

[b] 5% rotenone; data taken from Marking and Bills (1976)

[c] 96% active ingredient; data taken from Marking and Olson (1975)

[d] 99% active ingredient; data taken from Marking and Hogan (1967)

[e] The headwater chub (*Gila nigra*) was recently split from the roundtail chub.

Chapter 13. Integrating Piscicides into Management Strategies for Nonnative Fishes in the Southwestern United States

by Verdel K. Dawson and Cynthia S. Kolar

Integrated management offers a more effective and efficient means of controlling nonnative fishes than any single management technique. The application of piscicides is most effective when integrated with a carefully planned management program. Over the last 50 years or so, chemical treatments have been relied on as the foundation of pest management. However, it is generally acknowledged that chemicals have their limitations, and combining chemical treatments with other management tools in an integrated pest management program is often more effective. In some instances, this may involve complete eradication of fishes in certain reaches of streams followed by restocking. If the native species in the stream are classified as threatened or endangered, some fishes may have to be collected and moved to refugia until after treatment. Detoxification stations may be needed on some streams to prevent piscicides from affecting populations in downstream reaches (Lennon and Berger 1970, Dawson et al. 1976). In areas where the entire watershed cannot be treated, physical barriers may have to be constructed to prevent reinfestation of critical sections of streams. Intensive education programs should be developed to inform landowners and stream users of the importance of not reintroducing nonnative species into reclaimed watersheds. Legislation may have to be enacted to discourage transplantation and introduction of nonnative fishes (Clugston 1986). There are a number of other techniques for management of fish populations that should be evaluated for inclusion in an integrated management program. Some are used routinely, while a variety of others have merely been proposed (see Chapter 9 for examples). These new techniques are in the early stages of development and may not be of much help in the near future. However, if this next generation of techniques is not initially used in fishery management to replace the use of piscicides, surely some will routinely be used in future integrated management programs (Lamsa et al. 1980).

Invasive fish species are present in all watersheds in the southwestern United States (see Chapter 2), and there are a number of documented instances where they have been shown to be detrimental to populations of native species (Pacey and Marsh 1988, Marsh and Pacey, in press). Because of predation and competition for food and habitat, some of the invasions have resulted in severe reductions in numbers or even total loss of some native species (Minckley 1973, Rinne 1995). In those situations, timely action is needed to prevent further loss of native fish populations. Even though the control of nonnative fishes may be most desired in waters often visited by the public and where many native and nonnative fishes currently coexist, it may be advantageous to keep initial efforts small in scope regardless of the type of pest management strategies used. Small-scale initial control efforts allow for the tailoring of conventional treatment methods to localized conditions, training of field personnel, and for determining protocol changes necessary for larger areas or for more complicated situations. Ideal locations for initial management efforts would be waters with either isolated, localized populations of nonnative fishes, or those that are hydrologically isolated, such as ponds or small lakes without inlets or outlets. Alternatively, candidate control locations could be ponds or small lakes with barriers installed, headwater streams, or stream reaches bound by barriers, whether naturally occurring or human made. In all of these situations, the probability of recolonization by nonnative fishes is less than would be expected from more open systems. Low fish species richness would ease monitoring and control efforts, improve survivorship of native fishes by reducing handling time during chemical control, and may improve the chances of successful reclamation by reducing interspecific responses to control efforts. Candidate locations should also have relatively small surface areas to minimize labor costs and be easily accessible.

If only nonnative species are present in a particular reach of a stream, then treatment is a relatively simple matter. However, if critical or threatened and endangered native species are present, then as many of the native fishes as feasible should be temporarily removed by electroshocking or other capture techniques and placed in refugia until after detoxification (i.e., do not risk selective treatment in the vicinity of threatened or endangered species). If critical habitat or species are present downstream of the treatment area, then detoxifying stations should be established. As the block of chemical reaches the detoxifying site, potassium permanganate or activated carbon are metered into the stream in quantities sufficient to detoxify the chemical (Appendix F). Barriers may be required to prevent re-infestation of the reclaimed reach of the stream.

Chemical control is an important if not central part of integrated pest management of nonnative fishes. Because only four toxicants are currently registered for use as piscicides, and two of those are restricted-use to control sea lampreys in the Great Lakes basin (TFM and Bayluscide®), chemical choice is probably limited to antimycin (Fintrol®) or rotenone unless special local needs (Section 24c) permits are obtained. Although both of these chemicals are registered as general piscicides, both have been used in selective treatments to kill some fishes while leaving others unharmed (see Chapter 4.1). Therefore, an important decision in planning chemical control will be whether to treat generally, such that all fish are killed, or to treat selectively, to kill only undesired fishes. Given the native and nonnative species represented in the southwestern United States, it is unlikely that either antimycin or rotenone could be used successfully as selective toxicants. The effects of antimycin exposure are generally not reversible. Therefore, any fishes warranting protection must be moved to refugia prior to treatment and then released back into the waters from which they were removed following detoxification. Conversely, fish can recover from sublethal exposure to rotenone if promptly removed to fresh water. Therefore, after application of this chemical, native fishes warranting protection could be netted out of the treatment area when exhibiting distress, held for the remainder of the treatment and detoxification, and then released (Willis and Ling 2000).

There are some candidate piscicides that have been proposed for selective control of certain species. These include either Dibrom®-malathion or thanite for selective removal of green sunfish, Guthion® for selective removal of centrarchids and ictalurids, and GD-174 for selective removal of common carp. These chemicals may have application if native species could be shown to be more resistant than nonnative species and if the chemicals could be registered or used under experimental use or emergency use permits. Unfortunately, because of concerns about applying these chemicals in the water (i.e., Dibrom®-malathion and Guthion® are cholinesterase inhibitors, thanite releases cyanide in water solution, and GD-174 was effective in the laboratory but not in field trials), it would be highly unlikely that any of these chemicals could be registered for use as piscicides. A systematic search for selective piscicides may identify additional candidate chemicals, but the process would require substantial investment of time and money. Advancements and improvements in formulations and application methods of currently registered piscicides will continue to increase their utility. For instance, timed-release formulations of antimycin (this formulation not yet registered) and Bayluscide® have been developed for treating benthic or bottom-dwelling species. Fishes of these species could be selectively removed in the presence of more pelagic species if water depth is sufficient.

Any of the four registered piscicides could be used effectively as a general toxicant for complete removal of all fish from water bodies in the southwestern United States. Ictalurids (catfish and bullheads) are more tolerant to the effects of both antimycin and rotenone than other fishes, so either piscicide could be used to selectively remove other fish while not harming ictalurids (Table 12-1). To also remove ictalurids, chemical treatment concentrations would have to be elevated substantially (Table 12-1; Appendix F). Antimycin and rotenone are both currently registered as piscicides for use throughout the United States. Both chemicals can be readily detoxified (usually with potassium permanganate; Gilderhus et al. 1969). This could be important if populations of fish need to be protected in a downstream section of the stream being treated, and the treatment needs to be terminated before it reaches that section. Antimycin is more expensive per unit of chemical than rotenone, however, antimycin is more toxic so less chemical is required. This results in similar costs per treatment (Table 13-1). Fish can detect and are repelled by some formulations of rotenone (Dawson et al. 1998, Hogue 1999), which makes complete reclamations more difficult. A new liquid formulation of rotenone is currently being developed that does not contain the petroleum-based solvent suspected of causing avoidance reactions in fish. If the body of water to be treated is alkaline (high pH) then rotenone may be a better choice since antimycin is less effective at pHs above 8. Antimycin and rotenone are currently undergoing a reregistration review by the EPA. Data required for the reregistration of rotenone have been submitted to the EPA and the process for rotenone is nearing completion. However, the analytical methods to adequately detect and quantify antimycin and its metabolites at use-pattern levels are not currently available. Therefore, the EPA may allow only a limited and restricted use label, and require development of a specific standard operating procedures manual for antimycin use (Finlayson et al. 2002). To assure their protection, native species of concern would have to be captured and transferred to refugia before the treatment effort and be reintroduced after treatment operations were completed. An understanding of the toxicity of the registered piscicides to native fishes of concern would be required prior to attempting selective removal of nonnative species using chemicals. However, on the basis of the limited data available, none of the four chemicals demonstrate a margin of safety sufficient to permit selective removal of nonnative fish without harming native species (Table 12-1).

Table 13-1. Typical treatment concentrations and costs for the four registered piscicides antimycin, rotenone, TFM, and Bayluscide®.

Species	Antimycin (µg/L)	Rotenone (mg/L)	TFM (mg/L)	Bayluscide® (mg/L)
Typical treatment concentration range	1-10	0.025-0.25	1-10	0.025-0.25
Typical chemical costs ($/acre-ft)	$10-$100	$10-$100	$50-$500	$1.50-$15

The lampricides TFM and Bayluscide® could effectively remove ictalurids since both chemicals are more toxic to ictalurids than to most other fish species (Table 12-1). Because the lampricides are not currently registered for general use outside of the Great Lakes region, with the exception of Bayluscide® which is also registered for use in snail control, additional permits would be required (see Chapter 8) such as an emergency exemption or a special local needs permit. The safety margin, however, is too narrow for selective removal of ictalurids in habitats where multiple species exist. As an example, based on toxicological data reported by Boogaard et al. (2003) and approximate pH and total alkalinity estimates of the Gila River (pH 8.1, total alkalinity 230; USGS 2003), the predicted 12-hour LC_{50} for ictalurids with respect to TFM would range from 5.08 to 8.04 mg/L and would range from 8.52 to 12.5 mg/L for native minnows and suckers (based on common shiner and white sucker data). A treatment concentration of 8.04 mg/L would kill only half of the ictalurid population. Complete removal of ictalurids from the river would require a 12-hour TFM application at a concentration much higher than 8.04 mg/L and would likely have significant impact on native populations if their toxicity to TFM is comparable to the common shiner and white sucker. Similarly, the 96-h LC_{50} for Bayluscide® against channel catfish is 0.082 µg/L while that against minnows and suckers ranges from 0.08 to 0.1 µg/L (Table 12-1).

As a first step in a piscicidal treatment, the stream is surveyed and the section of stream and tributaries to be treated are identified. Then, federal and state permits are obtained. In some instances, an environmental impact statement is required. Trained and certified, licensed applicators are required to dispense the chemical. Availability of standard operating procedures for each piece of equipment and procedure must be documented. Advance notification of appropriate jurisdictional agencies, utilities, property owners, water users, media, and the general public are conducted. Water quality (pH, dissolved oxygen, temperature, etc.) assessments and on-site toxicity tests are conducted to help establish treatment concentrations and effective contact times (Klar and Schleen 2000). Antimycin and TFM are particularly sensitive to the effects of pH; both chemicals are less toxic in alkaline water. If there is a pronounced diurnal fluctuation in pH in a particular reach of a stream, the treatment may have to be conducted during the nighttime when pH levels are typically lower, to minimize the amount of chemical required for these pH-sensitive piscicides. Stream discharge and velocity estimates are determined. Dye dilution studies are useful for understanding flows and dilution patterns (Klar and Schleen 2000). Treatments during low discharge require less chemical, but extremely low discharge can result in poor mixing and incomplete coverage. The chemical (usually in liquid formulation) is metered into the stream at the upper reach inhabited by the target species. The application continues long enough so that the block of chemical is maintained at the desired concentration with a duration sufficient to achieve an effective contact time. Tributaries and all connected water in the stream should also be treated. Treatments generally are timed so the leading edges of the chemical blocks in the tributary and the main stem of the stream arrive at the confluence of the two at the same time. The concentration of the chemical in the stream is monitored so application rates can be adjusted and boost stations can be established as needed to correct for dilution and block spreading. The stream should be monitored post-treatment to assess effectiveness of the treatment and to dispose of mortalities.

While chemical control will undoubtedly be a primary tool for managing nonnative fishes, the most efficient programs will involve integrated pest management techniques. These could include, for example, the use of a variety of barriers to restrict range expansion of nonnative fishes and to prevent reinfestation after chemical reclamations. Water-level manipulation, netting, trapping, and electrofishing could be used to augment chemical controls. Attractants or repellents including the use of pheromones could be used to manipulate or concentrate populations of fish for more efficient removal. The integrated pest management techniques could also involve genetic manipulations to produce monosex populations of fish through gynogenesis (Stanley et al. 1975) or the use of daughterless technology (Carmody 2003, Stucky

2003). Immunocontraceptive agents have been proposed as a means of species-specific fertility control (Hinds and Pech 1997). The integrated pest management methods that have been suggested, but not yet fully developed or approved include the use of species-specific viruses (Crane and Eaton 1997), chromosomal manipulation, gender manipulation, and the introduction of inducible fatality genes by way of transgenic methods (Grewe 1997).