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Integrated Management Techniques to Control Nonnative Fishes

Completion Report
Interagency Agreement Number: 01-AA-32-0040

Prepared for

Bureau of Reclamation
P.O. Box 81169, Phoenix, Arizona 85069-1169

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December 2003

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Abstract

Many species of native fish from the southwestern United States, including those in the Gila River basin in Arizona and New Mexico, are critically imperiled in part because of the introduction and establishment of nonnative fishes. Effective methods for eradication and control of nonnative fishes are needed to rehabilitate the imperiled native fish fauna of the Gila River basin. The objective of this report is to assess the potential of applying techniques of integrated pest management to protect imperiled native fishes in the southwestern United States from invasive nonnative species. To accomplish this, reviews of pertinent literature were conducted in selected topic areas and the information presented in a series of chapters to document findings. Subject areas of the review included (1) life-history strategies for both native and nonnative species in those waters; (2) evaluation, identification, and characteristics of successful integrated pest management programs; (3) identification of potential and existing chemicals and appropriate chemical formulations for use as general and selective piscicides; and (4) procedures and costs associated with the discovery and development of new and perhaps taxon-specific piscicides. Characteristics of native fishes of concern were compared with those of nonnative fishes, and the geographic ranges of native and nonnative fishes were mapped to identify potentially vulnerable conditions around which control strategies could be developed. The concept of chemical receptors and receptor responses are presented to help explain the basis of selective toxicity. A total of 45 chemicals were identified that have either been used as piscicides, or are currently in various stages of development. A rating system was developed that evaluates the usefulness of these chemicals in resolving problems caused by nonnative fishes. Only five of the chemicals (antimycin, rotenone, TFM, Bayluscide®, and Squoxin) achieved ratings of 75 or greater out of a possible score of 100. Chemical reclamations have not always been successful as indicated by reviews of hundreds of fish control projects with reported successes ranging from 43% to 82%. It is unlikely that the present arsenal of approved selective piscicides would be effective for controlling nonnative fishes in the southwestern United States because the fish communities are different from most areas where selective piscicides are being used, and the currently registered taxon selective piscicides target sea lampreys. A comprehensive list of formulations and associated delivery systems for applying registered piscicides are presented. The development of new chemical tools for selectively managing fish populations may be facilitated by the knowledge of the mode of action of candidate piscicides and their structure-toxicity relationships. An evaluation of the costs and benefits of chemical treatments, as well as the cost associated with the development and registration of new piscicides, are provided. Reclamation of habitats that are critically imperiled by invasive fishes may need to be implemented using general piscicides such as antimycin or rotenone. This would require that important extant native species be temporarily moved to refugia until after the treatments. In less critical situations, efforts could be directed toward development of integrated pest management techniques that include development and use of barriers, water-level manipulations, targeted overharvest, stocking of predators, sterilants, toxic baits, selective piscicides, attractants and repellants, immuno-contraceptive agents, viruses, chromosomal manipulations, gynogenesis, and transgenics.

Key words: Arizona, control of nuisance fishes, Gila River basin, integrated pest management, nonnative fishes, reclamation, selective removal, southwestern United States, taxon-selective piscicides

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Chapter 1. Introduction

by Cynthia S. Kolar

The biodiversity of native fishes in Arizona, with approximately 30 native species recorded since the late 1800s (Minckley 1973, Rinne 1995), is low compared with the specious freshwater fish faunas of the eastern United States. High rates of endemism characterize fishes from the southwestern United States; specialization of form is the rule rather than the exception (Rinne 1995). In the Gila River basin, which drains approximately 212,380 km^2 in Arizona and New Mexico, 5 of 17 native fishes are the only species in their genus (Miller 1961, Rinne 1995). Fishes native to the southwestern United States typically are adapted to tolerate waters of high temperature or salinity. They are also habitat specialists in areas such as thermal springs or highly erosive streams, but have evolved generalizations that promote resistance to extinction (Minckley and Meffe 1987).

While habitat specialization has enabled these fishes to persist in habitats few other species can withstand, it has also left them vulnerable to habitat alterations and invasive species. As the human population has grown throughout the region and demand for water has intensified, aquatic ecosystems have been greatly altered. Numerous dams and intensive livestock grazing practices have changed water temperatures and flow regimes, usually reducing habitat quality for native fishes (Rinne and Minckley 1991). Fish introductions, mostly for sport and food, but also from aquaculture, aquarium releases, additional forage, and for biological control have also been common in the southwestern United States (Rinne 1995). The number of fish species established in Arizona has almost tripled since the beginning of the 20th century as a result of the introduction of nonnative fishes (Rinne 1991). Many of these introduced fishes are better adapted to the highly altered systems now found in the southwestern United States than are native species (Rinne and Minckley 1991). As a result, native fishes of the southwestern United States are becoming increasingly imperiled.

Of the approximately 20 fishes native to the Gila River basin, the largest watershed in Arizona, around 70% are federally listed as endangered or threatened (Rinne 2003), and one is extinct. The plight of native fishes in this basin is typical of most basins in the southwestern United States. The inherent rarity of fishes native to the southwestern United States is exacerbated by factors such as habitat alteration and the introduction of nonnative fishes (Minckley and Meffe 1987). Along with habitat alteration and destruction, competition with and predation by nonnative fishes have been identified as the driving forces for the imperilment of many of the native fishes of concern in the Gila River basin (Table 1-1). Twelve of these native species and twelve nonnative species have been identified as those of most concern in discussions with Bureau of Reclamation personnel and literature sources (Table 1-2). In some instances, self-sustaining populations of native fishes appear to be unable to persist in habitats where nonnative fishes have become established (Marsh and Pacey, in press). For example, in areas where the introduced red shiner (scientific names of fishes used in this report are found in Appendix A) are

Table 1-1. Population status and summary of primary threats for native fishes of concern in the Gila River basin. Scientific names are given in Appendix A. SOC = U.S. Fish and Wildlife Species of Concern.

Common name	Status	Primary threats
Desert sucker	SOC (1)	Stream flow depletion, diversion, and introduction of nonnative species; competition by red shiner (1).
Sonora sucker	SOC (1)	Stream flow depletion, diversion, and introduction of nonnative species (1); predation by nonnative species, especially flathead catfish (2).
Spikedace	Threatened 1986 (2)	Stream flow depletion, diversion, habitat alterations, competition and predation by nonnative species, especially crayfish and red shiner (2). As of 1997, Arizona populations limited to Aravaipa Creek and upper Verde River (1).
Razorback sucker	Endangered 1991 (2)	Altered flow hydrology, cool tailwater discharge from reservoirs, diversion, predation by and competition with nonnatives. Wild populations extirpated (3). Habitat loss (e.g., flooded bottomlands), degradation, and fragmentation. Predation by nonnative red shiner, ictalurids, and centrarchids (1).
Loach minnow	Threatened 1986 (2)	Dewatering of stream reaches, impoundment, livestock grazing, habitat alteration, and introduction of nonnative fish, predation by piscivorous species, such as flathead and channel catfishes, bullheads, and red shiner (2). Sedimentation and embedding of riffle habitats, diversion, and channelization. Competition by introduced nonnative species, such as *Micropterus* spp. (1)
Longfin dace	SOC (1)	Stream flow depletion, diversion, invasion of nonnative fishes. Considered to be the most successful and highly adaptable native cyprinid in the desert Southwest (1).
Gila chub	SOC (1), proposed as endangered (3)	Stream flow depletion, diversion, competition and predation by introduced nonnatives, especially crayfish and largemouth bass. Extirpated from New Mexico (2). Dewatering of spring habitats by arroyo cutting. Present in less than 20 streams in central and southern Arizona (1).
Desert pupfish	Endangered 1986 (2)	Spring habitat alterations, drought, predation by and competition with nonnative fishes. No natural populations remain in Arizona (2). Reintroduced in 1983 into four areas (1).
Speckled dace	SOC (1)	Introduction of nonnative predatory fishes. Widespread and abundant and not in danger of extinction (2).
Gila topminnow	Endangered 1967 (1)	Spring habitat development, aquifer pumping, habitat destruction, drought. Predation by and competition with nonnative fishes (2). Predation by introduced mosquitofish (1).
Roundtail chub (4)	SOC (1), petitioned for federally endangered (3)	Aquifer pumping, stream diversion, reduction in stream flow. Predation by and competition with nonnative fishes. Habitat destruction and parasites (1). Several mainstem river populations extirpated (3)

(1) Biota Information System of New Mexico (2000) (2) Arizona Game and Fish (2001) (3) Desert Fishes Team (2003) (4) Headwater chub *Gila nigra* is a recently described species that was split from the roundtail chub

Table 1-2. Native and nonnative fishes considered in this report to be species of concern in the Gila River basin.

Order	Family	Common name	Scientific name
		Native species	
Cypriniformes	Cyprinidae	Loach minnow	*Tiaroga cobitis*
		Spikedace	*Meda fulgida*
		Roundtail chub	*Gila robusta*
		Headwater chub	*G. nigra*
		Gila chub	*G. intermedia*
		Longfin dace	*Agosia chrysogaster*
		Speckled dace	*Rhinichthys osculus*
	Catostomidae	Sonora sucker	*Catostomus insignis*
		Desert sucker	*C. clarki*
		Razorback sucker	*Xyrauchen texanus*
Cyprinodontiformes	Poeciliidae	Gila topminnow	*Poeciliopsis occidentalis*
	Cyprinodontidae	Desert pupfish	*Cyprinodon macularius*
		Nonnative species	
Cypriniformes	Cyprinidae	Red shiner	*Cyprinella lutrensis*
		Common carp	*Cyprinus carpio*
Siluriformes	Ictaluridae	Channel catfish	*Ictalurus punctatus*
		Flathead catfish	*Pylodictis olivaris*
		Black bullhead	*Ameiurus melas*
		Yellow bullhead	*A. natalis*
Perciformes	Centrarchidae	Smallmouth bass	*Micropterus dolomieu*
		Largemouth bass	*M. salmoides*
		Green sunfish	*Lepomis cyanellus*
		Bluegill	*L. macrochirus*
		Redear sunfish	*L. microlophus*
Cyprinodontiformes	Poeciliidae	Mosquitofish	*Gambusia affinis*

found in Arizona, two native federally threatened species—spikedace and loach minnow—are absent (Minckley 1973). Spikedace and loach minnow have also been replaced by introduced fishes such as channel catfish and flathead catfish in some Arizona rivers (Rinne 1995).

To be successful, Rinne (1995) suggests that conservation of the native fishes in the southwestern United States requires that biologists be innovative and vigilant and should include research on the interactions of native and nonnative fishes. Restrictions on the importation of nonnative fishes, incorporation of a value system for native fishes, and a focus on the conservation and restoration of habitats for native species would also be required (Rinne 1995). Where historically inhabited waters are no longer suitable for native species because they are occupied by nonnative fishes, successful conservation of native fishes may rely on the removal or substantial reduction of nonnative fishes.

Effective treatments for the eradication and control of nonnative fishes include chemical renovation of stream reaches (usually in concert with installation of physical fish barriers), followed by the stocking of desired species (Rinne and Turner 1991), or application of species-specific piscicides in rare situations. Application of a species-specific piscicide is an intuitively appealing approach for controlling nonnative fishes, but has not been practiced in the southwestern United States because such piscicides are not available for the nonnative species of concern in the region. Chemical renovation is expensive, logistically difficult, usually more effective in smaller headwater areas, and usually requires retreatment for success. Other strategies (e.g., selective harvest, regulatory control) are generally not effective in controlling fishes. Thus, effective management of nuisance nonnative fishes in the southwestern United States, as well as in other ecosystems, probably will need to integrate various methods of control into one management program. For example, the use of piscicides combined with other innovative approaches—such as the use of sterilants, attractants or repellants, or reproductive inhibitors—that are used in an integrated manner to manage against nonnative fishes may improve the probability of successful renovation of streams and rivers in the southwestern United States. In addition, natural events such as flooding or fires that remove nonnative fishes could be exploited. The chapters in this report address the nonnative fish ecology, distributions, and their impacts on native fishes in the southwestern United States and provide background information on how similar situations have been and are being handled in other locations. They also provide methods and insights for developing new management tools and suggestions for programs involving integrated pest management.

Kolar et al. (Chapter 2) describe the biological and ecological characteristics of fishes found in the Gila River basin. Characteristics of each life stage, habitat preferences, and physicochemical tolerances of native fishes of concern are compared with those of nonnative fishes to identify potential conditions around which control strategies might be developed.

Gingerich and Stehly (Chapter 3) discuss piscicides with an introduction to the science of toxicology and the scientific basis for selective toxicity. This is followed by a brief overview of what makes toxicants selective to particular species including species differences in biochemistry and differences among species in their ability to process toxicants. The concept of using physiologically based pharmacokinetic models is discussed in the context of developing and screening selective fish toxicants.

Dawson (Chapter 4) provides a comprehensive literature review to identify currently registered and potential, but unregistered, general and taxon-specific piscicides. Each chemical is rated on its potential for use as a piscicide based on selectivity for target species, ease of application, safety to humans, rate of degradation to nontoxic materials, cost, and its persistence in animals, plants, or the physical environment.

Dawson (Chapter 5) reviews some of the past successes and failures of using piscicides to remove undesirable fishes. The review provides some insight concerning the potential for successful piscicide treatments and ways to avoid certain problems. Based on the high percentage of failed treatments, there is an apparent need for improving piscicides, formulations, and methods of application. Also, suggestions are provided for using piscicides in conjunction with a variety of integrated pest management techniques.

Boogaard (Chapter 6) highlights current formulations of piscicides and the techniques and equipment used to deliver them to the aquatic environment. He lists active and inert ingredients and manufacturers of each formulation of piscicide currently registered by the U.S. Environmental Protection Agency (EPA). Factors to consider when choosing a delivery system for a chemical treatment are provided.

Gingerich (Chapter 7) identifies newly discovered chemicals that may prove useful as candidates for future development as piscicides. He describes identified chemical inhibitors of energy production and proposes through structure-activity relationships how these classes of compounds may provide candidates for new piscicides in the future. Suggestions are provided for development of specific combinations of currently registered piscicides to provide selective toxicity between target and nontarget fishes of concern.

Hubert (Chapter 8) presents the process of piscicide development from start to finish. This includes screening or developing chemicals, testing and refining procedures, identifying possible development laboratories, describing environmental regulatory constraints and procedures, and estimating time and cost for research, development, and production.

Hubert and Dawson (Chapter 9) discuss the development of a focused integrated pest management strategy. They describe the types and forms of integrated pest management systems needed to achieve pest control goals. Integrated pest management systems include chemical, biological, and physical controls. Examples are provided of integrated pest management systems that are currently in use and in various stages of development.

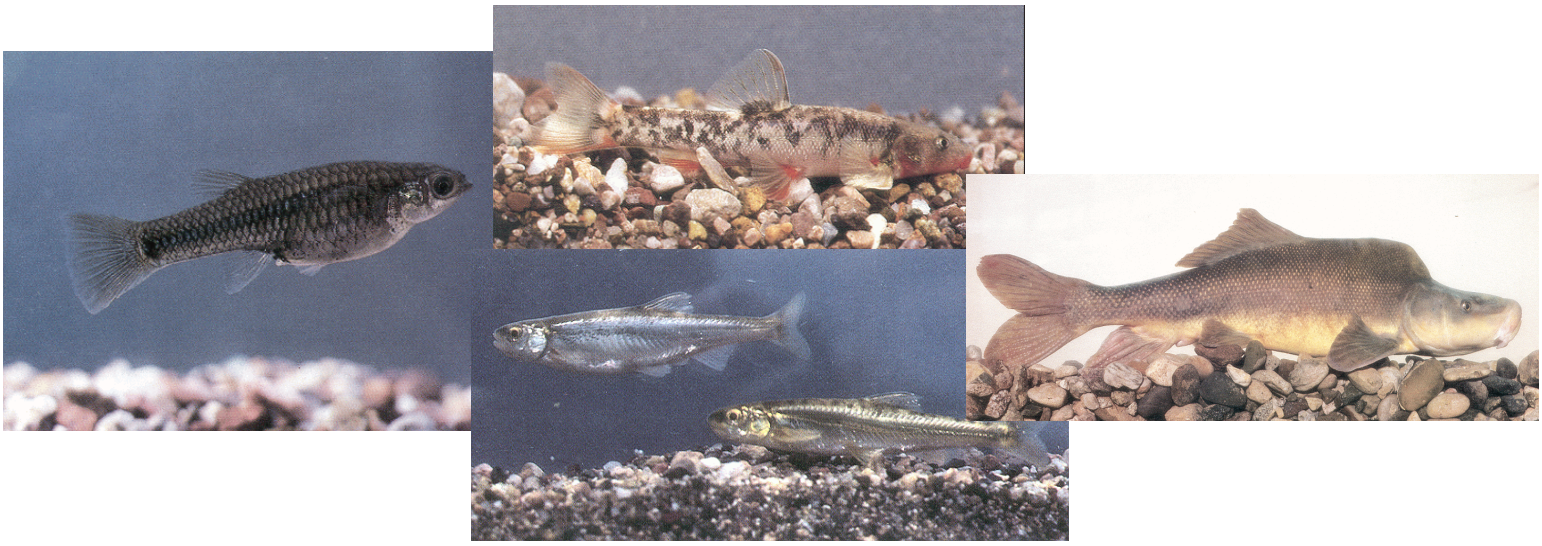
Hubert (Chapter 10) analyzes the costs and benefits associated with development of a pest control program. Included is an assessment of the costs and time involved in registering a piscicide with the EPA. An analysis of factors contributing to the cost of piscicide treatments is balanced against the benefits to recreational and commercial fishing and the ecosystem.

Kolar et al. (Chapter 11) discuss a case study of a successful fish control program. This includes the life history of the target organism, selection and development of piscicides, formulations, and application methods, and development of an integrated pest management program.

Dawson (Chapter 12) evaluates the feasibility of developing taxon-specific piscicides for management of nonnative fishes in the southwestern United States. Difficulties associated with management of selected taxa are discussed along with suggestions for using currently registered toxicants for urgently needed reclamations while developing new integrated management tools and incorporating them into future management programs.

Dawson and Kolar (Chapter 13) describe integrated pest management scenarios that generally involve use of chemicals in combination with other management techniques. Comparative toxicities of registered piscicides to native and nonnative fishes of concern are provided. Also provided are suggested treatment concentrations and costs for each piscicide.

Dawson (Chapter 14) provides a summary of topics that are included in this report on integrated management techniques to control nonnative fishes. Recommendations as to whether or not to proceed with development of piscicides or an integrated management program for nonnative fishes in the southwestern United States are discussed.



Chapter 2. Distribution and Ecological Characteristics of Native and Nonnative Fishes of Concern in the Gila River Basin

by Cynthia S. Kolar, Michelle R. Bartsch, John E. Kalas, and Brent C. Knights

Evidence shows that the imperilment of native fishes of concern in the Gila River basin results, in large part, from direct and indirect negative interactions with nonnative fishes (Table 1-1). Successful conservation of these fishes depends on (1) habitat protection and restoration, (2) greater knowledge of the interactions between native and nonnative fishes (Rinne 1991, Rinne 2003), (3) preventing the further introduction and spread of nonnative fishes, and (4) the control and removal of nonnative fishes from some waters.

Before developing control strategies for nonnative fishes in the Gila River basin, it is important to closely examine their biology and distribution. A thorough understanding of the biology and distribution of nonnative species may identify life stages, habitats, and geographic locations where control could be most effective. Likewise, a thorough understanding of the biology and distribution of native species of concern would allow for the development of control strategies that maximizes the probability of reducing or removing nonnative species while minimizing impacts to native species of concern.

Information on the life-history characteristics and physicochemical tolerances of these species were collected and summarized. Life-history information on native and nonnative fishes was compiled from selected literature and summarized in a referenced format (Appendix B). Species-specific information on habitat preferences, biology, and physicochemical tolerances are presented by life stage. Data on the history of invasion, threatened and endangered status, and the degree to which the species is used by humans were also collected for each species (see Table 2-1 for description of characteristics). Life-history data were collected from a variety of sources, including pertinent primary and gray literature, Web sites, and expert opinion. See Pacey and Marsh (1998) for life-history information of nonnative fishes of the Lower Colorado River, which also includes several species in the Gila River basin. Life-history characteristics and tolerances of native fishes of concern were statistically compared with those of nonnative fishes of concern by one-factor analysis of variance. Data used in these analyses can be found in Tables B-13 and B-14 of Appendix B.

Table 2-1. Explanation of the species characteristics collected for each native and nonnative fish of concern in Arizona and results of one-way analysis of variances comparing these characteristics. Data used to conduct analyses found in Tables B-13 and B-14 of Appendix B. Bold indicates variables for which substantial amounts of data were lacking. N = native species; NN = nonnative species; * = $P \leq 0.05$; ** = $P \leq 0.01$.

Characteristics	Variable	How species characteristic was evaluated (units)	*P*	Direction
Human use	Categorical	Human uses of fishes were ranked by economic benefit and ranks of all uses for each species were summed [Kolar and Lodge 2002].	**	N<NN
Introduction history	Yes/no	Whether the species has a history of introduction [Froese and Pauly 2002].	**	N<NN
Past invasiveness	Yes/no	Whether the species has a history of spreading greatly beyond the site of introduction [Froese and Pauly 2002].	**	N<NN
Family	Rank	Ranking of fish families from the most ancestral to the most derived [Moyle and Cech, Jr. 2000].	*	N<NN
Habitat type	Categorical	Whether the species lives in lotic or lotic and lentic environments.	**	N<NN
Mature length	Continuous	Average length (cm) at sexual maturity.	0.36	
Mature age	Continuous	Average age (year) at sexual maturity.	0.12	
Longevity	Continuous	Average life span (year).	0.87	
Diet items	Categorical	Diet breadth and diversity of foraging habitats [Kolar and Lodge 2002].	0.88	
High temperature	Continuous	Maximum lethal temperature (ºC) threshold.	*	N<NN
Egg diameter	**Continuous**	**Average diameter (mm) of mature ova.**	**0.26**	
Incubation	**Continuous**	**Average length of time (days) from spawning of eggs until hatching.**	**0.23**	
Fecundity	**Continuous**	**Average number of eggs produced by a mature female per year.**	*	**N<NN**
Larval length	**Continuous**	**Average length (mm) of newly hatched larva.**	**0.76**	
Spawning seasons	Rank	Number of seasons (1-4) during which the species spawns in Arizona.	**	N>NN
Parental care	Categorical	Ranked by amount of parental care provided to young [Kolar and Lodge 2002].	*	N<NN

The analyses highlighted the important differences between the native and nonnative fishes of concern in Arizona in terms of developing control strategies for nonnative fishes (see Table 2-1): most of the nonnative fishes of concern were purposefully stocked because they had a successful history of being stocked elsewhere (history of introduction; $F_{1,20} = 45.00$, $P < 0.0001$) and were perceived as being useful either for sport, forage, or biological control (human use, $F_{1,20} = 42.61$, $P < 0.0001$). Nonnative fishes of concern in the Gila River basin also have a history of being invasive elsewhere whereas native fishes do not (past invasiveness; $F_{1,20} = 12.00$, $P = 0.03$). In addition, the nonnative species selected for stocking (i.e., catfishes and sunfishes), tended to be from more phylogenetically advanced families than native species (family; $F_{1,20} = 5.74$, $P = 0.03$). When compared with nonnative species, native species were more confined to flowing lotic habitats (habitat type; $F_{1,20} = 26.67$, $P < 0.0001$), had lower maximum temperature thresholds (high temperature; $F_{1,19} = 5.42$, $P = 0.03$), lower fecundity (fecundity; $F_{1,20} = 4.5$, $P = 0.05$) and provided their progeny with less care (parental care; $F_{1,20} = 5.82$, $P = 0.03$). Pacey and Marsh (1998) and Marsh and Pacey (in press) also found that nonnative fishes of the Lower Colorado River provided more care to their young than native fishes in that ecosystem. Native fishes tended to use more seasons throughout the year to spawn, whereas nonnative fishes had shorter and more defined spawning periods (spawning seasons; $F_{1,20} = 6.81$, $P = 0.02$). In addition to the ecological characteristics we reviewed here, native and nonnative fishes in the southwestern United States differ in that maintenance of natural flow regimes is key to the sustainability of native fishes, although it is not required for nonnative fishes (Rinne et al., in press).

This comparison of species characteristics between native and nonnative fishes provides some insight into developing control strategies for nonnative fishes in the Gila River basin. Some habitats (i.e., lentic areas and areas with temperatures too high for native species) may be more appropriate for control measures because of differential selection between native and nonnative fishes. Similarly, control measures may be more effectively applied at particular life stages because of differential vulnerabilities (e.g., prolonged period of parental care by nonnative fishes as compared with native fishes). Although prolonged spawning periods by native species suggest that a control program for nonnative species may also affect the most vulnerable life stage (young of year) of native species, it also suggests that native fishes may have the opportunity to successfully spawn after a control event. In addition to using ecological differences between native and nonnative fishes to more effectively reduce or eliminate nonnative fishes, knowing the distribution of each species could also be used to selectively control nonnative species.

Information on the distribution of native and nonnative fishes in the Gila River basin can be used to identify areas inhabited solely by native or nonnative species, or to identify key intersections between these groups. The Arizona State University Lower Colorado basin geographic information system fish summary database (http://www.peter.unmack.net/gis/fish/colorado) was used to determine the distribution of native and nonnative fishes. This database included data through 2001 for native and nonnative fishes and summarized species occurrence by major and minor drainages. The sources for the database included museum specimens, primary and gray literature, and the Arizona Game and Fish Department Nongame Branch database.

This database revealed several patterns of distribution between native and nonnative fishes of concern. Most areas within the Lower Colorado River basin where native fishes still exist without nonnative fishes occur in the Gila River basin (Figure 2-1). In addition, virtually all of the Colorado River and many of the tributaries of the Gila River had native and nonnative fishes. While this coarse scale of range overlap between native and nonnative species can indicate general patterns in distribution, the overlap of particular species within reaches will be important

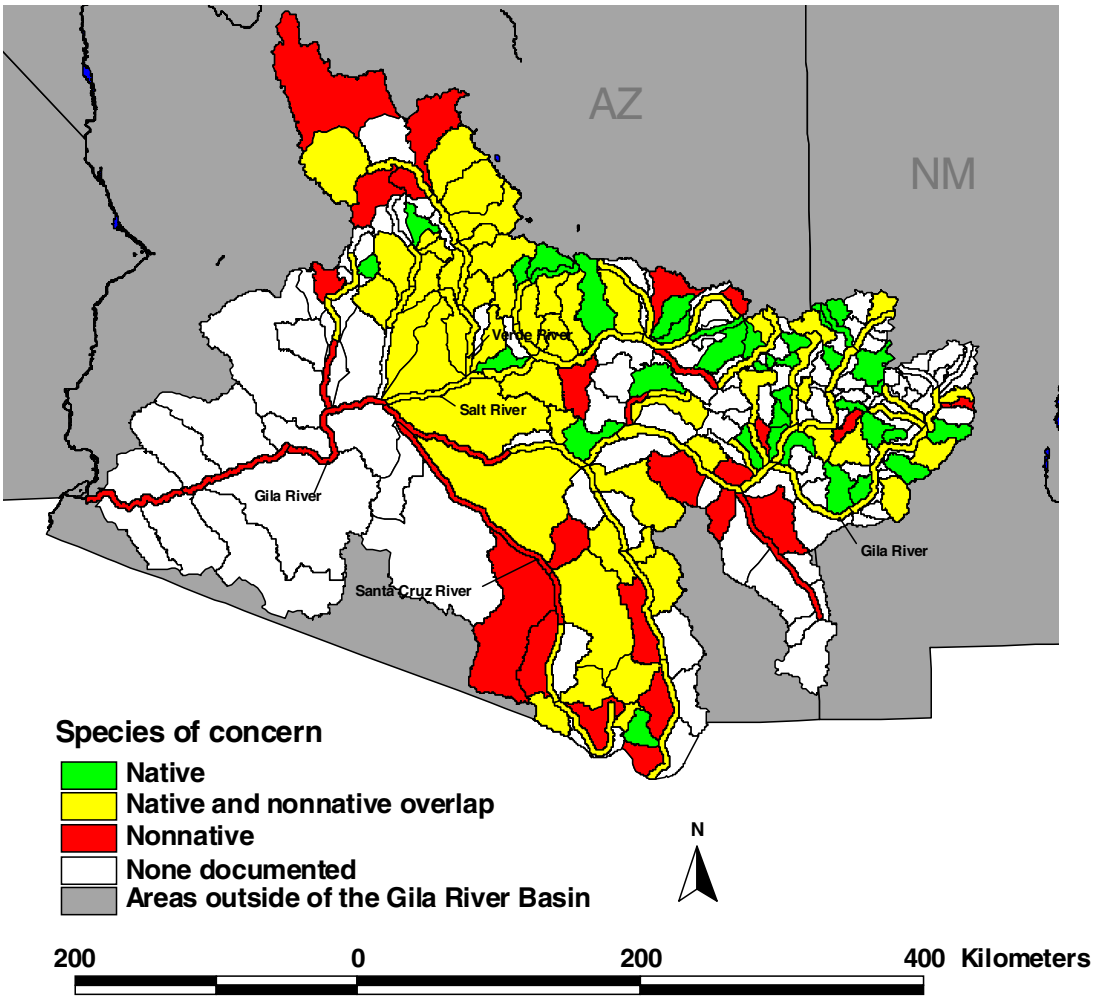


Figure 2-1. Map depicting the distribution of native and nonnative fishes of concern in the Gila River basin using records current through 2001 (Table 2-1).

in developing a control program for nonnative fishes. Examining the overlap of particular native and nonnative species indicates the scope of the problem nonnative fishes pose for imperiled native species and can serve as a starting point for risk assessment. For example, the complete spatial overlap between the native Gila topminnow and the nonnative mosquitofish (Figure 2-2) combined with the knowledge that the mosquitofish is a key threat to the Gila topminnow (Schoenherr 1977) suggests a critical need to implement conservation measures.

While data on life-history characteristics, environmental tolerances, and distribution of native and nonnative fishes do not provide a solution to controlling nuisance fishes, they could, when used as a means to focus control measures (such as the use of chemicals), be used to identify critical life stages, habitats, or geographic areas that might be most appropriate for control.

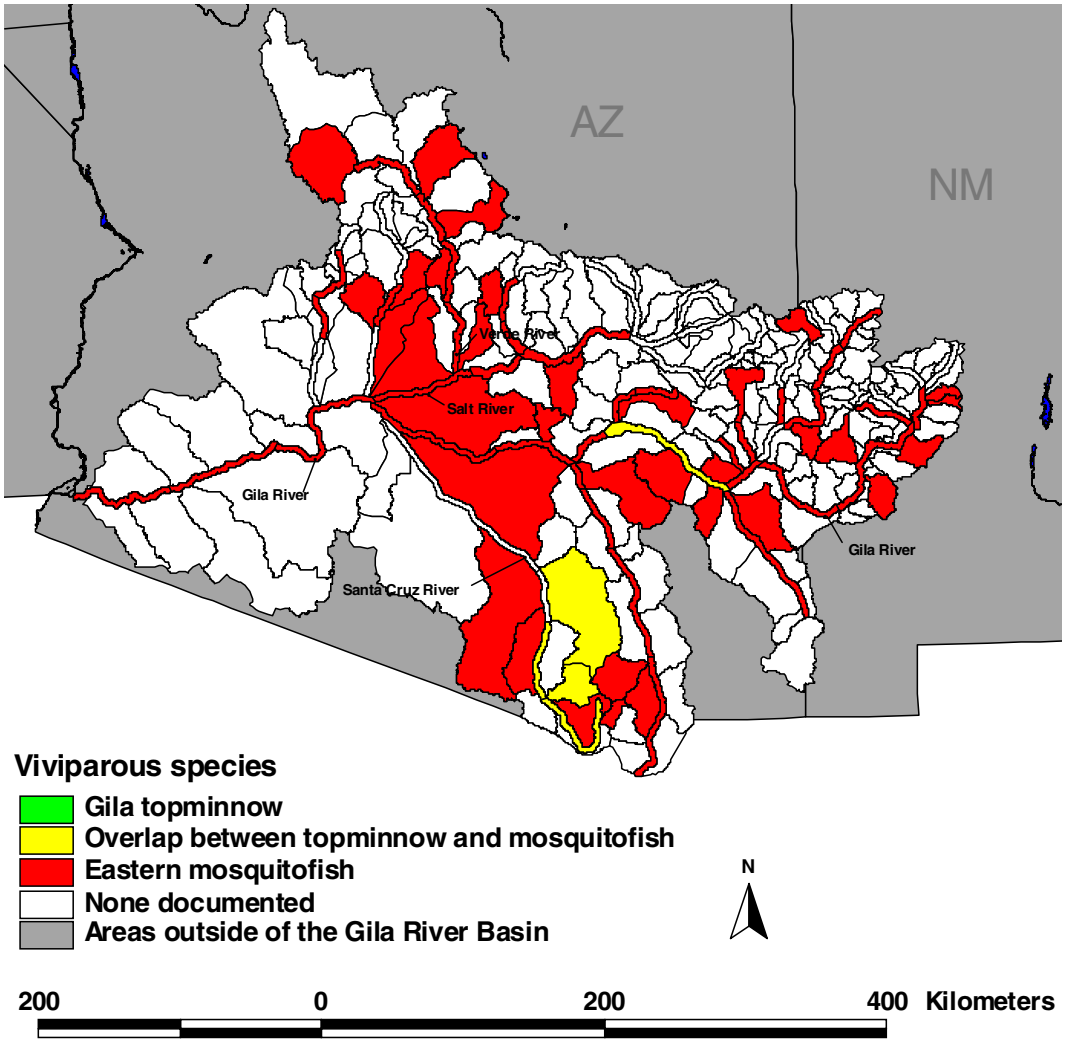
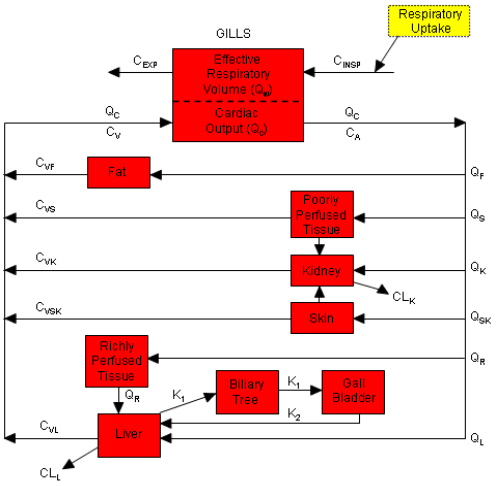


Figure 2-2. Map depicting the complete spatial overlap of the native Gila topminnow and the nonnative mosquitofish.

Chapter 3. General Considerations for Understanding the Actions of Selective Toxicants

by William H. Gingerich and Guy R. Stehly



Today there are literally millions of known chemicals; their origin being either synthetic or natural. The Chemical Abstract Service Registry contains records for more than 21 million organic and inorganic substances with about 4,000 new chemical structures being added daily (http://www.cas.org/casdb.html). In contrast, the Registry of Toxic Effects of Chemical Substances listed 139,704 entries of chemicals with known toxic properties, less than one half of one percent of all known chemicals (http://www.cdc.gov/niosh/97-119.html). Of those chemicals, only a small subset are used specifically because they are toxic to living things. These chemicals find applications as pesticides, herbicides, parasiticides, microbicides, fungicides, and antibiologicals including antimicrobials and chemotherapeutic agents. In the broadest sense, these commercially applied chemicals have been developed specifically because of their toxic properties to some living system. Some chemicals demonstrate modest selective toxicity between closely related organisms. In general, selectivity is most commonly observed between phylogenetically divergent organisms. It is more common to find selective chemical toxicity between plants and animals, or between animals and microorganisms than it is to find selectivity among closely related animals, such as a mouse and a rat (Albert l985). However, there are examples of selective toxicity between closely related organisms. As examples, males and females of the same species are differentially sensitive to some drugs, and there are differences in some drug sensitivities between human races (Lennard 1993). The specific factors that confer selective toxicity between different animal species are only now becoming understood.

In this chapter, the concept of receptors and receptor responses will be presented followed by several general causal mechanisms that help explain the basis of selective toxicity. The chapter provides an overview of the potential usefulness of models of drug kinetics in animals and the potential usefulness of pharmacokinetic models of toxicants including physiologically based pharmacokinetic (PBPK) models to serve as screening tools to identify selective piscicides.

3.1 Receptors and Drug/toxicant Action in Organisms

The principles and general concepts of toxicology are founded in the understanding of drug actions on biological systems that have been developed for pharmacology, the science of drug action on biological systems. Indeed, toxicology is still considered a subset of the overarching science of pharmacology, and, therefore, the concept of drug and toxicant effects are closely aligned. Most drugs are designed to facilitate a particular function within an organism and may act to either speed up or slow down a process or make more or less of a critical reactant in a biochemical pathway. Given in excess, drugs can produce unwanted effects that can be toxic.

Toxic agents produce effects to the extreme such that the survival of the organism is jeopardized. However, given in lower doses, even toxic agents can produce beneficial effects.

An example is the now routine cosmetic use of the potent nerve poison botulinum toxin, Botox, to reduce some of the effects of aging. At the extreme end of the toxic spectrum of chemicals are those intentionally applied biological poisons, i.e., pesticides that are used to kill a specific group of target organisms. The key to understanding how toxicants may be selective is derived largely from an appreciation of the interaction of toxicants with specific biological elements called receptors.

The biological effects of chemical exposure are considered to be mediated by the interaction of the chemical with specific endogenous biological components termed receptors. This interaction serves as the basis for discussing selective toxicant design and structure-activity relationships of toxicants.

Operationally, a receptor may be defined as a macromolecular element of an organism, which when combined with a complementary endogenous chemical agent (ligand), acts to control, regulate, or otherwise enable critical biological functions in the organism (Ross 1995). Interactions of the chemical ligand with the receptor generally involves most known types of chemical bindings including covalent, ionic, and hydrogen bonding, as well as van der Waals and hydrophobic interactions (Ross 1995). Receptors currently are considered to function in two ways. First, the receptor defines a binding domain or specific three-dimensional configuration that sterically accommodates a variety of complementary ligands of roughly similar physicochemical properties. Second, the receptor-ligand complex results in a defined array of subsequent effects, in essence an effector domain, that results in a particular biological effect or constellation of effects (Ross 1995). The biological consequences resulting from the receptor-ligand interaction may vary from tissue to tissue within the organism. By this model, it has been possible to explain the observable diversity of structure-activity relationships in living organisms by two means. First, it allows for the possibility that a number of diverse receptors and diverse ligands can interact to produce binding complexes that result in effects by similar or common biochemical pathways. Second, the model allows for the possibility that a single chemical ligand can bind to a variety of structurally unrelated receptors to produce a variety of resultant binding complexes that act to produce a different effect by independent and unrelated mechanisms (Ross 1995). This is a critical concept in considering mechanisms of selective toxicity since biochemical diversity may form the basis of some selectivity to organisms.

The majority of receptors are proteins. Examples of receptor macromolecules are those for endogenous chemicals, such as hormones, growth factors, neurotransmitters, and a variety of enzymes that regulate metabolic, regulatory, or neuronal functions (Ross 1995). The effects of exogenous chemical ligands on the receptor-ligand effector domain can be either to enhance or impair the normal endogenous chemical/receptor interactions. Chemicals that mimic or enhance the effects of endogenous chemical agents are termed agonists; those that retard or block an effect are termed antagonists. The agonistic action of many pharmaceuticals is to supplement or support an existing biological ligand that has been reduced or degraded by pathological processes, genetic deficiencies, or aging. Conversely, the antagonistic actions of many chemical toxicants are to inhibit, either reversibly or irreversibly, biological processes important to support critical life functions. Clearer understandings of receptor structure and function have formed the basis for new drug discovery through structure-activity relationships between the receptor and agonistic or antagonistic ligands (Kuntz 1992) and will serve in this report as a science-based tool to identify new potential candidate piscicides.

3.2 Basis for Selective Toxicants

Concerning the discovery and development of taxon selective piscicides, it is unlikely that purely physicochemical differences in primary receptors are sufficiently great among

phylogenetic classes of fish to account for the perceived differences in toxicity that are known for piscicides. It is more likely that the selectivity is the product of both differences in the expression of biochemical response to toxicants between species and differences between species in the rates and routes by which sensitive receptor sites are occupied by the toxicant. A generalized overview follows of several factors thought to contribute to the basis for selectivity of toxicants to different species—comparative biochemistry and comparative toxicant distribution.

Comparative Biochemistry

Most organisms persist in their environments by taking in food, converting that food to energy and using the derived energy to perform basic life tasks, such as mobility, growth, and reproduction. These processes are facilitated by a number of basic biochemical pathways and are regulated by the action of critical branch point enzymes that act to limit flow of substrates down individual key pathways. While most of the biochemical pathways are similar among organisms and their functions highly conserved, individual groups of organisms may use one pathway over another because of unique life-history requirements. In general, the greater the phylogenetic difference between the organisms, the greater the difference in the use pattern and integration of the particular pathways. Differences in the expression of these pathways may lead to the basis of selectivity. Selectivity may be achieved by using a specific inhibitor ligand to block one vital biochemical pathway used exclusively by a particular animal group.

Poikilothermic organisms must adapt to a diverse variety of abiotic factors if they are to persist. For temperate freshwater animals, accommodation to changing temperatures presents an important challenge. Freshwater fish in temperate to subarctic latitudes have evolved a number of molecular mechanisms to compensate to changes in temperature to maintain relatively normal physiological processes in the face of rising or falling temperatures (Hochachka and Somero 1971, Hazel and Prosser 1974). Differences in the strategies taken by individual groups of poikilotherms to adapt to fluctuating abiotic factors, either seasonally or in specialized areas, characterized by rapidly fluctuating physical environments may make one group more susceptible than another to a toxicant at a particular critical time. These different adaption strategies, then, may serve as the basis for a species selective treatment with a toxicant.

Comparative Toxicant Distribution

A unifying principle in quantifying the response of an animal to an exogenous chemical is that the responses are generally based on the concentration of the chemical delivered to the appropriate receptor(s) and the time it takes for a critical number of receptors to form a receptor-ligand complex. Differences in the degree of physical access of the chemical to common receptors between different organisms can be a powerful determinant of selective toxicity. A model depicting factors that affect delivery of a chemical ligand to cellular receptors is presented in Figure 3-1. A mathematical representation of the model could be made as a series of differential equations of the change between free and bound drug concentration available in each of the several levels of biological organization over time. The rates of change are dependent both on the concentration of free chemical in the system and the tenacity with which the drug is bound to storage or binding ligands that are not the drug receptor.

Figure 3-1 shows that the important factor in eliciting a response is the number of ligand-receptor complexes formed. In many instances, the ligand is loosely bound to the receptor and is free to disassociate. Therefore, the concentration of free ligand that remains in the immediate vicinity of the receptor population is a factor in determining the magnitude and length of the drug response. For the free ligand to reach sufficiently high concentrations at the receptor site, a

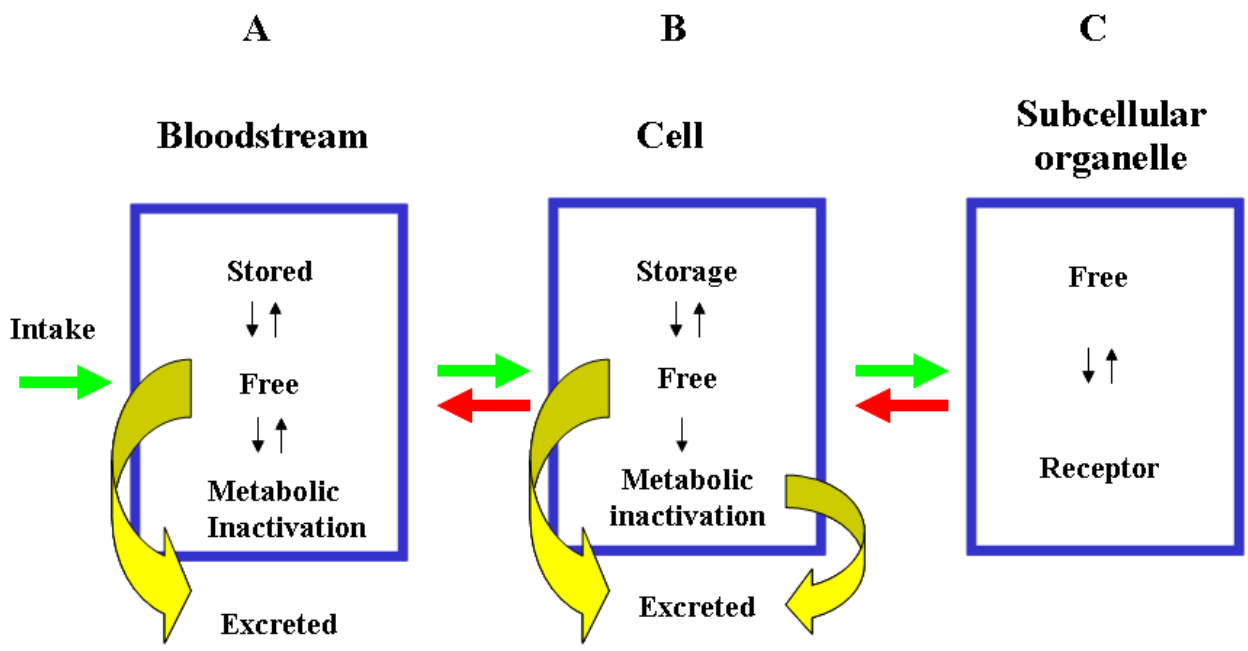


Figure 3-1. Some of the physicochemical factors that control the transport of a chemical ligand to a receptor. Opposing arrows suggest equilibrium conditions between and among different physiological spaces (*boxes*) while the equal sizes of the arrows denote similar rates of transfer into and out of each space. Spaces are separated by membranes. Diffusion across the membranes may be by simple diffusion driven by differences in the concentration gradient of the chemical ligand on either side of the membrane, facilitated diffusion that requires a transporter molecule to assist the ligand across the membrane but does not require energy, or active diffusion against a concentration gradient and driven by metabolic energy. Transfer of chemical in and out of each compartment may occur at different rates and thereby increase or reduce the concentration of the chemical transferred into or out of a compartment. At intake, the chemical enters the bloodstream (*A*) where it is distributed throughout the organism. The concentration of free chemical in the blood drives the equilibrium into the next space and is controlled by the amount of chemical ligand reversibly stored in inert storage sites such as plasma proteins and the amount of ligand inactivated either by metabolism or excretion. Free ligand in the bloodstream diffuses to individual cells (*B*) where it again can be held in an inert state at storage sites or reduced by cellular metabolism and/or excretion. Finally, a portion of the intracellular free chemical is available to diffuse into a subcellular organelle (*C*) where it is available to interact with a receptor to produce an effect.

series of generally reversible reactions are likely to occur between the ligand and the storage or transport molecules that distribute the ligand throughout the body. Metabolism of the parent ligand to a form that is not compatible with the receptor is another mechanism by which the concentration of free drug reaching the receptor population is reduced. However, most drugs with distinct pharmacological characteristics act only in a specific manner and only in tissues that are susceptible to the chemical; i.e., those that have a specific ligand-receptor effector domain.

Uptake, distribution, and elimination of chemicals by fish depends greatly on the physicochemical properties of the chemical and includes the degree of lipophilicity, generally expressed as the differential solubility between n-octanol and water or the octanol-water partition coefficient (Neely 1979). Because fish are essentially continuously exposed to chemicals in water solution, a chemical with a favorable n-octanol/water partition coefficient is generally conceded to enhance uptake and bioaccumulation in fish (Veith et al. 1979).

Physicochemical properties that enhance rapid uptake and distribution are considered a positive attribute for candidate piscicides.

Uptake of waterborne chemicals by fish is generally conceded to be primarily across the thin respiratory membranes of the gills. The gills are the primary regulating surface between the external water medium and the fish's internal medium. As such, the gill functions in a variety of capacities as a respiratory surface area, a site of active ion exchange, and a site for excretion of nitrogenous wastes. The significance of the gill as a site of uptake of waterborne chemicals is that virtually all circulating blood passes through the gill.

At least three vascular networks have been identified in the gill: (1) a respiratory pathway, (2) a nutrient pathway for branchial tissues, and (3) an interlamellar pathway reminiscent of mammalian lymphatic capillaries (Olson 2002*a*). Gill circulation is complex and appears to be controlled by a variety of neurocrine, endocrine, and autocrine signals (Olson 2002*b*). The general complexity of the system suggests that it may be a likely site for differential toxicity among fish, particularly since different groups of fish with different physiological requirements may be able to modify their blood exposure to the water by increasing or decreasing the functional water/blood surface area of the gill for gas exchange (Burggren et al. 1979, Hughes 1980, Nimi and Morgan 1980), thereby also altering the functional gill area for uptake of toxicant. There is some evidence that the lamprey-specific toxicants 3-trifluoromethyl-4-nitrophenol (TFM) and 2-aminoethanol salt of 2',5-dichloro-4'-nitrosalycylanilide (Bayluscide®), both weakly acidic organic molecules, act specifically to damage branchial organic anion transport cells in sea lamprey gills (Mallatt et al. 1985, 1994). The sensitivity of these cells in the sea lamprey has been suggested to be the basis of the selectivity of both chemicals for sea lamprey. Others have found that a partial explanation of the relative sensitivity of lamprey to TFM and Bayluscide® is that, unlike higher bony fishes, lamprey lack adequate activity of the enzyme glucuronyl transferase that acts to detoxify both chemicals by secondary conjugation with a glucuronide moiety (Lech and Statham 1975). It is likely that most of the selectivity observed in the classes of toxicants that have been developed for fishery management purposes is the result of differences in how the chemicals are taken up, distributed, metabolized, and eliminated by the individual organisms.

Predicting Selective Chemical Toxicity Based on Pharmacokinetic Models

One of the principal mechanisms for the selective toxicity of pesticides to undesirable species compared with desirable species concerns differences in the distribution (i.e., pharmacokinetics) of the compound among species (Albert 1985). Differences in absorption, distribution, and excretion can account for differences in toxicity. Further, the relative ability of a species to absorb, distribute, or excrete compounds can sometimes be predicted on the basis of knowledge of anatomical and physiological differences in the species.

The field of pharmacokinetics studies the time course of chemical absorption, distribution, metabolism, and excretion by an organism (Gibaldi and Perrier 1982). A common method of characterizing the pharmacokinetics of a compound in pharmacology and toxicology is to follow the concentration of a chemical within the blood or plasma through time after administration. Based on knowledge of concentration of the drug in the plasma, information can be inferred on its distribution in other tissues.

Pharmacokinetic models, mathematical characterizations of a drug or foreign chemical in the body of an organism, are used to describe the relationship between the concentration of the compound in blood or plasma over time. The data are fit to several possible model equations that describe the disposition of the compound; the one that best fits the data is determined.

These models are referred to as compartmental models because the chemical is said to act as if the organism was made up of one or more compartments (Figure 3-2). Most common compounds display characteristics as if they were distributed among two or three compartments.

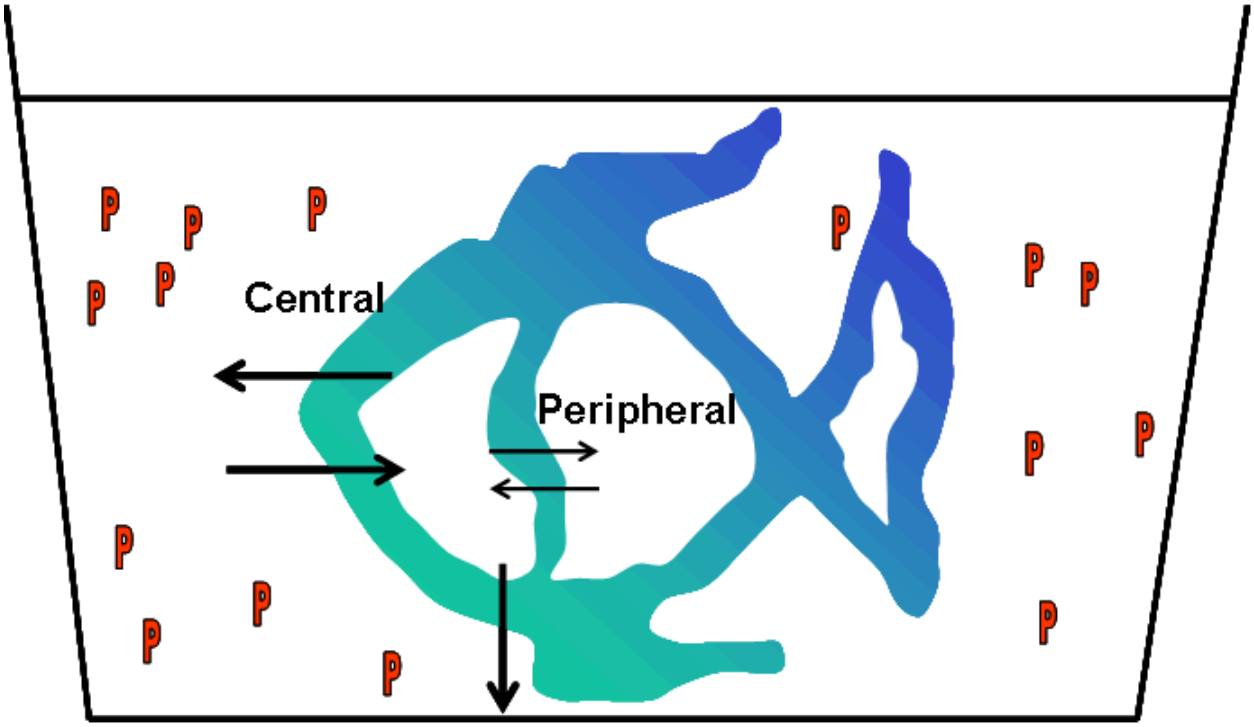


Figure 3-2. A two-compartment pharmacokinetic model for a piscicide in fish. Piscicide (*P*) enters the central compartment where it can exit unchanged, be metabolized (*bold arrows*), or enter a peripheral storage compartment (*lighter arrows*).

The plasma and well-perfused tissues represent one compartment (referred to as the central compartment) where elimination occurs. Tissues with less perfusion, such as fat and muscle, comprise a second or third compartment (peripheral compartment) where the compound is stored until transferred to the central compartment where it can be eliminated. With fish that are too small for multiple blood sampling, pharmacokinetics of a compound can be characterized on the basis of concentrations of parent compound and metabolites in the whole body of the fish and in the water used for waterborne exposure (Stehly and Hayton 1989). These models are similar to compartmental models on the basis of plasma concentrations of the compound, but they are fit simultaneously to data for concentrations of the compound in the fish and water.

Theoretically, registered or proposed piscicides used in fishery management could be evaluated to determine if distributional or elimination characteristics account for species differences in toxicity. It may then be possible to predict pharmacokinetic characteristics resulting in greater toxicity to a particular species. This strategy relies on the chance finding of a piscicide that is more toxic to a target invasive species than to nontarget species. A number of residue studies have been conducted on compounds currently registered with the EPA or with candidate fishery management chemicals. These studies were not designed to determine pharmacokinetics of the compound in a fish species. If this information was developed, pharmacokinetic models could then be used to predict plasma concentrations. Since this information has not been developed for

any species of fish, evaluation of differences between native and nonnative fish species cannot be made yet.

Although compartmental pharmacokinetic models are relatively easy to develop, their results cannot be extrapolated to different species, dosages, or other factors that may change the distribution or elimination of the compound. Piscicides would probably be used at a particular dose and therefore, as with development of many human pharmaceuticals, extrapolation of dosage may not be particularly important. Compartmental models, however, would still have limited usefulness in extrapolation to other species and conditions.

More complex models based on the specific physiology of the individual species and physicochemical characteristics of the compound can and have been used to allow for better predictive capability on chemical disposition within an organism. These models, known as PBPK models, have been used most often for risk assessment of toxicity in humans on the basis of laboratory studies in animals, such as rats and mice. These models are generally composed of a number of compartments that are important to describe the disposition of a chemical (Figure 3-3). The compartments defined in the model include the central compartment (e.g., well-perfused tissues), storage compartments (e.g., poorly perfused tissues, such as adipose tissue), elimination compartments (e.g., liver, kidney), and for fish, the gills that may be important for uptake and elimination of compounds.

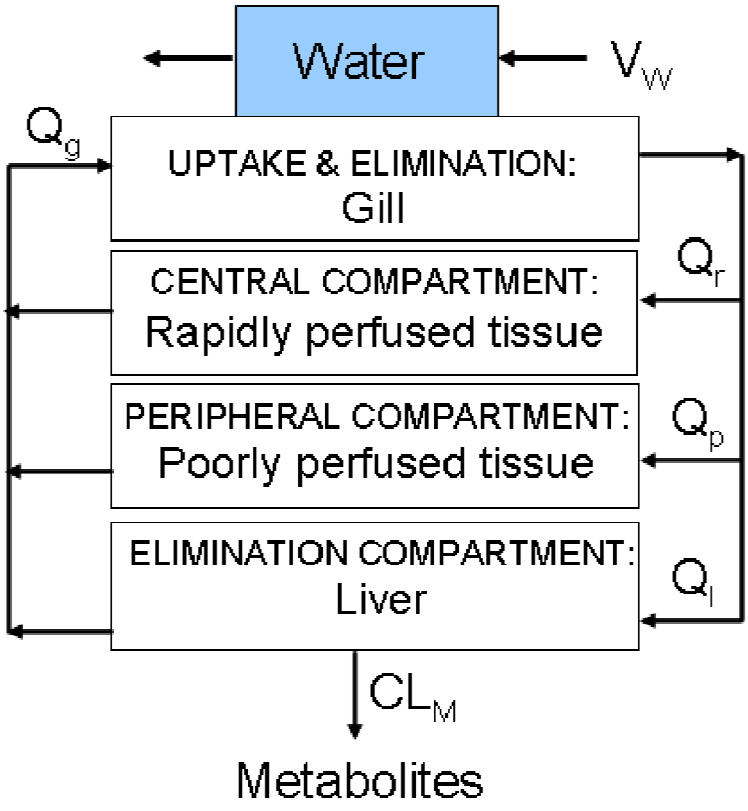


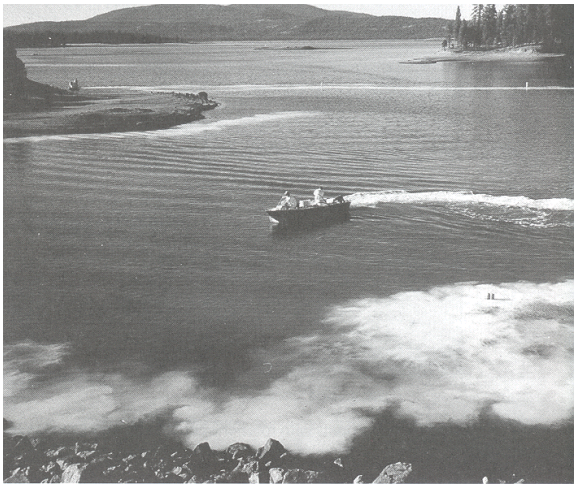
Figure 3-3. A simple physiologically based pharmacokinetic model for fish with a component for transfer of a chemical between the water and fish through the gill, a compartment composed of tissues with a relatively large perfusion of blood, a storage compartment (poorly perfused), and an elimination compartment (liver) that produces metabolites of the chemical. Arrows denote blood flow among tissue groups (Q_g, Q_r, Q_p, Q_l), flow of water through the gills (V_W), or metabolic clearance from eliminating organs (CL_M).

Physiologically based pharmacokinetic models require a large amount of data that must be obtained from the literature or experimentally, including physiological variables (i.e., clearances and metabolism), transport variables (i.e., absorption, permeability), thermodynamic variables (i.e., tissue/blood partition coefficients), and anatomical values (i.e., blood flows, tissue volumes; Lutz and Dedrick 1985). The PBPK models are considered superior to simpler compartment models because they can provide an exact description of the time course for the compound in any organ or tissue within the body and are based on the physiology of the animal. Additionally, any biological process important to chemical disposition that can be described mathematically can be incorporated into the model. Because these models are based on anatomy and physiology, they are useful for extrapolation to other doses, species, and conditions affecting physiology (e.g., increased respiration). The PBPK models have been used to interactively determine the most appropriate experiments to validate the model (Conolly et al. 1999). More recently, the kinetics of individual compounds in chemical mixtures were interactively evaluated. This evaluation provided an alternative to the large number of possible experiments required to test interactions of chemical mixtures. The authors termed the computer modeling as "in silico" toxicology (Dobrev et al. 2002).

Although there is interest in using physiologically based pharmacokinetic models to assist in developing data to support registration of pesticides and pharmaceuticals, this method has not been applied successfully to date. Efforts are currently under way in the pharmaceutical industry to approve new pharmaceuticals using PBPK modeling to develop preclinical data. Efforts also have been made to predict partition coefficients of chemicals between tissues and plasma on the basis of chemical characteristics and physiological make up of tissues rather than to experimentally collect these data. The U.S. Food and Drug Administration (FDA) is expecting that drug sponsors will submit data in the form of PBPK models in support of clinical trials (Peter Lee, FDA, personal communication). Scientists at the Upper Midwest Environmental Sciences Center (UMESC) have also proposed use of the crop grouping concept to support the idea of multiple fish species approvals for aquaculture drugs partly on the basis of use of PBPK models (Gingerich et al. 1998). The crop grouping concept hypothesizes that fish can be grouped or data normalized concerning depletion of drug residues on the basis of phylogeny, thermodynamics of the residue or temperature related activity differences among different fish species. This could result in satisfying FDA data requirements in residue depletion for multiple species of fish on the basis of testing a few surrogate fish species. The FDA has acknowledged use of pharmacokinetics to support crop grouping, but does not specifically limit it to use of PBPK models (FDA 1999).

Physiologically based pharmacokinetic models have been used to describe the disposition of a limited number of chemicals in fish for compounds such as chlorethanes, pyrene, and an organophosphate pesticide (Law et al. 1991, Nichols et al. 1993, Abbas and Hayton 1997). One problem with using these models to extrapolate among species of fish is the lack of basic information on physiological differences among species, in particular ventilation at the gill, blood flows to tissue groups, and relative volumes of tissue groups.

In summary, pharmacokinetic data have not been developed for registered or potential piscicides that would allow comparison of their disposition between native and nonnative fishes. Development of PBPK models in fish is in its scientific infancy, few data are available on physiological differences required for the models in fish species, and these models are only now being considered to develop medicinal drugs. Although PBPK models could conceivably be used to develop species-specific piscicides, cost requirements to identify these compounds is probably greater than direct testing of the chemicals species by species and therefore use of PBPK models to identify species-specific piscicide is premature at this time.



Chapter 4. Background Information on Use of Registered and Unregistered Piscicides

by Verdel K. Dawson

After an introduced population of fish has been determined to be undesirable (defined as virtually any species that does not meet human needs; Wiley and Wydoski 1993), at least six management options exist: eradication, single treatment control, sustained control, sporadic control, commercial harvesting, and no control (Braysher 1993). The use of chemicals is often considered as a tool in the first four options. In almost every instance where fish toxicants or piscicides have been used as a management tool, the ecology of the system (pond, lake, or stream) had been disrupted by one or more nonnative species.

Eradication of undesired fishes began almost 100 years ago, but accelerated during the last part of the 20th century as more introduced fishes became invasive and as better piscicides became available. Before undertaking an eradication program, consideration must be given to whether the action would be worthwhile. Successful eradication depends on (1) killing the pest at a faster rate than it is being replaced, (2) no immigration into the treatment area, (3) the vulnerability of all individuals of the undesired species to treatment, (4) the feasibility of monitoring populations at low densities, (5) a favorable socio-political environment, and (6) a cost-benefit analysis that favors eradication over control (Bomford and O'Brien 1995). Chemical eradication may achieve (1) and (3), but are subject to (5) and (6) because chemicals are expensive to purchase and to use, and managing collateral damage is also expensive. Piscicides can be general toxicants (e.g., antimycin and rotenone) that usually have been used to eliminate all fish from a body of water in preparation for restocking with desired species, or they may be selective toxicants (e.g., TFM and Squoxin) that kill only target species while causing minimum harm to other aquatic organisms in the treatment area.

Worthwhile fish toxicants must have properties that meet the needs of fishery managers while minimizing other adverse effects. The ideal toxicant should (1) be effective against the species of fish targeted, (2) be easy and safe to apply, (3) degrade to harmless constituents in a limited time without the aid of a detoxicant, (4) be harmless to nontarget organisms (plant and animal), (5) be effective over a broad range of water quality conditions, and (6) be registered for use in the aquatic environment (Lennon et al. 1970). No currently registered fish toxicant meets all of these criteria. Therefore, fisheries managers must carefully balance the benefits of using toxicants against their potential adverse environmental effects.

In many instances, chemicals developed for agricultural use have been successfully adapted for use as piscicides. There has been less specialized development of chemicals for use as piscicides probably because neither human health nor food production imperatives have driven the process (Sanger and Koehn 1997). A notable exception is the scale of research and management efforts devoted to addressing the introduction of sea lamprey into the Great Lakes in the 1960s. The United States and Canadian governments contributed to a massive study that involved toxicological screening of more than 6,000 chemicals that resulted in identifying a compound

that was selectively toxic to sea lamprey larvae at concentrations that did not severely affect other aquatic life. See Chapter 11 for a description of the evolution of the Sea Lamprey Control Program in the Great Lakes.

Environmental assessments provide a formal mechanism to plan a control project and select the best alternative to accomplish management objectives (Table 4-1). Environmental assessments must include reasons for the proposed treatment, a description of the proposed treatment and treatment area, environmental impacts of the proposed treatment, discussion of adverse impacts, mitigating measures to offset adverse impacts of the proposed treatment, discussion of irreversible and irretrievable commitments of resources, documentation of public and agency interest, and alternatives to accomplish the proposed work. Control programs must be based on an understanding of the biology and habitat of both target and nontarget species. In addition, all effective methods of control should be considered, and a realistic understanding must be developed for the level of control that is feasible and required.

Table 4-1. Factors to consider in planning a chemical treatment to remove undesired fish species (modified from Wiley and Wydoski [1993]).

Factors
Determine the need for chemical treatment to restore the sport fishery based on pretreatment surveys of the fish population.
Obtain and evaluate necessary water quality and fishery statistics.
Determine the volume (lake or pond) or length and volume (stream) of water to be treated.
Determine the amount of toxicant required to obtain desired treatment (amounts of toxicant may be decreased if lake levels can be lowered or the flow of regulated streams reduced).
Determine if the chemical must be detoxified (some chemicals break down to nontoxic components quickly because of water temperature, sunlight, etc.); accurately determine the amount of material required to detoxify the specific concentration of the toxicant.
Inform the public and provide an opportunity for public comment on the treatment.
Ensure that the treatment will not contaminate potential sources of drinking water.
Evaluate the potential adverse impacts on environmentally sensitive species (including threatened and endangered species).
Develop a detailed operational plan that completely describes all aspects of the project.

The application of chemical piscicides is one of the most widely used methods that fishery managers have available for controlling undesirable fish species. Considerable effort has gone into the search for new and improved general and selective fish toxicants. A large number of chemicals have either been used historically, proposed for use, or are currently in various stages of development for use as piscicides. Appendix C provides technical data for each chemical, when available, on alternative names, chemical names, formulations, primary use, secondary use, mode of action, toxicity (fish, birds, invertebrates, and mammals), safety hazards, persistence in the environment, and registration status. Additional toxicity and regulatory information for over 6,000 pesticides against a variety of test organisms can be obtained from an online pesticides database (Pesticide Action Network North America 2003).

Piscicides have normally been applied directly to the water (waterborne), however, a limited few have been formulated for oral ingestion as a bait. The advantages of using the chemical in a bait is that less chemical is required and nontarget organisms are less likely to be exposed to the chemical. A section on the use of piscicides that have been formulated as baits is found at the end of this chapter. None of the piscicides formulated as baits are currently registered for that use.

4.1 Registered Piscicides

Only four toxicants are currently registered by the EPA for use as piscicides: rotenone, antimycin, TFM, and Bayluscide® (Schnick et al. 1986). In the United States, regulations governing piscicide use are administered by the Federal Government (Federal Insecticide, Fungicide and Rodenticide Act [FIFRA] of 1947, as amended, 7 U.S.C. Sections 136-136y; FIFRA 1947) and by the respective states. Most states require that pesticides (including piscicides) be used only by certified applicators. Fish killed using these chemicals should not be used as food. Use of chemicals to control fish are sometimes referenced in state conservation codes. Two of the toxicants (rotenone and antimycin) are registered for general use and are used on a nationwide basis, and two (TFM and Bayluscide®) are registered as restricted-use lampricides with primary use in tributaries to the Great Lakes.

General Piscicides

Rotenone.—Roots of *Derris* spp. were used by people in southeast Asia and South America to collect fish more than 100 years ago, and rotenone was first used as a piscicide in North America in 1934 (Lopinot 1975). Rotenone is the active ingredient in *Derris* extracts (Morrison 1988). Rotenone is the most commonly used general fish toxicant and is presently registered for nonfood use as such. Davies and Shelton (1983) and more recently Finlayson et al. (2000) describe the use of rotenone in lakes and streams including calculations of amount of toxicant to use, equipment needed for a treatment, species sensitivity, use of a detoxifier, and methods to carry out a treatment project. McClay (2000) conducted a survey of rotenone use and reported that 37 states from 1988 to 1997 used almost 100,000 kg of rotenone. Manipulation of fish communities to maintain sport fisheries was the most common reason for using rotenone, accounting for 72% of the chemical used. Treatments aimed at the eradication of nonnative fishes accounted for 18% of rotenone use (McClay 2000).

Rotenone is relatively nonpersistent in the environment and detoxifies more rapidly in warmer water (Gilderhus et al. 1986). Where chemically induced detoxification is necessary, such as near potable water supplies or to protect downstream fishes, potassium permanganate is usually added in an amount equal to the rotenone used plus the permanganate demand of the water (Davies and Shelton 1983). Rotenone can also be removed from water with activated carbon (Dawson et al. 1976). Toxicity of rotenone is affected by water temperature, light, dissolved oxygen, turbidity, and alkalinity. The emulsified formulations of the chemical (rotenone 2.5 or 5% liquid) and rotenone 7.5% powdered cause avoidance reaction in fish (Dawson et al. 1998). 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 (Brian Finlayson, personal communication). Rotenone has low toxicity to birds and mammals. In fact, rotenone-killed fish were formerly collected enthusiastically by the public for consumption (Lennon 1970).

Although usually considered a general piscicide, Willis and Ling (2000) describe a technique for using rotenone to control nonnative mosquitofish in wetlands containing native black mudfish. When the mudfish (approximately twice as sensitive as mosquitofish to the effects of

rotenone) surfaced to gulp air as a result of the rotenone exposure, they were removed and placed in rotenone-free water where they fully recovered. Rotenone has also been used for selectively killing gizzard shad in lakes (Bowers 1955) and streams (Lowman 1958, 1959). The authors suggested that gizzard shad tend to be more sensitive than other fish to rotenone, and the treatments were concentrated in the surface water where gizzard shad tended to congregate.

Antimycin.—Antimycin (Fintrol®) is an antibiotic produced in cultures of streptomyces and is the only other compound besides rotenone registered as a general fish toxicant. Antimycin was discovered in 1945 by scientists in the Department of Plant Pathology at the University of Wisconsin (Lennon 1966). The first reported use of antimycin as a piscicide was in 1963 (Lopinot 1975). Antimycin is currently undergoing reregistration with the EPA. Antimycin is toxic to fish eggs and to all life stages of fish, fry through adults. The toxic action is irreversible (Berger et al. 1969).

Piscicidal concentrations of antimycin do not elicit an avoidance response in fish (Dawson et al. 1998). It is highly toxic to some rotenone-resistant species, but scale-less fish (e.g., ictalurids) are resistant to concentrations that control scaled fish (Burress and Luhning 1969*a*,*b*). Antimycin is pH-sensitive and is inactivated within a few hours at a pH of 8.5 and above (Marking 1975). In waters with great diurnal variations in pH, reclamations should be conducted in the early morning to ensure that target fish get a lethal exposure before the pH rises and reduces the efficacy of the toxicant. In soft, acid waters, antimycin usually degrades to nontoxic components within 7 to 10 days (Lennon et al. 1970). The compound is deactivated quickly and easily with potassium permanganate (Gilderhus et al. 1969) or by adsorption on activated carbon (Dawson et al. 1976). Various formulations of antimycin have been developed (see Chapter 6 of this report).

Antimycin is also usually considered a general piscicide, but it has been shown to be selective for certain fish species. Antimycin has been used extensively to remove scaled fish from catfish production ponds without harming the resident channel catfish (Burress and Luhning 1969*a*,*b*). Cumming et al. (1975) described the selective removal of brown trout, common carp, bluegill, green sunfish, and grass carp without killing channel catfish. Radonski (1967) used antimycin to eliminate yellow perch from a soft, acid lake in Wisconsin while leaving the rest of the fish population intact.

Selective Piscicides

TFM.—TFM, 3-trifluoromethyl-4-nitrophenol, originally used as an herbicide, was found to selectively kill sea lamprey and not harm other fish (Applegate et al. 1961) and its use is an important component of the Sea Lamprey Control Program for the Great Lakes. The mode of action is not well understood, but there is evidence that TFM acts by damaging branchial organic anion transport cells in sea lamprey gills (Mallatt et al. 1985, 1994) and by uncoupling oxidative phosphorylation (National Research Council of Canada 1985).

The chemical is environmentally nonpersistent. At treatment concentrations, it does not affect birds, mammals, or aquatic plants (although photosynthesis may be temporarily reduced), has a varied effect on invertebrates depending upon habitat and species, and may reduce associated fish populations (Wiley and Wydoski 1993). TFM does not undergo significant volatilization or hydrolysis, but it is photodegraded by sunlight yielding several products (Dawson 1973, Carey and Fox 1981, Fathulla, unpublished data). TFM is rapidly taken up by teleost fish and conjugated with glucuronic acid, primarily in the liver and kidneys, and then undergoes biliary and renal excretion. In contrast, TFM is taken up by sea lamprey larvae more rapidly, and the degree of conjugation is much less (National Research Council of Canada 1985).

This is probably the primary reason for the selectivity of TFM for sea lamprey. Boogaard et al. (1996) proposed the use of TFM as a selective piscicide for controlling the spread of the Eurasian ruffe in Lake Superior. They reported that ruffe were three to six times more sensitive than native fish species to TFM.

Bayluscide®.—Bayluscide®, 2-aminoethanol salt of 2',5-dichloro-4'-nitrosalycylanilide, was developed for the control of mollusks in tropical areas and was first used as a lampricide in 1963 (Cumming 1975). Hamilton (1974) conducted an extensive review of the use of Bayluscide® in fisheries. As a lampricide, it is used primarily as an economic synergist with TFM. The toxicity of the two chemicals is essentially additive, however, since Bayluscide® is less expensive than TFM, use of the mixture reduces the cost of lampricide treatments. Although Bayluscide® was found to be about 43 times more toxic than TFM to larval lampreys, it was not selective between rainbow trout and sea lampreys (Howell et al. 1964). A mixture of 98% TFM and 2% Bayluscide® kills ammocetes at about half the concentration of TFM that would be required without Bayluscide®. Bayluscide® has been formulated as a wettable powder, coated on sand granules, and as a delayed-release granule (see Chapter 6 of this report). The mode of action of Bayluscide® is thought to be similar to that of TFM, but the exact mode is unknown (National Research Council of Canada 1985). The chemical is environmentally nonpersistent, is pH-sensitive, moderately toxic to mammals, and toxic to mollusks and aquatic annelids (Wiley and Wydoski 1993).

4.2 Unregistered Piscicides

Fishery managers have been searching for years for selective piscicides that can be used to control specific species without harming nontarget fish species or other aquatic organisms. Historically, chemicals were used indiscriminately in the search for better fish toxicants. Fishery managers are still attempting to develop improved piscicides. The application of chemicals in the environment, however, is currently strictly regulated by the EPA. For most of the candidate general and selective piscicides listed below, the data required to satisfy the safety and efficacy requirements of this regulatory agency are not available. Furthermore, most of the chemicals are either too toxic to nontarget organisms or too persistent in the environment to ever be registered for use as piscicides by the EPA (see Appendices C and D). The following is a listing of chemicals that have been used as piscicides or are being considered for this use.

General Piscicides

Ammonia.—Klussman et al. (1969) and Prentice et al. (1976) evaluated use of anhydrous ammonia in fishery management. More recently, Ramaprabhu et al. (1990) described the use of ammonia as a fish toxicant. Temperature and pH affected the amount of ammonia required for each treatment. Desirable fish were salvaged by netting them out immediately after application when they came up in distress while others had died within a day. Thorough distribution of the chemical was required because fish were repelled by the ammonia. They concluded that in addition to being a fish toxicant, the herbicidal, algicidal, and fertilizer value make ammonia an ideal chemical for integrated pest management in aquaculture. Ammonia is nonpersistent in water and treated water is nontoxic to mammals.

Aqualin.—St. Amant et al. (1964) described the use of Aqualin (acrylic aldehyde) as a fish toxicant. Goldfish and other fishes were eliminated in several treated lakes in California. They cautioned, however, that this compound is lacrimatory (eye irritant) and toxic and that it must be kept in tightly closed containers and be injected under water by a closed pumping system.

Baythroid®.—Baythroid® is a synthetic pyrethroid that has been proposed as a control agent for rusty crayfish (*Orconectes rusticus*) but is toxic to fish at higher concentrations. It is fairly nonpersistent in water. It is primarily an insecticide and has little support for development as a piscicide (Marking 1992).

Bleaching powder and urea.—A combination of commercial bleaching powder (at 5 mg chlorine/L) and urea (at 5 mg total ammonia = $[NH_4^+ + NH_3]$/L) was shown to be effective in killing fish in India (Ram et al. 1988). Mohanty et al. (1993) used 5 and 3 mg/L (ppm), respectively, of the two components to kill fish under laboratory and field conditions. The advantages of these compounds are the ease of application, quick restoration of normal pond conditions, and reduced costs.

Calcium hypochlorite.—Chlorine (the active ingredient of calcium hypochlorite) has been used since at least the mid-1930s for sanitation in fish culture facilities (Connell 1939). Panikkar (1960) recommended calcium hypochlorite for eradication of fish and tadpoles in partly drained fish ponds. Jackson (1962) conducted a more comprehensive study on the use of chlorine as a fish toxicant. He suggested that chlorine must be applied in amounts sufficient to meet the chlorine demand of the water, plus the lethal dosage for the species to be controlled. Marking et al. (1983) evaluated the feasibility of using chlorine to augment other barriers in preventing introduction of nonnative species with the Garrison Diversion project that proposed transfer of Missouri River water to a large part of eastern North Dakota for agricultural and industrial uses. They concluded that concentrations >2 mg/L of chlorine would effectively eliminate eggs and larvae of common carp and rainbow smelt. Chlorine is nonpersistent in water and has potential for use in reclamation of water supply reservoirs where other toxicants may be forbidden. The ease of neutralizing chlorine with sodium thiosulfate is an additional advantage. Chlorination under certain conditions can result in formation of deleterious byproducts, and its release into the environment is closely regulated by a number of states.

Copper sulfate.—The use of copper sulfate as a fish toxicant was first suggested by Titcomb (1914). Some negative side effects of its use as a piscicide included decimation of phytoplankton, zooplankton, insect larvae, and mollusks (Smith 1935). After the introduction of rotenone and other fish toxicants, the use of copper sulfate as a piscicide has declined.

Croton seed powder.—Croton seed powder is the residue after croton oil is expressed from croton seed (*Croton tiglium* L.). The powder has been used in China for many years to eliminate predatory fish from carp nursery ponds (Lennon et al. 1970).

Cunaniol.—The leaves of *Clibadium sylvestre* have been used by South American Indians as a fish toxicant. Aqueous extracts of the leaves (polyacetylenic alcohol) were extremely toxic to guppies and goldfish. The exposed fish exhibited hyperactivity, followed by loss of coordination, paralysis, and finally death (Quilliam and Stables 1968).

Dieldrin.—Perschbacher and Sarkar (1989) compared the toxicity and cost of a number of candidate piscicides in bioassays against snakehead. They reported an effective concentration for dieldrin (1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-endo-1,4-exo-5,8-dimethanonapthalene) of 0.5 mg/L. Dieldrin was listed as "by far the least expensive of the tested toxicants." However, dieldrin concentrates in aquatic invertebrates several thousand times the applied dosages and represent a health hazard to fish, aquatic life, and humans (Perschbacher and Sarkar 1989). Its use has been discontinued in the United States.

Endosulfan.—Endosulfan or Thiodan® (1,4,5,6,7,7-hexachloro-5-norbornene-2,3-dimethanol cyclic sulfite) is used as a fish toxicant in India. Schoettger (1970) described the use of

Endosulfan and its toxicity to fish and aquatic invertebrates. He reported that the chlorinated hydrocarbon insecticide was at least seven times more toxic to fish than to invertebrates. Toxicity was influenced by temperature and length of exposure. The median tolerance limits of rainbow trout and white suckers to Endosulfan were 0.3 to 8.1 µg/L (ppb). The chemical was relatively nontoxic to fish eggs, but after hatching, the fish became increasingly susceptible with age. Paul and Raut (1987) evaluated the toxicity of Endosulfan to several species of carp. The 96-h LC_{50} (lethal concentration expected to cause 50% mortality among exposed organisms) values ranged from 0.26 to 8.7 µg/L. The toxicity of Endosulfan decreases as hardness or pH increase. The chemical has little value as a selective piscicide against rough fish, but has been proposed as a general fish toxicant.

Endrin.—Henderson et al. (1959) reported endrin (Compound 269) to be the most toxic of the insecticides to all species of fish. They reported toxic levels ranging as low as 0.6 µg/L. Endrin has been used extensively in Malaysia where Soong and Merican (1958) removed all fish from 108 bodies of water before restocking. Hooper et al. (1964) described a treatment of a small lake in Michigan with 8 µg/L of endrin that was only partly successful. They referred to another application of endrin where residues were found in fish tissues 1 month after the treatment. They recommended that endrin not be used in fisheries because of zero tolerance levels in food products.

Juglone.—Juglone (5-hydroxy-1,4-napthoquinone) is a biologically active chemical occurring in various parts of walnut trees (Family Juglandacae: *Juglans nigra, J. cinerea*, and *J. regia*). It can be extracted from walnut husks or synthesized by oxidation of 1,5-dihydroxynaphthalene (Windholz 1983). Juglone is toxic to fish at <0.1 mg/L and is not significantly affected by temperature or hardness, but it is less toxic at higher pHs. Juglone degrades easily in the natural environment, but is persistent long enough to eliminate fish before degradation (Marking 1970).

Lime.—Lime (calcium oxide) has been used for many years to control unwanted organisms in fish culture ponds. Prather et al. (1953) reported that hydrated lime used as a disinfectant in ponds would kill undesirable fish.

Limil.—Sanger and Koehn (1997) reported that in 1961-62, extensive and large-scale poisoning was conducted to eradicate common carp from dams in south Gippsland, Victoria, Australia, and a total of 1,300 dams were poisoned with limil, santobrite (sodium pentachlorophenate), or rotenone. The treatments were deemed successful from surveys the following year. However, no further information was provided about limil.

Ozone.—Coler and Asbury (1980) described the use of ozone for prevention of encroachment of undesirable fish species in a water diversion project. Concentrations of <1 mg/L were effective against many species of fish larvae and eggs. Leynen et al. (1998) confirmed the sensitivity of a number of species of larval fish to ozone. They also indicated that *Daphnia magna* were even more sensitive to ozone than were fish larvae.

Phostoxin®.—Perschbacher and Sarkar (1989) conducted bioassays of a number of candidate piscicides including Phostoxin® (aluminum phosphine) against snakehead. They reported a 24-hour LC_{100} for Phostoxin® of 0.25 mg/L, the most toxic of the chemicals tested. Detoxification of Phostoxin®, as determined by survival of carp fry, occurred in 4 days in laboratory tests and in 1 day in earthen ponds.

Polychlorpinene.—Polychlorpinene (PCIP) is a chlorinated turpentine, resembling toxaphene in some respects. By 1963, 118 lakes in Russia had been treated with the compound at 0.05 to

0.20 mg/L to control rough fish (Schäperclaus 1963). The toxicant persisted up to 1.5 years in lakes in northern Russia, and degradation in water was dependent on concentration, temperature, alkalinity, depth, and the extent of water mixing. Polychlorpinene has the disadvantage of being nonspecific to fish, persistent in water, and unsafe.

Potassium permanganate.—Hinton and Eversole (1979) evaluated the toxicity of potassium permanganate to the American eel in a search for controls for diseases and parasites. They reported a 96-hour LC_{50} value of 4.86 mg/L. Marking et al. (1983) evaluated the feasibility of using potassium permanganate in preventing introduction of nonnative species with the Garrison Diversion project. They concluded that a concentration of >10 mg/L of potassium permanganate for 24 hours would be required to effectively eliminate eggs and larvae of rainbow smelt and common carp.

Salicylanilide I.—Marking (1972) determined the toxicity of salicylanilide I (2',5-dichloro-3-tert-butyl-6-methyl-4'-nitrosalicylanilide) to 20 species of freshwater fish in laboratory toxicity tests and to 15 species in outdoor pool exposures. The 96-hour LC_{50} values ranged from 0.3 to 8.6 µg/L. Toxicity was similar to all species making it a good candidate as a general piscicide. Its toxicity was not significantly affected by water quality or temperature, however, it degraded more slowly at colder temperatures. He concluded that it offers advantages over presently used fish toxicants. Marking and Bills (1981) compared the toxicity of salicylanilide I to four species of nonnative carp now in the United States—common carp, grass carp, bighead carp, and silver carp. The 96-hour LC_{50} values ranged from 1.5 to 9.35 µg/L for the four species, common carp being the most sensitive.

Saponins.—Saponins are water-soluble glycosides that occur in 300 to 400 species of plants, including azalea, camellia, rhododendron, and heath. They have been known historically as "fishing plants" in Asia for collecting fish in ponds, rivers, and marine estuaries. They are foaming agents with a history of uses in washing silk, wool, and cotton fabrics, in preparing sparkling wines, and as components in expectorant medicines. Tea-seed cake is a common form of the piscicide, and it is the saponin-bearing residue remaining after the oil is expressed from the seeds of camellia (Tang 1961). Tang (1961) reported that it is customary for Chinese fish farmers to use tea-seed cake for control of undesirable fish in ponds before stocking. He successfully controlled predaceous fish in shrimp ponds with powdered saponins and crumbled tea-seed cake. Saponins extracted from sugar beets have been used in Russia for ridding inland waters of nuisance fishes (Lennon et al. 1970). Chiayvareesajja et al. (1997) described the use of tea-seed cake as a piscicide in earthen ponds at a concentration of 25 mg/L against five species of fish, i.e., walking catfish, common carp, mosquitofish, tilapia, and silver barb. Mortalities of the five species ranged from 28% to 65% after 24 hours of exposure. They found that the ponds could be restocked 4 days after applying the piscicide.

Sodium cyanide.—The first application of sodium cyanide for fishery management was made by Bridges (1958). He observed that this economical and readily soluble salt was effective against a variety of fish in low concentrations (0.5-1.5 mg/L). The period of toxicity varies from 4 to 20 days depending on temperature and water depth. Cyanide has been used as a fish toxicant and to aid in collection. Miller and Madsen (1964) described 40 treatments in Nebraska that included live removal of northern pike from nursery ponds, the salvage of fish from irrigation canals, lake renovations, lake and stream sampling, and fish salvage. The advantages of the use of sodium cyanide include fast immobility and rapid recovery of fish with no ill effects, and low cost. However, cyanide is extremely hazardous to humans when it is inhaled or absorbed through the skin. The use of sodium cyanide in fisheries is currently restricted.

Sodium fluoride.—Marking et al. (1983) conducted studies to determine the toxicity of sodium fluoride to rainbow smelt and common carp as part of a study to determine the feasibility of using chemicals to prevent the introduction of nonnative species during the Garrison Diversion project. The 96-hour LC_{50} for rainbow smelt larvae was 10 mg/L, and almost six times as much fluoride was needed to kill rainbow smelt eggs.

Sodium hydroxide.—Jackson (1956) dropped pellets of sodium hydroxide into the nests of problem sunfishes to kill eggs and fry. The technique was effective, however, control was limited to waters where nests could be located and treated easily, and required considerable expenditure of time and effort.

Sodium nitrite.—The feasibility of using sodium nitrite to augment other barriers to prevent the introduction of nonnative species with the Garrison Diversion project was evaluated by Marking et al. (1983). They reported a 96-hour LC_{50} for rainbow smelt larvae of 0.6 mg/L. However, the chemical was either nontoxic to eggs or the concentrations required to kill them would be impractical for field use.

Sodium pentachlorophenate.—Walker (1969) reported that concentrations of sodium pentachlorophenate (santobrite) as low as 0.06 mg/L are lethal to fish under laboratory conditions and that piscicidal activity varies with temperature, pH, and other factors. The chemical has been used to remove fish from ponds without harming tadpoles or snails (Lennon et al. 1970). Sanger and Koehn (1997) reported that in 1961-62, extensive and large-scale poisoning was conducted to eradicate common carp from dams in south Gippsland, Victoria, Australia, and a total of 1,300 dams were poisoned with limil, santobrite, or rotenone. The treatments were deemed successful from surveys in the following year. Residues of sodium pentachlorophenate were detrimental to fish during early developmental stages, causing excessive mortalities and teratogenesis, especially in goldfish (Lennon et al. 1970). The chemical is a suspect carcinogen and is banned by the EPA.

Sumithion®.—Perschbacher and Sarkar (1989) compared the toxicity and cost of a number of candidate piscicides in bioassays against snakehead. They concluded that a concentration of 14 mg/L of Sumithion® (O,O-dimethyl-O-[3-methyl-4-nitrophenyl] phosphorodithioate) was required to kill all of the fish and that it was too expensive for use as a piscicide.

Tobacco waste.—Tobacco wastes are used as a piscicide at about 2,000 kg per ha in ponds in Taiwan. The combination of nicotine from the tobacco and oxygen-depletion resulting from the decomposition of the plant acts to poison and suffocate fish, fish parasites, and possibly bacteria (Lennon et al. 1970). Nicotine was less toxic to aquatic insects than to fish. Konar (1970) described the use of nicotine as a fish-collecting aid and toxicant. Rohu exposed to 3.2 mg/L of nicotine and punti exposed to 5.0 mg/L surfaced within 5 to 10 min and recovered within 2 to 4 min in fresh water. Some of the fish remaining in the solutions were killed.

Toxaphene.—Toxaphene is a mixture of polychloro bicyclic terpenes with a predominance of chlorinated camphene. It is a highly toxic insecticide and was first tested against fish by Surber (1948). He observed that 0.04 mg/L of Toxaphene killed all fish in a small pond. Toxaphene is more toxic to fish than rotenone, but the killing action is slower, extending over a period of days. It is also less expensive than rotenone. However, it is more toxic to warm-blooded animals and may persist for several months. McCarraher and Dean (1959) reviewed the results of 4 years of reclamation efforts with Toxaphene in Nebraska lakes. They found that at least 0.5 mg/L of Toxaphene was required for complete fish kills in Sand Hill Lakes having moderate alkalinity, high turbidity, and pH ranging from 8.5 to 9.5. They reported extensive waterfowl kills during aerial applications of Toxaphene and suspected kills of other wildlife. The use of Toxaphene in

the United States was banned in 1963 by the U.S. Department of the Interior because of its persistence in water, its high toxicity to invertebrates and vertebrates, especially waterfowl, and the accumulation of residues in plants and animals (Dykstra and Lennon 1966).

Selective Piscicides

DANEX-80.—Ari (1990) reported on the use of DANEX-80 (80% dimethyl-1,2,2-trichloro-1-hydroxyethylphosphonate as the active ingredient) for removing tilapia from common carp-rearing ponds. DANEX-80 is a relatively inexpensive insecticide. Concentrations of 40 mg DANEX-80/L selectively removed the tilapia. However, 150 mg/L killed the common carp as well.

DDVP.—Srivastava and Konar (1966) reported that DDVP (Vapona® or Dichlorvos) is a promising selective toxicant for predaceous fishes and insects and competitor fishes in fish culture ponds in India. The lethal doses for fish are much higher than those for aquatic insects. Konar (1969) conducted comparative trials of DDVP and phosphamidon, both organophosphorus insecticides, and demonstrated that DDVP is superior to phosphamidon because it is more efficacious against fish, is not adversely affected by turbidity, and degrades more rapidly.

Dibrom®-malathion.—Hoff and Westman (1965) evaluated the toxicity of a 3:2 mixture of Dibrom® and malathion (active ingredients) at 0.1 mg/L in softwater ponds. They reported that white perch, chain pickerel, bluegill, pumpkinseed, and other sunfishes were controlled selectively without harming largemouth bass. Other tests in hard water failed to demonstrate the selective toxicity of the chemical mixture.

Euphorbia antiquorum extract.—*Euphorbia antiquorum* is a succulent species of plant indigenous to India. Thomas et al. (1997) described the use of extracts of *E. antiquorum* for selective removal of guppies from prawn culture. Concentrations of approximately 100 mg/L were effective for removing fish. All the prawns survived even at a concentration of 700 mg/L.

GD-174.—Marking (1974) described the toxicity of 2-(digeranylamino)-ethanol (GD-174) to a number of freshwater fish species in laboratory studies with the most notable being the relative sensitivity of common carp. Common carp are considered an undesirable nonnative fish in many bodies of water in the United States. The compound was several times more toxic to common carp than to centrarchids. Marking (1974) also reported the chemical was relatively nonpersistent in aquatic solutions. Gilderhus and Burress (1983), however, conducted 23 pond trials in which 19 trials failed to kill all of the common carp. They were unable to identify the cause of the failure, but suggested that multiple environmental factors may have been involved in the unpredictable loss of activity. Additional studies to determine the mechanisms responsible for the selectivity and the loss of activity should be conducted. Other chemicals with similar structure to GD-174 may exhibit selectivity without interference by environmental factors.

Guthion®.—There have been anecdotal reports by fish farmers that Guthion® is effective for selective removal of centrarchids from bait minnow ponds. The chemical is generally regarded as unsuited for such use in catfish ponds, but Meyer (1965) treated ponds in Arkansas with Guthion® and effectively removed green sunfish and other undesirable species without harm to channel catfish. Water quality and temperature had little effect on the performance of Guthion®. The chemical is highly toxic to mammals.

Malathion.—Malathion is biologically active against fish and aquatic invertebrates (Walker 1969). There is a wide range of toxicity among fish species (parts per billion to several parts per

million) depending on exposure, temperature, pH, and water hardness. Fish farmers have made use of this differential toxicity to control predaceous or competitor fishes in production ponds (Walker 1969). Undesirable sunfishes have been removed selectively from minnow ponds by applying 0.5 mg/L of malathion (U.S. Bureau of Sport Fisheries and Wildlife 1970). Malathion is a cholinesterase inhibitor.

Phosphamidon.—Srivastava and Konar (1965) determined the toxicity of phosphamidon (Dimicron) to rohu, and predatory fishes, such as cuchia, koravai murrel, nandus, khalisa, climbing perch, and tengra. They concluded that predatory fishes and predatory insects could be eradicated without harm to the common carp.

Sodium sulfite.—Westman and Hunter (1956) applied 168 mg/L of sodium sulfite to a small pond to salvage and/or reduce the numbers of fish. They concluded that salvage operations would be practical in small bodies of water, but that the compound is too expensive for large waters. Sodium sulfite lowers the concentration of dissolved oxygen in the water and fish suffocate. Affected fish are salvaged by removing them to fresh water. Vanderhorst and Lewis (1969) used cobalt chloride to catalyze sodium sulfite and concluded that the combination had promise for selective removal of fish, particularly channel catfish.

Squoxin.—Squoxin (1,1'-methylenebis[2-naphthol]) was reported by MacPhee and Ruelle (1969) to be a selective piscicide against the northern pikeminnow. The ability to selectively control the northern pikeminnow is of interest because of the damage (both predatory and competitive) this species causes to trout and salmon in the northwestern United States. Concentrations of 15 µg/L killed northern pikeminnow but caused no adverse effects on other tested species of aquatic plants, zooplankton, invertebrates, insects, amphibians, reptiles, birds, mammals, and fish (Tarr 1985). The toxic concentration of Squoxin is 30-fold lower for northern pikeminnow than for steelhead trout (Tarr 1985). Squoxin decomposes rapidly in water to form a number of oxidation products (Oliver et al. 1983). There has been considerable research effort expended on the development of Squoxin as a selective piscicide, however, it is currently not registered for use in the United States.

Thanite.—Thanite (isobornyl thiocyanoacetate) was first found to have anesthetizing and killing properties when Summerfelt and Lewis (1967) screened 40 chemicals for potential fish repellency. Thanite repelled green sunfish at concentrations from 2 to 20 mg/L and killed them at 0.5 mg/L if the exposure lasted 6 hours. The compound first anesthetizes the fish, allowing desirable species to be collected easily at the surface. Lewis (1968) demonstrated that largemouth bass collected from the surface of a pond treated with thanite would rapidly and completely recover when transferred to fresh water. He also found that centrarchids were selectively killed in the presence of ictalurids and cyprinids. Cumming et al. (1975) and Burress et al. (1976) confirmed these observations in a series of pond studies. Thanite is believed to deactivate cytochrome oxidase in fish through the reaction of cyanide with the trivalent iron of the enzyme (Cumming 1975). When fish are treated with thanite, cyanide and increased lactic acid are found in the blood, and fish exhibit symptoms of hypoxia (Hunn 1972).

Toxaphene.—Fukano and Hooper (1958) observed that 5 µg/L of Toxaphene in hard water killed small fish, but left large bluegill and largemouth bass unharmed. They suggested that the compound may have potential as a selective poison. Henderson et al. (1959) observed some selectivity for certain species. Toxaphene, however, is persistent in the environment.

Toxic Baits

Rotenone.—Rotenone impregnated baits were developed, primarily for control of common carp and grass carp. Nontoxic pellets were used for about 2 weeks to train the target fish to congregate and begin feeding before switching to the toxic bait. However, due to stability problems, these baits are no longer registered or available for use (see Chapter 6).

Antimycin.—An antimycin impregnated bait was recently develop for controlling common carp (Rach et al. 1994). It contained about 0.1% antimycin in fish meal, binder, and water. Preliminary trials resulted in 19% to 74% reduction in abundance of common carp. This was an experimental formulation that was never registered for use (see Chapter 6).

Calcium carbide.—Huston (1955) described an innovative technique for selectively poisoning common carp with calcium carbide impregnated bait. Pellets of the compound were coated with beef tallow, paraffin, liquid plastic, or placed in gelatin capsules to make them waterproof and attractive to common carp. After the pellets were ingested, the coating material dissolved, and carbide reacted with liquid in the gut to form a large quantity of acetylene gas. The inflation of the gut led to death of the fish. Results were inconsistent and were not always selective. Calcium carbide is not selectivity toxic; the method of delivery allowed selectivity for common carp.

Ichthyothereol.—People in the Lower Amazon basin in Brazil have used the leaves of the small herb *Ichthyothere terminalis* as a fish poison for many years (Cascon 1965). The leaves are incorporated into baits prepared with locusts or manioc flour, and the baits are thrown into the water to be swallowed by fish. The active ingredients in the herb leaves are ichthyothereol and ichthyothereol acetate.

4.3 Rating Chemicals for Their Potential Use as Piscicides

In order to better evaluate these chemicals for their potential for controlling nonnative fishes, a rating system was devised (Appendix D). The chemicals presented in Appendix C were given overall ratings for their potential as piscicides on the basis of eight criteria: selectivity among fish taxon, ease of application, toxicity to nontarget organisms, safety to humans, persistence in the environment, tendency to bioaccumulate, cost, and registration status. Only five of the chemicals achieved ratings indicating a good overall potential for use as a piscicide (score of 75 or greater; Appendix D). As might be expected, those included the registered piscicides antimycin, rotenone, TFM, and Bayluscide®, and Squoxin, a candidate selective piscicide. Several other chemicals had ratings in the high 60s and low 70s and may deserve consideration for development as piscicides. These include *E. antiquorum* extract (rating of 71), GD-174 (73), lime (73), ozone (68), potassium permanganate (68), sodium nitrite (68), and sodium sulfite (73). However, most of these chemicals tended to score high because they are relatively benign, not because they are particularly effective piscicides. Before these chemicals could be used in the United States as piscicides, additional data on efficacy and safety would be required to obtain a registration with the EPA. Requirements for developing a piscicide for registration are presented in Chapter 8 of this report.

Chapter 5. Successes and Failures of Using Piscicides

by Verdel K. Dawson

Graham (1944) glibly stated the following about species introductions: "When a species is introduced into an area where it has not lived before, it is almost impossible to foretell the consequences, although it is quite probable that it will either succeed gloriously or eventually fail entirely." Assessing the success or failure of a species introduction, regardless of whether or not the introduction was intentional or accidental, should include not only whether the species became established, but also whether the introduced species negatively affected native species. Using these assessment criteria, many fish introductions would be classified as failures. Documented uses of piscicides have included both successes and failures. A review of some of those successful and failed applications may provide some insight concerning the criteria for successful piscicide treatments and ways to avoid some problems.

Titcomb (1914) was one of the earliest to describe uses of poison to remove unwanted fish from a body of water. Copper sulfate, an algicide known to be toxic to fish if used at high concentrations, was used to exterminate introduced species from Silver Lake, Vermont. The lake was treated with 1,225 kg of copper sulfate dragged in bags over the lake's surface, and because this treatment was insufficient, an additional 1,633 kg was added to the lake that had an area of <26 ha and a maximum depth of 7.6 m. The second treatment was only partly successful.

Many substances have since been reported to be toxic to fish, but in most instances, poisoning of fish has been incidental to their intended uses. Solman (1950) discussed the use of several potential control chemicals including a pulp processing chemical (phenyl-mercuric lactate), a water-soluble fraction of crude oil, insecticides (DDT [1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane], chlordan, Toxaphene, tetraethyl pyrophosphate, and rotenone), herbicides (2,4-D®, tributyl phosphate), and chlorinated hydrocarbons (such as benoclor), HTH (calcium hypochlorite), and cresol. Some were successful, but many were not.

The first documented use of rotenone in fishery management was by the Michigan Institute of Fisheries Research in 1934 (Solman 1950). Two small ponds on a private estate in Michigan were treated with an aqueous solution of powdered *Derris* spp. root (5% rotenone) to remove abundant common carp and goldfish. Some fish survived, probably because of the relatively weak concentration of rotenone used (< 0.1 mg/L). A lake in Michigan was also treated with *Derris* to remove a population of stunted yellow perch so that it could be restocked with trout. The treatment was only partly successful. However, over the next few years, the chemical was used to successfully eliminate yellow perch from several other Michigan lakes (Ball 1948).

By 1938, the National Park Service and the states of Illinois and New Hampshire were beginning to use rotenone for fish management (Solman 1950). For example, New Hampshire

began work on reclaiming streams with rotenone, and *Derris* was used on a larger scale to successfully treat 145-ha Back Lake (Siegler and Pillsbury 1946). The 121-ha Sabbath Day Lake, Maine, also was treated. November was chosen for this treatment because the lake was at the turnover state that favored distribution of the poison by vertical currents to deeper water; however, the toxicity of the poison was reduced by low water temperature (4°C). During this treatment, approximately 200,000 white perch and 300,000 other fish were removed (Solman 1950).

Until 1938, poisons had been used solely for eradicating entire fish populations from bodies of water. In that year, Stillman Wright introduced the concept of selective poisoning (Greenbank 1940). At Fish Lake, Utah, he spread *Derris* in shoal areas at each end of the lake where chub gathered in large numbers to spawn. Although many chub were killed, the brook trout that congregated in the main part of the lake, remained unharmed. In 1939, Greenbank (1940) applied the concept of selective treatment in a somewhat different manner. By applying rotenone in August to two thermally stratified lakes (each about 15 m deep), he was able to successfully eliminate the warmwater species (yellow perch, rock bass, largemouth bass, and others) while not harming the coolwater species (rainbow trout, brook trout, brown trout, lake trout, and white suckers). The coolwater fish congregated below the thermocline where the *Derris* presumably would not penetrate and were not affected by the chemical treatment. Greenbank concluded that in lakes deep enough for species segregation, selective poisoning could be carried out satisfactorily. Smith (1950) agreed, stating that "selective poisoning of undesirable fish in a lake without materially affecting game fish, thus reducing population pressure against the latter and presumably improving the habitat for them, has been found possible if the undesirable and game fish are segregated by habitat preferences."

Prevost (1960) recognized that poisoning fish was the best lake rehabilitation tool available. Hooper et al. (1964) concluded that rehabilitation of a lake trout fishery was sound management where fishing pressure was moderate to heavy, and the chances of reintroduction of undesirable fish were low. Dykstra and Lennon (1966) recognized the growing concern and mounting public interest in the effects of toxic chemicals on human health. They believed it was, in large measure, because of the publicity surrounding the book "Silent Spring" by Rachel Carson, published in 1962.

The waters in Strawberry Valley, Utah, were chemically treated with rotenone in 1990 to restore a recreational salmonid fishery. This treatment was one of the largest chemical rehabilitation projects ever undertaken. Approximately $3.8 million were required to complete the task. The treatment was considered successful; fishing pressure, fishing success, and the size of the fish caught by anglers have all increased following the treatment. However, Utah chub and Utah sucker have since reappeared in the reservoir (Lentsch et al. 2001). Fish managers generally concede that successful eradications often require multiple treatments. As an example, a tributary of Yellowstone Lake, Wyoming, was treated with antimycin in 1985 and again in 1986 to preserve a population of Yellowstone cutthroat trout that were being threatened by an introduced population of brook trout. Post-treatment surveys in 1987, 1988, and 1989 indicated that brook trout were eliminated after the second treatment (Gresswell 1991).

While there have been many successful piscicide applications, there have also been notable failures. One example is the runaway rotenone application on the Green River, Utah, in 1962. The intention was to apply potassium permanganate to detoxify rotenone at the lower reach of the treated zone. Rotenone concentrations were higher than expected and insufficient quantities of potassium permanganate were available. Consequently, the project caused unexpected fish mortalities that had far-reaching impacts on politics and management policies. Many native fishes are now protected by law, and there is no question that the Green River project helped

speed the process that brought about awareness not only of the native fishes but also of the natural ecosystems on which they depend (Holden 1991). Another type of "failure" is represented by the rotenone treatment of Lake Davis, California, for control of northern pike. Lake Davis was treated in 1997, but the presence of northern pike in Lake Davis was again verified in 1999. A list of 40 alternatives for controlling northern pike at Lake Davis was eventually condensed to 12 containment and control actions to be implemented during 2000. Chemical treatment of the lake was not included as a control action because of concern for possible harmful chemicals in formulated rotenone (Lee 2001).

LesVeaux (1959) conducted a survey of the United States and Puerto Rico and summarized their findings of fishery management problems around the country. Although he found a diversity of opinion among aquatic biologists, he also discovered that some concerns were region specific. New England wanted an improved general toxicant, the South and Southeast wanted to eradicate gizzard shad from bass waters, the North Central region wanted to eradicate common carp, and the Mountain and West Coast states wanted to eradicate common carp and suckers from trout waters. He concluded that more research was required to find improved specific and general piscicides. However, he recognized that even after discovery of an effective chemical, its application would be impeded by state laws, public opinion, and political obstacles.

Lennon et al. (1970) were commissioned by the Food and Agriculture Organization of the United Nations to review the literature on the reclamation of ponds, lakes, and streams with fish toxicants. As part of this task, they circulated a questionnaire to 1,300 locations around the world concerning the use of toxicants for removal of undesirable fish. The survey showed that as of 1970, 49 U.S. states and at least 29 countries had used chemical methods to manage populations of undesirable fish. The results also indicated that sport fishing was improved in the vast majority of lakes that received total treatments. Partial treatment on the other hand had not been as successful, but had the benefits of reduced costs. Chemicals were also being used in reclamation of streams and rivers. Although many successfully completed projects were identified, some problems frequently encountered during treatments were as follows:

1. The justification for reclamation often was not adequately demonstrated. Therefore, target fishes may not have been well-defined, or no evidence was provided to conclude that the target fish were the cause of the problem and that their elimination would improve the fishery.

2. The biology of target species in the water to be treated was seldom investigated or reported.

3. A novice crew was often assigned to reclaim a body of water, and the numbers of some crews were too small to efficiently execute pre-treatment, treatment, and post-treatment operations.

4. Pre-treatment surveys on the biology and chemistry of receiving waters were frequently lacking or were inadequate to detect and evaluate factors that may have influenced the performance of a toxicant and compromised the success of reclamation. For example, low temperature or high turbidity may have reduced the effectiveness of rotenone, or high pH may have caused rapid degradation of antimycin. Another overlooked fact was that target fish must be exposed to a given concentration of toxicant for a defined length of time for death to occur. Fishery managers often underestimated the importance of on-site bioassays of a candidate toxicant against target fishes in the particular receiving water to delineate the dose (concentration × exposure) needed to produce the desired effect.

5. Post-treatment surveys of chemical applications were often sketchy, and objective evaluations of treatment effectiveness were conspicuously absent in much of the reclamation literature. If evaluations were mentioned at all, they were usually subjective or reported as being in progress.

6. The toxicants or formulations selected may have been inappropriate for the management application. Residues of some toxicants were persistent in some waters, contaminating invertebrates, fish, and wildlife for months or years thereafter. Moreover, some insecticides that were used as fish toxicants were damaging to aquatic invertebrates that were an important forage base for resident fish. Toxicants applied in agricultural formulations may have failed to penetrate thermal barriers, thus permitting target fish in deep water to escape poisoning.

7. Application methods were often deficient. Improvised equipment for dispensing and dispersing toxicants in water were often primitive and inefficient.

8. Economic considerations, rather than biological and chemical factors, often governed the selection of a toxicant or formulation and the application. Seldom was recognition given to the fact that the cost of a toxicant was only a fraction of the total cost of a reclamation project and that true economy could be achieved by using the best toxicant for the job.

9. The value of barriers and other measures to prevent re-infestation of reclaimed waters by undesirable fish had been proven; however, the benefits of many reclamations were short-lived because appropriate steps were not taken to prohibit the rapid return of unwanted fishes.

10. Many fishery managers viewed fish toxicants as a panacea and that a single application would correct problems and result in bountiful fishing for a long time. Few recognized that some intensively fished and managed waters may have to be re-treated regularly with toxicants to remove undesirable fishes to enhance survival/growth of desired fish. Conducting extensive pre-treatment biological surveys are cost-effective when multiple-year treatments are likely to be necessary. Also, better treatment efficiency will often result from knowing which biological life stage and/or habitat occupied by the target organism is most vulnerable to a particular piscicide.

Lopinot (1975) summarized the use of toxicants for rehabilitation of fish populations in the Midwest. He stated that more than 405,000 ha of water were treated with fish toxicants in the United States from 1954 to 1973. He indicated that the Midwest region had more than 2.4 million ha of lakes, reservoirs, and ponds exclusive of the Great Lakes and Mississippi River backwaters. Not all of this acreage could produce satisfactory sport fishing without manipulation of the fish populations. In 1963-72, a total of 49,000 ha of water (an average of more than 4,900 ha per year) and nearly 6,800 km of streams were treated with piscicides to improve the fishery. According to Lopinot (1975), about 82% of such treatments were considered successful. In 1972, the most popular fish toxicant was rotenone, followed by antimycin. Other toxicants used were Toxaphene, sodium cyanide, and Thiodan® (Endosulfan). The type of treatment and total number of waters treated in the Midwest in this 10-year period were (1) 5,597 treatments for complete eradication in 36,000 ha, (2) 377 treatments for partial eradication in 9,000 ha, and (3) 133 treatments for selective eradication of certain species in 3,700 ha. One of the most successful selective piscicide programs has been the Sea Lamprey Control Program in the Great Lakes. See Chapter 11 for a thorough exposition of this program.

Meronek et al. (1996) reviewed 250 fish reclamation projects from peer-reviewed literature and agency publications and reports. They determined the success rates of chemical and physical fish control methods, stocking, and combinations of these methods. The projects occurred on water bodies ranging from 0.2 to 55,752 ha from 36 U.S. states and 3 countries. Fish species were designated as game fish, panfish, or rough fish for the purposes of the review. Chemicals used in treatments included rotenone, antimycin, copper sulfate, Squoxin, and Toxaphene. Physical treatments included removal of fish by nets, traps, seines, electrofishing, and increased predation by means of reservoir drawdown. They judged success from changes in standing stock, growth, proportional stock density, relative weight, catch to harvest rates, other intangibles (e.g., angler satisfaction), and the authors' conclusions (although they did not always agree). Generally, they required evidence of improvement documented over a period of at least 1 year post-treatment to classify a treatment as successful. Occasionally they considered a project successful when it was based on data collected less than 1 year after treatment if the standing stock of the target species was substantially reduced. The most common determinant of success was a reduction in standing stock of the target species. When more than one criterion was considered, the second determinant was improved catch or harvest of sport species. If the only evidence of success offered was reduction of a target species, success may have been overestimated if there was not a corresponding improvement in the standing stock or harvest of desired species. Overestimation of success may also have been caused by any bias against publishing results of unsuccessful fish control projects.

In the review by Meronek et al. (1996), panfish were the target species in 124 of the 250 treatments, followed by rough fish (92) and game fish (12) whereas 22 projects targeted more than one group. Success was greater for control of rough fish (53%) than for the other categories. Success rates were 40% for panfish, 42% for game fish, and 23% for the mixed categories. Of the 221 fish control projects that reduced target species without stocking piscivores, 170 (77%) attempted partial reductions, and 51 (23%) sought total elimination. Projects that attempted total elimination had a greater mean success rate (63%) than those that attempted partial elimination (40%). The success of fish control projects was not strongly related to the size of the water body.

Chemical treatment, predominantly rotenone and antimycin, was the most commonly identified method of fish control (used in 145 or 58% of the projects). Rotenone was successful in 48% of projects and antimycin in 45%. Rotenone was used more often for rough fish and antimycin was used more often for panfish. Of the six projects that used a combination of chemical and physical treatments, four (67%) were successful. In 17 projects, chemical or physical treatment was followed by supplemental stocking of piscivores to control other fishes; 10 (59%) of these projects were considered successful.

Overall, Meronek et al. (1996) considered 43% of the 250 projects successful, 29% unsuccessful, and 28% as having insufficient data to determine success or failure. The authors of the papers reviewed considered 54% of the projects successful, 29% unsuccessful, and 17% as lacking sufficient data. Differences in ratings were usually because of bias derived from short-term assessments by authors. These results suggest that there was considerable room for improvement of fish control projects; less than 50% of 250 fish control projects were considered successful. Meronek et al. (1996) recommended that fish control projects include explicit rationale, objectives, and pre-treatment and long-term post-treatment studies. This could allow for objective determination of whether fish control projects were successful or determine the reasons for failure.

Some authors have concluded that reclamation of waters using fish toxicants is the best tool available to fishery managers. In general, the better studied and more carefully executed

projects have been more successful. Continuing research on (1) general and selective toxicants, (2) formulations for aquatic use, (3) means for distributing toxicants in water, (4) controls to be integrated with toxicants, and (5) survey and assessment equipment and techniques will help improve the success ratio for reclamation (Lennon et al. 1970).

Based on surveys of past chemical treatments, currently available piscicidal treatments do not provide a panacea for fishery managers. While there are a number of success stories, there seem to be almost as many failures. There apparently needs to be improvements made in the piscicides or piscicide formulations that are available and the methods of application. Chemical treatment projects could also benefit from better planning. It appears that piscicides should be considered as one tool that should be used in conjunction with a variety of integrated pest management techniques to effectively control unwanted fish species.



Chapter 6. Delivery Systems of Piscicides

by Michael A. Boogaard

Successful application of chemicals to control or eradicate invasive fishes depends on the system used to deliver the piscicide into the aquatic environment. Delivery systems can consist of combinations of various piscicide formulations and application techniques. This chapter highlights current formulations of piscicides and the techniques and equipment used to deliver them to the aquatic environment. Factors to consider when choosing a delivery system for a chemical control treatment include (1) the formulation and amount of the toxicant, (2) the objectives of the application, (3) the area and depth of waters to be treated, (4) the physicochemical characteristics of the waters to be treated, (5) treatment site accessibility, (6) the obstacles that prevent complete distribution and dispersion of the toxicant, (7) concerns of chemical toxicity to applicators and nontarget organisms, (8) the speed with which the application must be completed, (9) the time of year when the application must be made, and (10) the residual of the toxicant in water over time and distance (Lennon et al. 1970).

A piscicide is rarely applied in its pure form (i.e., as the active ingredient). Instead, it is mixed with inert ingredients to create a formulation that allows safe and effective application of the piscicide. Trade names, active and inert ingredients, and manufacturers of each formulation of piscicide registered by the EPA are given in Table 6-1. Piscicides are generally formulated as either liquids or solids. Liquids exist as emulsifiable and water soluble concentrates. Emulsifiable concentrates are formulated for active ingredients that are insoluble in water. The active ingredient is dissolved in an appropriate solvent and emulsifiers are added to allow the piscicide to be effectively and uniformly mixed with water. When applied to water, emulsifiable concentrates form a suspension or emulsion of the active ingredient in the water column. The emulsion allows the active ingredient to be delivered to the target organism. Water soluble concentrates are formulated with water or a water-soluble solvent that allows the active ingredient to dissolve in water. When applied, the result is a true solution of the piscicide in water.

Piscicides formulated as solids include bar formulations, wettable powders, and granules. Bar formulations contain the active ingredient incorporated into a matrix of one or more surfactants. The resulting bar, when applied to the treatment area, allows the piscicide to be released slowly and uniformly as the bar dissolves in water. Wettable powders consist of the active ingredient combined with a dry diluent, such as clay or talc. These formulations may also include wetting or dispersing agents that help keep the formulation in suspension when applied. Wettable powders are often mixed with a small amount of water to form a slurry before application. In granular formulations, the active ingredient is coated on inert particles, usually sand. When

Table 6-1. Chemicals, trade names, active and inert ingredients, and manufacturers of currently registered piscicide formulations.

Chemical	Formulation	Formulation active ingredient	Inert ingredients	Manufacturer(s)
TFM	Lampricid® TFM Sea Lamprey Larvicide	36-40% 3-trifluoromethyl-4-nitrophenol Other TFM-related ingredients: 1.5-4.0% 4-hydroxy-3-nitrobenzoic acid 3.0-8.0% 3-nitro-4-hydroxybenzoic acid 2.0-6.0% 5-trifluoromethyl-2-nitrophenol	35-43% water 11-13% isopropyl alcohol 6.4-7.8% sodium hydroxide	Clariant LSM (America), Inc. 3411 Silverside Road Wilmington, Delaware 19810 Kinetic Industries, Inc. 139-36 58th Avenue Flushing, New York 11355-5311
TFM	TFM Bar	22-24% 3-trifluoromethyl-4-nitrophenol	21.3% magnesium silicate <4.2% sodium lignosulfonate 0.9-1.0% amorphous silica <1.1% alkylated napthylene sulfonate, sodium salt <0.1% crystalline silica	Bell Laboratories, Inc. 3699 Kinsman Boulevard Madison, Wisconsin 53704
Niclosamide	Bayluscide® 70% Wettable Powder	69-74% niclosamide ethanolamine salt	21.3% magnesium silicate <4.2% sodium lignosulfonate 0.9-1.0% amorphous silica <1.1% alkylated napthylene sulfonate, sodium salt <0.1% crystalline silica	Pro-Serve 400 E. Brooks Road PO Box 161059 Memphis, Tennessee 38186-1059
Niclosamide	Bayluscide® 3.2% Granular Sea Lamprey Larvicide	3.0-3.6% niclosamide ethanolamine salt	68-72% amorphous silica 18-20% polyoxyethylene-polyoxypropylene block copolymer 4.0% ethyl cellulose 2.0% hydroxypropyl cellulose salt	The Coating Place, Inc. Box 930310 Verona, Wisconsin 53593
Niclosamide	Bayluscide® 20% Emulsifiable Concentrate	20% niclosamide ethanolamine salt	64-68% N-methyl-2-pyrrolidone 12-14% coconut oil diethanolamide 1.1-1.3% diethanolamide	Pro-Serve 400 E. Brooks Road PO Box 161059 Memphis, Tennessee 38186-1059
Rotenone	5% Rotenone-Liquid	5% rotenone	80% aromatic petroleum solvent 7.5% acetone 1.5% Emulsifier #1 4.5% Emulsifier #2	AgrEvo Environmental Health, Inc. 95 Chestnut Ridge Road Montvale, New Jersey 07645 Prentiss, Inc. C.B. 2000 Floral Park, New York 11001

Table 6-1. Continued

Chemical	Formulation	Formulation active ingredient	Inert ingredients	Manufacturer(s)
				Tifa Limited 50 Division Avenue Millington, New Jersey 07946
Rotenone	2.5% Synergized Rotenone-Liquid	2.5% rotenone 5.0% other cube resins 2.5% piperonyl butoxide	90% Xylene range aromatic solvent	AgrEvo Environmental Health, Inc. 95 Chestnut Ridge Road Montvale, New Jersey 07645 Prentiss, Inc. C.B. 2000 Floral Park, New York 11001 Tifa Limited 50 Division Avenue Millington, New Jersey 07946
Rotenone	5% Powdered Rotenone	7.4% rotenone 11.1% other cube resins	81.5% ingredients (not available)	AgrEvo Environmental Health, Inc. 95 Chestnut Ridge Road Montvale, New Jersey 07645 C.J. Martin Company PO Box 630009 Nacogdoches, Texas 75963 Drexel Chemical Company 1700 Channel Avenue Box 13327 Memphis, Tennessee 38113-0327 Foreign Domestic Chemicals Corp. 3 Post Road Oakland, New Jersey 07436 Prentiss, Inc. C.B. 2000 Floral Park, New York 11001 Sureco, Inc. 9555 James Avenue South Millington, New Jersey 07946

Table 6-1. Continued

Chemical	Formulation	Formulation active ingredient	Inert ingredients	Manufacturer(s)
				Tifa Limited 50 Division Avenue Millington, New Jersey 07946 Zeneca Agro 250-3115 12 th Street NE Calgary, Alberta T2E 7J2 Canada
Antimycin	Fintrol® Concentrate	23% Antimycin A	77% inert ingredients (not available)	Aquabiotics Corporation 10750 Arrow Point Drive Bainbridge Island, Washington 98110

applied, the piscicide slowly releases as the granule sinks through the water column. In addition, some granular formulations incorporate an outer coating of surfactant-like materials to allow the granule to sink to a certain depth or to the bottom before the piscicide is released.

As presented earlier, only four chemicals are currently registered by the EPA for use as piscicides: TFM, Bayluscide®, antimycin, and rotenone. Because the goal of the present chapter is to provide a thorough description of delivery systems used to apply piscicides, descriptions of delivery methods and formulations of all four registered piscicides will be presented. TFM and Bayluscide®, however, are registered only for use in the control of sea lamprey in tributaries to the Great Lakes with the exception of Bayluscide® that is also registered for use in snail control. Labels and Material Safety Data Sheets of all piscicides currently registered with the EPA are in Appendix F.

6.1 Lampricides

TFM Sea Lamprey Larvicide

The lampricide TFM is a primary management chemical tool used to control parasitic sea lampreys in the Great Lakes basin. A water soluble concentrate form is used in field operations and is formulated as a sodium salt of the active ingredient dissolved primarily in isopropanol and water. The formulation is about 36% active ingredient. The amount of TFM applied to water during a treatment depends on the flow rate of the water being treated and the target concentration. Target concentrations are predetermined through toxicity bioassays of larval sea lamprey and one or more nontarget organisms, sea lamprey minimum lethal concentration prediction models based on the chemical properties of the water to be treated, and a review of historical treatment records of the water body. Because the toxicity of TFM is influenced by the chemical and physical properties of water, accurate measurement of stream flow rates, pH, alkalinity, and lampricide application volumes are needed to assure treatment effectiveness while protecting nontarget biota.

The lampricide TFM is applied with either a 12-volt DC peristaltic pump for smaller applications (20-600 L) or a 120-volt AC peristaltic or centrifugal pump for larger applications (> 600 L; Klar and Schleen 2000). A spreader system is used to apply the lampricide evenly across the stream. First, a perforated hose or plastic tube is situated perpendicular to the stream. Then the metered lampricide is fed into a sump where it mixes with stream water (Figure 6-1). A pump is used to deliver the diluted lampricide through the perforated hose.

Lampricide concentrations are monitored spectrophotometrically from samples collected far enough from the application site to allow complete mixing. Metering adjustments are made to the TFM concentration as needed (Klar and Schleen 2000). Volumes less than 20 L are applied with adjustable gravity-fed drip systems and are used primarily on smaller creeks and tributaries that flow into the main treatment stream. Backpack sprayers can be used to apply the lampricide directly to backwater areas that are difficult to reach with the main treatment block (Klar and Schleen 2000).

TFM Bar

The TFM Bar is a water-soluble solid formulation containing about 22% active ingredient incorporated into a matrix of two or more non-ionic surfactants. Developed by Gilderhus (1985), the bars are used to treat small tributaries (generally <85 L/sec) that flow into the main

Figure 6-1. Lampricide (TFM, 3-trifluoromethyl-4-nitrophenol) application apparatus showing treatment personnel loading Lampricid® into mixing tanks during the 1994 treatment of the Manistee River in northwestern lower Michigan.

treatment stream. When applied, the bar dissolves at a nearly constant rate over a period of 8 to 10 hours, depending on water temperature, and yields a TFM concentration of approximately 1 mg/L for every 7 L/sec of water discharge (Klar and Schleen 2000). With the development of the bar formulation, intensive stream monitoring of the lampricide concentration is no longer necessary and has thereby reduced the number of on-site personnel required to conduct a treatment. In addition, the bar formulation has allowed the successful treatment of smaller tributaries that once provided sea lampreys a refuge from the main treatment block.

Bayluscide® 70% Wettable Powder

Used in sea lamprey control operations, Bayluscide® 70% Wettable Powder (WP) is a powder formulation consisting of 70% Bayluscide® (59% active ingredient niclosamide) and 30% inert ingredients. Bayluscide® 70% WP is currently used in conjunction with TFM, primarily as a cost-saving measure to reduce the amount of TFM required to treat streams with high flows. When used in combination, the TFM:niclosamide ratio ranges from 98:2 to 99.5:0.5 (National Research Council of Canada 1985). An application of 1% niclosamide by weight of TFM reduces the amount of TFM required for efficacious treatment by up to 40%. To apply the formulation, stream water is drawn into a mixing tank where the powder is added (Figure 6-2). The resulting slurry is then metered into the stream at rates that achieve the desired percentage (0.5-2%) of the TFM concentration.

Niclosamide concentrations are monitored by high performance liquid chromatography from water samples collected at a site far enough downstream to allow complete mixing in the water. Adjustments in concentration are then made as needed (Klar and Schleen 2000).

Bayluscide® 3.2% Granular Sea Lamprey Larvicide

The granular formulation of Bayluscide® is used to control larval sea lamprey populations in lentic areas and also as a survey tool to assess larval abundance in deeper portions of streams not conducive to electrofishing. The formulation consists of Bayluscide® 70% WP coated onto sand granules with an outer coating of surfactant-like materials. The resulting formulation is

Figure 6-2. Bayluscide® 70% Wettable Powder mixing and application apparatus. The powder is mixed with fresh river water to form a slurry to facilitate application of the formulation to the river. Note the apparatus is self-contained to minimize applicator exposure to the lampricide formulation.

about 3.2% Bayluscide® by weight, and the formulation is applied over the surface of the target waters. The surfactant coating allows the granules to sink to the bottom of the water column before the active ingredient is released. The formulation has proven to be effective at killing larval sea lamprey at depths of up to 30 m. When applied according to label instructions, the result is a niclosamide concentration of about 9 mg/L in the bottom 5 cm of the water column and is effective at killing larvae within 30 min of application. A broadcast spreader mounted on the back of a boat is normally used to apply the granular formulation. Aerial applications have also been conducted, however, special permits must be obtained because this formulation is not registered for this method of application. See Chapter 11 for an example of aerial application of granular Bayluscide®.

Bayluscide® 20% Emulsifiable Concentrate

A new formulation of the lampricide Bayluscide® was recently developed for application in conjunction with TFM to control larval sea lampreys. The new liquid formulation, consisting of about 20% Bayluscide® (16% active ingredient niclosamide) dissolved in petroleum based solvents, emulsifiers, and other inert ingredients, was developed to improve the ability to apply the chemical uniformly and to eliminate the formation of dust encountered with the 70% WP during slurry formation. Because the new liquid formulation has only recently been registered

for use, application techniques have not been fully developed but will probably follow those used to apply TFM.

6.2 Antimycin

Fintrol® Concentrate

The only formulation of antimycin currently registered with the EPA is a concentrate of about 23% active ingredient. The formulation is registered as a general piscicide and is primarily used as a nonselective fish toxicant for partial or total reclamation of ponds, lakes, and streams although it has been shown to be selective for scaled fishes and is used in the aquaculture industry to rid undesirable fish species from catfish ponds. Fintrol® concentrate comes in a kit containing crystalline antimycin along with a diluent consisting mostly of acetone with other inert ingredients. Because antimycin degrades in acetone, application procedures require on-site mixing of the crystalline form and the diluent before addition to treated waters. Once the concentrate is formed, application techniques are similar to those of the lampricide TFM. Metering pumps, sprayers, and gravity-fed drip systems have all been successfully used to apply the concentrate to streams and shallow waters (Gilderhus et al. 1969, Lennon and Berger 1970, Engstrom-Heg 1971, Stefferud and Propst 1996). Fintrol® concentrate is applied to lakes and ponds with metering pumps or sprayers attached to motorized boats. The concentrate is applied to the propeller wash to aid in mixing. Deeper water can be treated using metering pumps connected to weighted perforated tubing that is lowered to the desired depth. Fintrol® concentrate has also been applied aerially. The formulation was originally applied using fixed-wing aircraft with spray booms at relatively fast air speeds. However, under these conditions the acetone carrier evaporated before the formulation reached the water causing the piscicide to precipitate and float resulting in an ineffective application. Since 1968, slower-moving helicopters have been successfully used to distribute Fintrol® concentrate to target areas (Selbig 1974).

Lethality of antimycin to fish varies from <1.0 µg/L for most salmonids to 25 to 200 µg/L for ictalurids; cyprinids and centrarchids are susceptible to concentrations of 5.0 to 10 µg/L (Berger et al. 1969). The relative resistance of ictalurids to antimycin makes it ideal for use in removing scaled fish from catfish ponds before restocking and in live-haul tanks to remove unwanted species, particularly green sunfish, from shipments of catfish fingerlings (Lloyd 1987). Gilderhus (1972) noted that at a concentration of 5 µg/L the effective exposure time to eliminate trout was 2 hours and 6 hours for common carp. Antimycin is typically applied at concentrations of ≤10 µg/L, although higher concentrations are needed in alkaline waters. Antimycin has been shown to be less toxic in waters of high pH (> 8.0; Berger et al. 1969, Schnick 1974), probably because of its rapid degradation in alkaline waters (Walker et al. 1964), and requires significantly longer contact time at lower water temperatures (< 5°C) to maintain effectiveness.

Although antimycin degrades rapidly in water (Gilderhus et al. 1969), detoxification of treated waters is sometimes necessary for partial stream reclamations or where the treated water could enter municipal water supplies. Detoxification of 5 µg/L of antimycin can be achieved with 300 µg/L potassium permanganate within 6 hours (Berger et al. 1969). Potassium permanganate, however, can be toxic to aquatic organisms (Marking and Bills 1975), and detoxification must be conducted with calibrated equipment to assure that metering rates are not excessive. Marking and Bills (1977) also found that 500 µg/L chorine detoxified 10 µg/L antimycin in 2 hours.

Fintrol® Granular Antimycin

In the late 1960s, two granular formulations (Fintrol®-5 and Fintrol®-15) of antimycin were developed for use in pond, lake, and reservoir reclamations. Developed as alternatives to the liquid formulation, these granular formulations were effective in several reclamation projects and particularly effective for removing undesirable fish species from catfish ponds. Although the formulations are no longer registered for use (annual registration renewal fees have not been paid since 1991), they do merit consideration. Fintrol®-5 consisted of a 1% by weight formulation of antimycin coated on sand. This formulation was designed to release the toxicant within the first 1.5 m of the water column and was particularly useful in shallow waters. Fintrol®-15 was a 5% formulation designed to deliver the toxicant within the first 4.5 m of the water column and was used to treat deeper waters. Both formulations were effectively delivered to target waters with broadcast spreaders mounted on boats or by aerial application. Helicopters were preferred over fixed-wing aircraft because of their maneuverability and adaptability to use varied equipment (Selbig 1974). The helicopter was equipped with a remote bucket consisting of a hopper, spreader, and a power source. Before being added to the hopper, one part granular Fintrol® was mixed with 10 parts of similar size sand because aerial application of the formulation alone could not be conducted at sufficiently low rates to achieve the desired antimycin concentration. The granular mix was routed from the hopper through an adjustable control box that delivered a specific quantity of the total mixture per unit time or surface area. From the control box, the mixture entered a powered spreader device that applied a uniform swath (Selbig 1974). In addition, granules could be applied by hand while the helicopter was hovering. This method used the wind turbulence from the helicopter rotors to uniformly disperse the granules and was particularly useful when treating small ponds or ditches or areas that were difficult to access by land (Selbig 1974).

In addition to Fintrol®-5 and -15, an experimental timed-release granular formulation of antimycin was developed by Gilderhus (1979) for controlling larval sea lampreys in lentic habitats. The 1% formulation proved effective in three of four lake trials, killing about 90% of larvae in 0.74- to 1.5-ha plots applied at 75 g/ha. In a similar study, a 0.25% granular formulation of antimycin was applied to the mouth of the Falls River, Baraga County, Michigan, resulting in a treatment effectiveness similar to that observed with the 1% formulation (Terry D. Bills, Great Lakes Fishery Commission, unpublished data). Although successful, registration of the timed-release formulations were not pursued because of the uncertain registration status of the parent compound.

6.3 Rotenone

Rotenone 5% and Rotenone 2.5% Synergized Liquid

Two liquid formulations of rotenone are currently registered by the EPA for use as general piscicides. Rotenone 5% consists of 5% active ingredient rotenone, emulsifiers, petroleum-based solvents, and other inert ingredients. Rotenone 2.5% Synergized is a synergistic formulation containing 2.5% active ingredient rotenone and 2.5% of the synergist piperonyl butoxide (PB), a derivative of piperic acid. Although Rotenone 2.5% Synergized contains only half of the active ingredient of its counterpart, its toxic effects are similar when applied at the same rates. Rotenone 2.5% Synergized was at least twice as toxic to rainbow trout as rotenone 5%, based on the amount of active ingredient (Marking and Bills 1976). Although the EPA does not recognize the effect of the synergist on the label instructions, the Canadian (Health Canada) label does and most applicators apply Rotenone 2.5% Synergized and Rotenone 5% at the same rates (Finlayson et al. 2000). It is unlikely, however, that PB will remain as a synergist in the 2.5% formulation for long. The registrants are no longer willing to support its aquatic use

because of the extensive data requirements for registration. A third liquid formulation of rotenone is currently being developed that does not contain the petroleum-based solvent that fish are suspected of avoiding.

Treatment concentrations range from 0.005 to 0.25 mg/L rotenone. The degradation rate of rotenone is affected primarily by temperature and sunlight (Gilderhus et al. 1986, Finlayson et al. 2000). The half-life of rotenone in water at 24°C was 13.9 hours compared to 83.9 hours in water at 0°C (Gilderhus et al. 1986). Alkalinity and pH also influence rotenone degradation. Waters with high alkalinity and pH degrade rotenone faster than waters of low alkalinity and pH (Finlayson et al. 2000). Additional rotenone is required in waters with high pH, alkalinity, sunlight penetration, and in waters organically rich with high volumes of suspended solids. Gilderhus (1982) noted that suspended clay particles reduced rotenone efficacy. Dawson et al. (1991) found that some rotenone was bound to suspended material in the water and that rotenone in the bottom sediments could take up to 14 days to decay below detection limits.

Several techniques have been developed to apply liquid rotenone to a variety of aquatic systems. Finlayson et al. (2000) described these techniques and recommended application rates based on the physicochemical characteristics of the water to be treated and the fish species targeted for removal. Treatment of smaller ponds was accomplished from shore or small boats with conventional commercial pesticide sprayers. Sprayers can be hand pumped, electric, or gas-powered equipped with 10- to 300-L tanks and can be mounted on backpacks, pick-ups, all terrain vehicles, or in small boats. Larger ponds, lakes, and reservoirs required gas-powered pumps using a venturi boat bailer system to deliver the liquid formulations to the water surface. Once applied, the liquid formulations readily disperse horizontally and vertically in shallow waters. Extended discharge hoses are weighted to prevent the hose from surfacing when treating deeper waters with a strong thermocline. Vertical mixing can be further facilitated by extending the water pump suction line near the bottom to draw cold, dense water to the surface where the rotenone is mixed (Finlayson et al. 2000). In addition, deep lakes were successfully treated in Michigan and Minnesota just before or during ice cover using lower concentrations of rotenone. Rotenone remains toxic longer in cold water providing longer exposure time. Concentrations of rotenone remained toxic for up to 2 months when applied to waters at these temperatures (Finlayson et al. 2000).

Aerial applications by fixed-wing aircraft or helicopters have been used for rotenone treatments when application by boat cannot be completed in a timely manner. In aerial applications, large droplets or streams of dilute rotenone are the preferred method of application over mist or small droplets. Mist or small droplet applications may result in drift that can reduce treatment efficacy and increase the risk of detrimental effects on nontarget organisms because of uncontrolled dispersion (Finlayson et al. 2000).

Application of liquid rotenone to rivers and streams is accomplished using techniques similar to those used to apply the lampricide TFM. Continuous drip systems (smaller streams) or metering pumps (larger streams and rivers) are used to deliver the chemical.

Depending on access, application sites are spaced at intervals sufficient to maintain the desired treatment concentration. For remote streams, liquid rotenone can be applied using a lightweight, constant-flow drip system that is easily portable. Originally developed by Stefferud and Propst (1996) for applying antimycin, this drip system can apply rotenone with better precision and consistency than drip systems used previously.

Powdered Rotenone 5-7.5%

Powdered rotenone is a formulation consisting of 5-7.5% active ingredient rotenone. The powdered formulation has been used extensively since the 1960s in reclamation and survey operations. Problems associated with powder applications, such as the inability to apply uniformly, human health considerations from accidental inhalation, and the subsequent development of the liquid formulations, significantly reduced the demand for powdered rotenone through the years. In 1990, the Utah Division of Wildlife Resources treated more than 4,900 ha of the Strawberry Reservoir with the powdered formulation (Lentsch et al. 2001). Spateholts and Lentsch (2001) developed a rotenone sand mix that comprised powdered rotenone, sand, and gelatin for use on smaller seeps and springs. The mixture successfully released rotenone for up to 12 hours after application and was applied in more than 450 situations where conventional treatments using drip systems were not normally possible.

A recent survey of rotenone use (1988-97) by McClay (2000) indicates that the preferred formulation of rotenone has shifted back to the powder formulation. This trend is probably because of reduced costs and improved application techniques of the formulation. In addition, increased environmental and public health concerns over the inert ingredients in the liquid formulations may contribute to the shift back to the powered formulation. Although the liquid formulations are proven safe and effective when applied according to label directions, some agencies find it difficult to plan and execute treatments using these formulations because they require environmental monitoring studies not normally needed for the powder formulation (McClay 2000).

6.4 Toxic Baits

Toxic baits are yet another system of delivering a known piscicide to a target organism. By formulating the piscicide into an edible bait, this method allows the compound to be delivered directly to the target organism thereby significantly reducing the amount of toxicant required compared to more conventional total water column piscicide applications and also avoids exposure of nontarget species. Although most, if not all, attempts to successfully formulate a toxic bait have ended in failure, some have resulted in marketable products.

Antimycin Impregnated Bait

Developed by Rach et al. (1994) as a control method for common carp, antimycin impregnated bait consists of a formulation of about 0.1% antimycin in fish meal, binder, and water. Trials of the formulation in 0.04-ha earthen ponds resulted in a 19% to 74% reduction in the abundance of common carp. The authors strongly caution, however, that this strategy should only be used in conjunction with other management techniques and under specific conditions, such as when common carp congregate to feed or when few other nontarget bottom-feeding species are present.

Rotenone Impregnated Bait

A similar study by Bonneau and Scarnecchia (2001) investigated the use of a rotenone impregnated bait for control of common carp. They conducted field trials where common carp were fed a nontoxic bait for 2 to 3 weeks followed by one feeding of rotenone impregnated bait. Common carp ceased feeding on the toxic bait within minutes and most did not eat enough bait to receive a fatal dose. Although the study was unsuccessful, the idea showed promise, especially if a more palatable pellet could be developed. Prentiss, Inc. (Floral Park, New York), has since developed and was marketing two formulations of a rotenone impregnated toxic bait

for controlling carp. The first, Prentox® Prenfish Grass Carp Management Bait (EPA Reg. No. 655-795), is a specially formulated bait containing 2.64% active ingredient and is specifically designed to control grass carp. Field trials show that the formulation is more palatable to the plant-eating grass carp than other fish species. Success is contingent upon training the grass carp to eat the pellets. Therefore, bait stations are placed in areas of known infestation, and nontoxic pellets (Prentox® Prenfish Grass Carp Management Trainer, typically 0.5-1 kg daily) are dispersed for up to 14 days. Feed retention rings are used to limit feed pellets from spreading and to concentrate fish at the bait station. Field trials have shown that grass carp will begin feeding within 1 to 14 days. Once routine feeding has been established, the toxic form of the pellet is distributed. Oral toxicity studies by Prentiss, Inc., have shown that a single pellet of Prentox® Prenfish Grass Carp Management Bait contains enough rotenone to kill a 1-2 kg grass carp.

The second rotenone bait formulation developed by Prentiss, Inc., targets common carp. Prentox® Prenfish Common Carp Management Bait contains the same amount of active ingredient (2.64% rotenone) as its counterpart but is formulated to be more palatable to common carp. Application procedures follow those for the grass carp bait with 14 days of training (Prentox® Prenfish Common Carp Management Trainer) followed by application of the toxic form. Prentiss, Inc., claims that in one experimental trial, 3,000 common carp were removed from Crooked Lake near Chicago, Illinois, using only 13.6 kg of the poison bait. Although both bait formulations have demonstrated the potential for use in carp control, stability problems have forced Prentiss, Inc., to pull their registrations. The company has no immediate plans to pursue development of new bait formulations because of low demand for the product.

Calcium Carbide Impregnated Bait

Huston (1955) described the selective poisoning of common carp with calcium carbide. Pellets of the compound were coated with beef tallow, paraffin, liquid plastic, or placed in gelatin capsules to make them waterproof and attractive to common carp. After the pellets are ingested, the coating material dissolves, and carbide reacts with liquid in the gut to form a large quantity of acetylene gas. Inflation of the gut leads to death of the fish. Results were inconsistent and not always selective. Because of the inconsistent results, efforts to register the formulation with EPA were never attempted.

Chapter 7. Identification of New Candidate Piscicides

by William H. Gingerich

Pesticides occupy a unique position in the array of chemicals in that they are used specifically to kill, disable, or injure pests of humans. In an ideal situation, the actions of such chemicals would be highly specific for a target species, however, most chemicals used as pesticides today are not highly selective in causing their effects and target and nontarget animals are generally affected (Murphy 1975). The selectivity of the pesticides then must be enhanced to maximize the effectiveness for their intended target animal by operational factors such as (1) selective and timed applications, (2) regulating the rate and proximity of pesticide release, and (3) extending or reducing the time of release. These operational procedures also apply to the use of piscicides to produce selective toxicity. Potential mechanisms of action for candidate piscicides will be identified from the several general classes of toxicants now available. Also, a focused evaluation of promising new candidate fishery piscicides will be presented on the basis of relative potencies of the candidate toxicants that have been identified by structure-activity testing of enzyme complex receptors and in some instances structure-toxicity testing of the chemical to aquatic species including fish.

7.1 Overview of Potential Piscicides from General Classes of Pesticides

Pesticides in general can be grouped into one of two broad categories based on their mechanism of action. First are those chemicals termed nerve poisons because they act by disrupting the nerve-facilitated integration of biological function. Pesticides in this category broadly include (1) central nervous system disrupting agents, (2) ganglionic blocking agents, and (3) neuromuscular blocking agents (Hayes and Laws 1991*a*,*b*,*c*). Susceptibility of the nervous system to chemical disruptors has been aggressively exploited by agrochemical companies in the production of a variety of agricultural pesticides, particularly insecticides. Included in this broad category of pesticides are synthetic organochlorine and organophosphate pesticides as well as derivatives of natural products, such as the permethrins. These pesticides have proven effective during the time that they have been used but have traditionally suffered from problems. Control failures, lack of sufficient selectivity, and resistance problems experienced with the use of nerve poisons have caused agrochemical companies to look elsewhere for potential pesticides (Wood et al. 1996). Moreover, most of the pesticides in this category are particularly toxic to the majority of aquatic organisms.

A second category of pesticides have the general mode of action of disrupting energy production by the mitochondria, thereby reducing the amount of cellular energy available within the animal to perform biochemical or physiological work. These pesticides include a large number of natural product and synthetic chemicals (Ray 1991, Nicolaou et al. 2000). Many of the natural product chemicals that have been discovered are derived from plants, molds, fungi, or yeast. The origin of these natural products are probably defensive chemicals used to fend off or discourage attack from natural predators.

Included in the category of cellular energy disruptors are specific inhibitors of the electron transport system (ETS) as well as inhibitors of adenosine triphosphate (ATP) synthesis and production. Inhibitors of ATP production are also known as oxidative phosphorylation (OP)

inhibitors or uncouplers. The mode of action of this broad class of pesticides is to block the biochemical pathways associated with ATP production. Because energy generation and storage is a basic requirement of all living organisms, selectively blocking the system has important implications in a number of areas including pesticide research and development. Candidate inhibitory chemicals of the energy generating pathways are currently being investigated for potential use as anti-tumor drugs, antibiotic agents, as well as pesticide uses including arachnicides, insecticides, parasiticides, fungicides, and piscicides (Schuler et al. 1999, Schuler and Casida 2001). This class of chemicals potentially provides a rich source of new candidate toxicants.

7.2 Energy Production Pathway Receptors as a Target for Inhibitory Ligands

The pathway of aerobic energy production in animals is a suitable target for development of pesticides because it is broadly similar among most obligate aerobic invertebrate and vertebrate animals. The generation and use of ATP are vital to support all life processes in prokaryotic and eukaryotic organisms. For most animals, energy in the form of ATP is derived from carbohydrate and lipid resources consumed by the organism, broken down to similar products of intermediary metabolism, and routed into common pathways for energy synthesis. The biochemical complex of enzymes required to synthesize ATP in eukaryotic cells is universally located within specific internal membranes of the mitochondria (Nelson and Cox 2000).

Energy production in eukaryotic cells occurs in the mitochondria and is carried out through the biochemical coupling of two integrated and complementary subsystems, an ETS and a system of OP. The ETS collects energy in the form of electrons from reduction products of intermediary metabolism and passes the captured energy from a state of higher to lower electromotive force by the controlled oxidation/reduction of a series of specific quinone or cytochrome substrates. In synchrony with the movement of electrons down this electrochemical gradient, protons are transported across the inner mitochondrial membrane thereby generating an electrochemical proton gradient across the inner mitochondrial membrane between the intermembrane space and the mitochondrial matrix space. It is the generation of the proton gradient between the inner mitochondrial membrane separating the matrix and intermembrane spaces that drives ATP synthesis (Boyer 1997).

The integrated ETS and OP systems are composed of five identified complexes located within and on either the matrix or intermembrane space side of the inner mitochondrial membrane (Nelson and Cox 2000). The mitochondrial energy production system showing known receptors and general sites of activity for known inhibitor ligands is depicted in Figure 7-1. Simultaneous oxidation/reduction events and proton translocations occur at three critical receptor sites in the electron transport chain, within complex I, complex III, and complex IV. Each receptor complex is unique and generally consists of a protein complex on the inner mitochondrial membrane termed an oxidoreductase and an associated water or lipid soluble coenzyme, generally ubiquinones and/or cytochromes (b,c_1,c, aa_3). The ATP formation in mitochondria is accomplished by ATP synthase (sometimes referred to as complex V) that is located on the matrix side of the inner mitochondrial membrane.

Because depletion of ATP in the animal cell is nearly always fatal, many inhibitors of energy production have been used successfully as general toxicants (Hollingworth and Gadelhak 1998). Five potential receptors exist within the integrated mitochondrial energy production system, each particular receptor being potentially sensitive to different inhibitory ligands. Critical receptor sites in the complexes have been identified and are generally associated with competitive binding by inhibitor ligands on sites of complexes I and III occupied by the cofactor ubiquinone (Xia et al. 1997, Darrouzet et al. 1998, Tormo et al. 2000, 2001), or on the heme A of

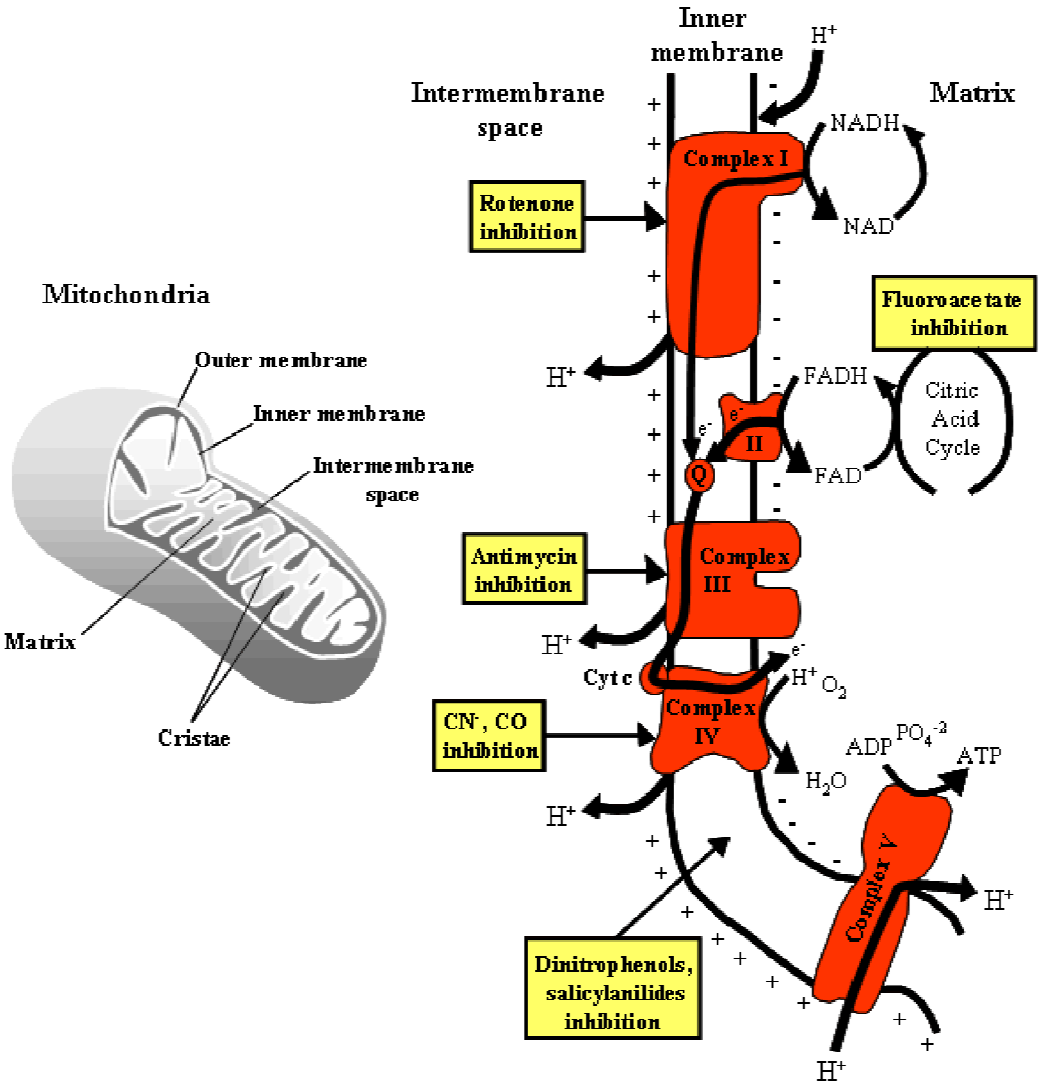


Figure 7-1. A representation of the inner membrane of a mitochondria and the relative positions of the inner membrane and matrix spaces. Electron transport complexes are embedded within the inner mitochondrial membrane and pass electrons from a state of higher to lower electromotive energies while capturing reductive energies from metabolic precursors. Hydrogen ions are simultaneously pumped from the matrix space to the intermembrane space by complexes I, III, and IV to create a proton gradient across the inner membrane. Adenosine triphosphate (ATP) synthase uses the proton gradient to synthesize ATP. Familiar electron transport system inhibitors and oxidative phosphorylation uncoupling agents used in fisheries block at various sites in the system. Rotenone blocks at complex I, antimycin A at complex III, and cyanide and carbon monoxide block at complex IV. Weakly acidic organic molecules, such as dinitrophenols and salicylanilides, act as protonophores to shuttle protons across the inner membrane and degrade the proton gradient required for ATP synthesis.

cytochrome c of complex IV (Tsukihara et al. 1996). Two broad classes of energy production inhibitors are ETS inhibitors and OP inhibitors/uncouplers. A listing of classes of energy production inhibitors and structures of representative chemicals in the class are given in Table 7-1.

Table 7-1. Identification of classes of naturally derived and synthetic electron transport and oxidative phosphorylation inhibitors as potential candidate fishery management chemicals.

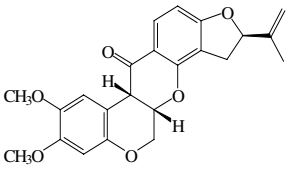
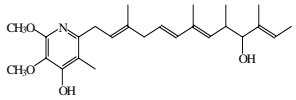
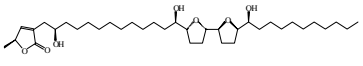
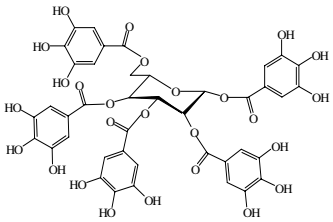
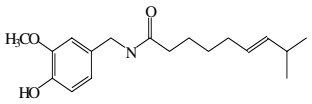
Classes of compounds (references)	Source	Representative compound(s)/ reference structure	Type of inhibition
Rotenoids (Fang et al. 1997; Fang and Casida 1997, 1999; Degli-Esposti 1998; Lummen 1998; Nicolaou et al. 2000; Schuler and Casida 2001)	Natural: plant species—*Derris* sp., *Lonchocarpus utilis*, and *L. urucu*	degulin, **rotenone**, and tephrosin 	Complex I - semiquinone antagonist
Piercidins (Tamura et al. 1963; Takahashi et al. 1968)	Natural: *Streptomyces* fermentations	**piercidin A** 	Complex I - quinone antagonist
Annonaceous acetogenins (Degli-Esposti et al. 1994; Gu et al. 1995; Landolt et al. 1995; Ye et al. 1996; He et al. 1997; Tormo et al. 1999, 2001)	Natural: plant family Annonaceae	**rolliniastatin-1**, cherimolin-1, itrabin, laherradurin, squamocin, otivarin 	Complex I - quinone antagonist
Tannins (Konishi and Tanaka 1999)	Natural: plant species *Sanguisorba officinale*	sanguiin H-11, **pentgalloylglucose**, oolonghomobisflavin A 	Complex I - NADH antagonist
Vanilloids (Shimomura et al. 1989; Yagi 1990; Satoh et al. 1996)	Natural: plants (e.g., capsicum)	**capcacin** 	Complex I - NADH antagonist

Table 7-1. Continued

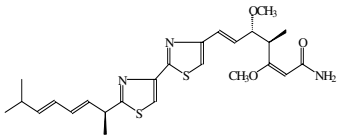
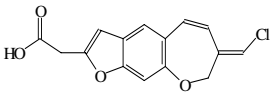
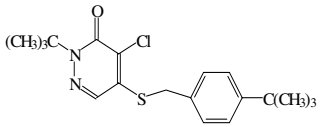
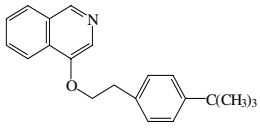
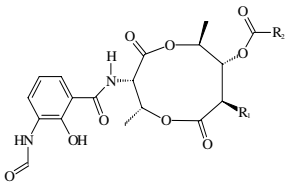
Classes of compounds (references)	Source	Representative compound(s)/ reference structure	Type of inhibition
Myxobacterial antibiotics (Degli-Esposti et al. 1993; Friedrich et al. 1994; Degli-Esposti 1998)	Natural: *Myxococcus*, *Stigmatella*	**myxothiazol**, aurachin A 	Complex I - quinol antagonist
Pterulinic acid (Engler et al. 1997*a*,*b*)	Fungal species *Pterula* sp. (basidiomycete)	**pterulinic acid**, pterulone 	Complex I - quinol antagonist
Pyridazinones (Degli-Esposti 1998)	Synthetic	**pyribaden** 	Complex I - quinone antagonist
Quinazolines (Hollingworth et al. 1994)	Synthetic	**fenazaquin** 	Complex I - quinone antagonist
Antimycin (Degli-Esposti 1998; Matsuno-Yagi and Hatefi 1999, 2001)	Yeast fermentations *Streptomyces* sp.	**antimycin A**, funiculosin, 2-nonyl-4-hydroxyquinoline-N-oxide 	Complex III - Q_i site inhibitor
Myxobacterial antibiotics (Degli-Esposti 1998; Matsuno-Yagi and Hatefi 1999, 2001)	*Myxococcus*, *Stigmatella*	**myxothiazol** (see above)	Complex III - Q_o site inhibitor

Table 7-1. Continued

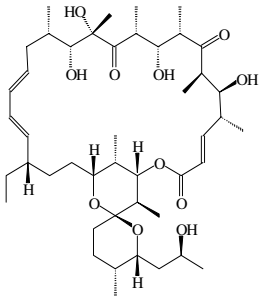
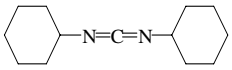
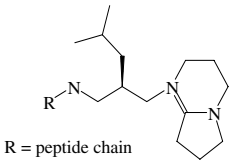
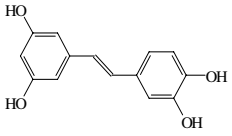
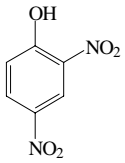
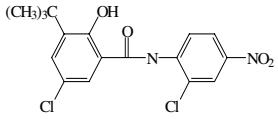
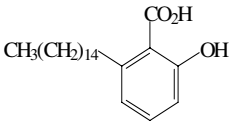
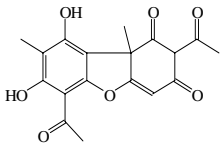
Classes of compounds (references)	Source	Representative compound(s)/ reference structure	Type of inhibition
Oligomycin (Matsuno-Yagi and Hatefi 1993; Vuorinen et al. 1995)		**oligomycin** 	F_0 transmembrane sector of F_0F_1-ATP
Dicyclohexylcarbo-diimide (Matsuno-Yagi and Hatefi 1993; Vuorinen et al. 1995)	Synthetic	**dicyclohexylcarbodiimide** 	F_0 transmembrane sector of F_0F_1-ATP synthase
Efrapeptins (Gupta et al. 1991; Krasnoff et al. 1991; Krasnoff and Gupta 1992; Abrahams et al. 1996; Bandani et al. 2000; Strasser et al. 2000)	Fungus of the genera *Tolypocladium*	 R = peptide chain	F_1 globular domain sector of F_0F_1-ATP synthase
Polyphenolic phytochemicals (Zheng and Ramirez 2000)	Plants	**piceatannol**, resveratrol, isoflavones, tannic acid 	F_1 globular domain sector of F_0F_1-ATP synthase
Nitrophenols (Toyomizu et al. 2000)	Synthetic	**2,4-dinitrophenol** 	oxidative phosphorylation uncoupler

Table 7-1. Continued

Classes of compounds (references)	Source	Representative compound(s)/ reference structure	Type of inhibition
Salicylanalides (Toyomizu et al. 2000)	Synthetic	**5-chloro-3-tert-butyl-2'-chloro-4'-nitrosalicylanilide** 	oxidative phosphorylation uncoupler
Anacardic acids (Kubo et al. 1986; Toyomizu et al. 2000)	Cashew nutshell liquid	**6-pentadecylsalicylic acid** 	oxidative phosphorylation uncoupler
Lichen acids (Abo-Khatwa et al. 1996)	Lichens (genera of *Usnea*, *Letharia*, *Parmelia*)	**usnic acid**, vulpinic acid 	oxidative phosphorylation uncoupler

A number of piscicides currently or formerly used by fishery managers are characterized as ETS inhibitors or OP uncouplers. The success of these agents in fishery management applications suggests both that ETS/OP inhibitors can be truly efficacious as piscicides and that additional and perhaps more effective fishery management agents can be found in this category of toxicants. Of the five receptors associated with the ETS inhibitors/OP system, the largest and most diverse group of inhibitor ligands have been identified for complex I, commonly referred to as Reduced Nicotinamide Adenine Diphosphate (NADH):ubiquinone oxidoreductase. Moreover, insects and fish seem particularly sensitive to complex I inhibitors (Fang et al. 1997, Fang and Casida 1999) suggesting the possibility that additional new candidate piscicides could be identified in this complex. For that reason, additional effort has been devoted to characterizing complex I and discussing the variety of its potential inhibitor ligands.

Complex I - NADH:ubiqinone oxidoreductase (EC 1.6.5.3)[1]

Complex I is the first energy transducing complex of the electron transport chain and also the first site of OP (Scheide et al. 2002). It is considered the largest, most complicated, most

[1]Unique enzyme complex number assigned by the Nomenclature Committee of the International Union of Biochemistry and Molecular Biology

studied, and probably the least understood of the four oxidation/reduction complexes in the ETS (Brandt 1997). Most characterization studies of complex I derived from eukaryotic species have been conducted with extracts of bovine heart mitochondria; characterization studies of complex I from fish mitochondria were not found in the literature. Because of its unique location at the beginning of the ETS and because of its function to transport electrons and translocate protons, complex I continues to be a preferred target receptor for those seeking to develop commercial insecticides, miticides, arachnicides (Degli-Esposti 1998, Lummen 1998), and conceivably piscicides.

Complex I appears to have the greatest numbers and diversity of natural and synthetic inhibitors of the five receptor systems in the energy producing ETS (Degli-Esposti 1998, Tormo et al. 2001). Complex I ligands include a variety of naturally derived and synthetic inhibitors (Degli-Esposti 1998). Among the natural inhibitors, four representative classes are recognized and include rotenoids (Fang et al. 1997, Fang and Casida 1997, 1999), annonaceous acetogenins (He et al. 1997), piericidins (Friedrich et al. 1994), and vanilloids (Shimomura et al. 1989). Additionally, several representative types of synthetic inhibitors have been developed: quinazolines and pyrimidines represented by the compound fenazaquin (Hollingworth et al. 1994, Hollingworth and Gadelhak 1998, Schuler et al. 1999), pyrazoles (fenpyroximate and tebufenpyrad; Hollingworth and Gadelhak 1998), and pyridazinones represented by the compound pyridaben (Hollingworth et al. 1994, Hollingworth and Gadelhak 1998, Lummen 1998, Schuler et al. 1999). Interest in developing inhibitors of complex I is derived from the potential for these inhibitors to serve as insecticides (Wood et al. 1996, Fang et al. 1997, He et al. 1997, Lummen 1998, Fang and Casida 1999, Jewess and Devonshire 1999, Schuler and Casida 2001), aracacides/miticides (Wood et al. 1996, Lummen 1998), and piscicides (Fang et al. 1997, Fang and Casida 1999). On the basis of a variety of physical observations of the receptor and on the diversity of structures of known inhibitors, Darrouzet et al. (1998) proposed a general structure for the complex I receptor (Figure 7-2). Armed with this information, it has been possible to devise computing algorithms to predict small chemical structures from combinatorial chemical libraries that optimize inhibition of complex I (Nicolaou et al. 2000).

Complex II - Succinate:ubiquinone oxidoreductase (EC1.3.5.1)

Complex II represents the second step in the energy transducing complex of the electron transport chain. It differs from the other three complexes in the electron transport chain in that it transfers an electron through the system without simultaneously generating and translocating a proton for ATP synthesis (Scheide et al. 2002). In addition, it is linked directly to the citric acid cycle of intermediary metabolism where the electron derived from the oxidation of succinate to fumarate is captured by Flavin Adenine Diphosphate (FAD) to form Reduced Flavin Adenine Diphosphate (FADH2).

Thenoyltrifluoroacetone and carboxanilides are potent inhibitors of mammalian complex II. However, these chemicals only weakly inhibit the prokaryotic form of the enzyme (Maklashina and Cecchini 1999). Certain 2-alkyl-4,6-dinitrophenols and pentachlorophenols are potent inhibitors of eukaryotic and prokaryotic enzyme systems (Tan et al. 1993, Yankovskaya et al. 1996). A survey of the recent literature suggests that broad phylogenetic similarities in complex II make the likelihood of phylogenetic differences small and that little work has been done to recognize additional inhibitors of this complex. It is unlikely that selective piscicides could be efficiently developed against this receptor.

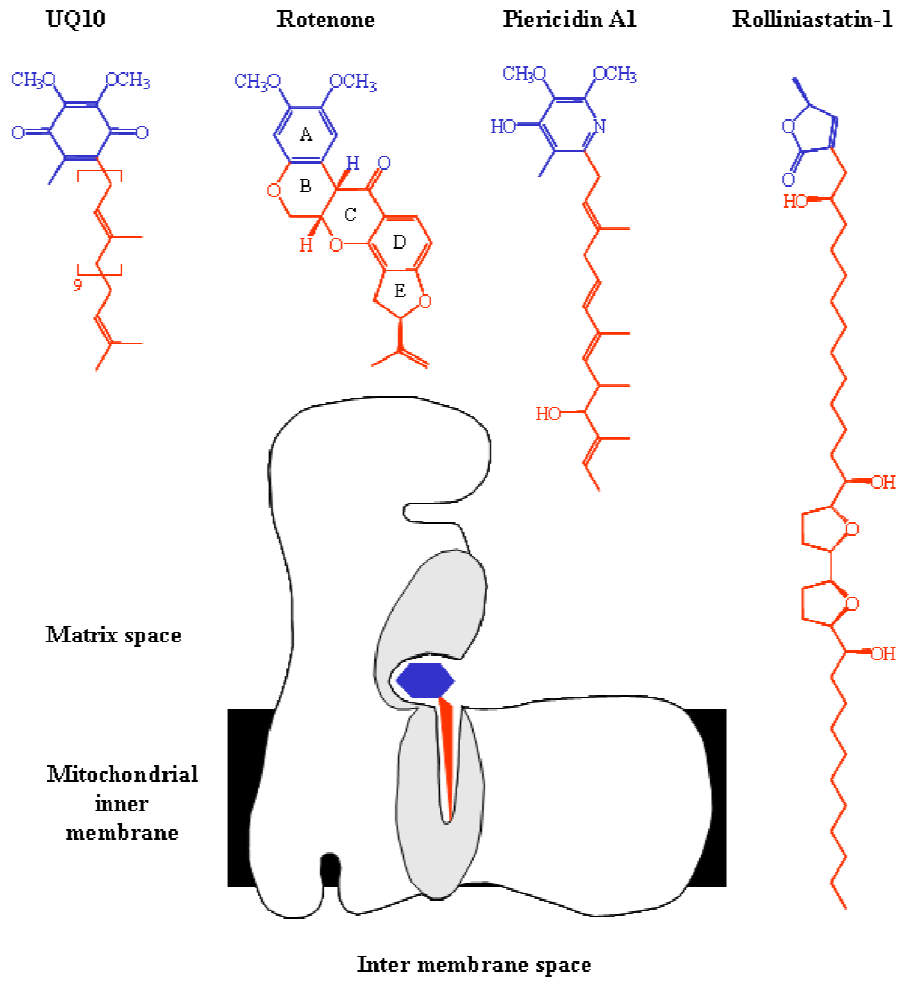


Figure 7-2. A representation of the complex I receptor for the electron transport cofactor ubiquinone (UQ10) and representatives of several classes of complex I inhibitor ligands. The membranous domain associated with quinone binding appears to be composed of two distinct subregions, an open and relatively hydrophilic region on the matrix side of the mitochondrial inner membrane surface of the complex (*blue*) and a more hydrophobic narrow cleft subregion that penetrates the membranous portion of the complex (*red*; after Darrouzet et al. 1998).

Complex III - Ubiquinol:ferrocytochrome c oxidoreductase (EC1.10.2.2)

Complex III or bc_1 complex represents the third complex in the energy transducing system of the electron transport chain in eukaryotic and prokaryotic cells. The complex catalyzes the transfer of electrons from ubiquinol to cytochrome c, an event that is coupled with the translocation of a proton from the mitochondrial matrix space to the intermembrane space.

Specific and potent inhibitors of the enzyme are known and include antimycin A (Bechmann et al. 1992, Matsuno-Yagi and Hatefi 1996, 1999, 2001), mucidin (Tokito and Daldal 1993), myxothiazol (Rauchova et al. 1992, Matsuno-Yagi and Hatefi 2001, Ouchane et al. 2002), and stigmatellin (Bechmann et al. 1992, Tokito and Daldal 1993, Matsuno-Yagi and Hatefi 1996, 1999, 2001). Only antimycin A has been developed for use as a piscicide (Morrison 1987, Finlayson et al. 2002). As with complex I, the function of complex III to simultaneously pass

electrons down the electron transport chain and translocate protons across the inner mitochondrial membrane make this complex a possible target for development of piscicides. Our review of the pertinent literature suggests that the number of candidate inhibitor ligands for this receptor complex is limited.

Complex IV - ferrocytochrome c:oxygen oxidoreductase (EC1.9.3.1)

Complex IV or cytochrome c oxidase represents the fourth and final complex in the electron translocating chain. The enzyme catalyzes the irreversible final step in the electron transfer chain, the transfer of reducing electrons to oxygen to form water.

Specific inhibitors of the enzyme system are known and include some familiar poisons, such as carbon monoxide (Miro et al. 1998), cyanide (Wilson et al. 1994, Ikegaya et al. 2001), hydrogen sulfide (Nicholson et al. 1998), and nitric oxide (Cleeter et al. 1994, Brown 2001, Shiva et al. 2001). These classic poisons inhibit cytochrome c oxidase mainly by interference with oxygen transfer to terminal cytochrome c. Less well known inhibitors of this enzyme have been identified and include dicarbanaborates (Drahota et al. 1996), valinomycin (Nicholls and He 1993), and N-retinyl-N-retinylidene ethanoloamine (Shaban et al. 2001). A cursory literature review of this enzyme did not reveal studies characterizing the enzyme system in eukaryotic and prokaryotic cells or studies emphasizing other phylogenetic comparisons. Because of the nature of the system, it is not likely that it represents a suitable target for development of either general or specific fishery management chemicals. Many of the identified inhibitor ligands for the complex, such as carbon monoxide, hydrogen sulfide, and cyanide could present major health problems for applicators.

Complex V - F_0F_1-ATP synthase (EC3.6.6.34)/Oxidative Phosphorylation Uncoupling Agents

Complex V catalyzes the production of ATP from adenosine diphosphate (ADP) and inorganic phosphate (P_i) in mitochondria and chloroplasts from eukaryotic cells, as well as in bacteria. The ATP production is tightly coupled to the mitochondrial proton electrochemical gradient developed across the membrane separating the mitochondrial intermembrane space and matrix (Walker 1994). The enzyme can also operate in the reverse direction, hydrolyzing ATP, and pumping protons in a retrograde manner against the normal proton gradient in the absence of a strong proton gradient (Walker 1994, Zheng and Ramirez 2000).

Two general classes of inhibitors block ATP production by F_0F_1-ATP synthase, those that directly inhibit F_0F_1-ATP synthase and those that act by degrading the transmembrane proton gradient and uncoupling ATP production from electron transport. Inhibitors of F_0F_1-ATP synthase at the F_0 moiety have been identified. Oligomycin, N,N'-dicyclohexylcarbodiimide, venturicidin, and tetracoordinate organotin compounds (R_3SnX) are potent inhibitors of the ATP synthase enzyme; all at the F_0 transmembrane sector (Matsuno-Yagi and Hatefi 1993). Efrapeptins, small polypeptides produced from fungus of the genus *Tolypocladium*, have been identified as potent inhibitors of the F_1 globular domain of complex V (Abrahams et al. 1996) and have been studied as candidate insecticides and fungicides (Krasnoff and Gupta 1992, Bandani et al. 2000, Strasser et al. 2000). A number of polyphenolic phytochemicals also have been purported to inhibit ATP synthase at high nanomolar to low micromolar concentrations; some inhibit the enzyme by binding to the F_1 subunit while others bind to the F_0 subunit (Zheng and Ramirez 2000).

Uncoupling agents function by increasing proton conductance across the inner mitochondrial membrane, thereby degrading the proton gradient and in the process reducing ATP formation

while allowing electron transport to continue in the mitochondria. That is, they uncouple the energy yielding reactions (i.e., electron transport) from energy conserving reactions (i.e., ATP formation). Lipid soluble weak acids, such as 2,4 dinitrophenol, carbonylcyanide, 5-chloro-3-tert-butyl-2'-chloro-4'-nitosalicylanilide, and 4,5,6,7-tetrachloro-2-trifluoromethylbenzimidazole, are recognized as uncoupling agents (Toyomizu et al. 2000). Similarly, lipid soluble weak bases also have been identified as uncoupling agents (Nagamune et al. 1993, Abo-Khatwa et al. 1996). It is assumed that the sea lamprey larvicides TFM and Bayluscide®, both lipid soluble, weakly acidic organic molecules, act in part by uncoupling OP (Lehninger 1975).

7.3 Identification of Energy Production Inhibitors as Candidate Piscicides

The properties of a chemical that confer selective toxicity are central to the issue of the development of a taxon-specific piscicide. The identification and development of chemicals are made challenging by the general requirements of the chemical to produce rapid toxicity to the target species while having little effect on nontarget species that may be residing in the same body of water. For a chemical to be toxic, it must rapidly produce effects such that the ability of the organism to persist is rapidly degraded. The rapid development of toxicity is generally desirable to reduce the chance that the animal could escape the toxicant field during treatment. Conversely, the toxicant may be effective at such low concentrations that it is undetectable by the animal. Because many of the physiological and particularly biochemical processes that are candidates for disruption by toxicants are highly conserved phylogenetically, many higher organisms share similar susceptible target sites for candidate toxicants thereby reducing the potential for selectivity.

Energy production inhibitors have been used extensively as general toxicants in fishery management applications. Examples of these general toxicants include rotenone (complex I inhibitor), fluoroacetate (citric acid cycle inhibitor linked to complex II), antimycin (complex III inhibitor), carbon monoxide and cyanide (complex IV inhibitors), and the lipophilic weakly acidic organic molecules TFM, niclosamide, and salicylanilide (purported OP uncouplers). It is significant that the only chemicals that are currently registered by the EPA for fishery management purposes belong to this class of diverse toxicants. These include antimycin, rotenone, and the sea lamprey larvicides—TFM and Bayluscide®. The sustained and successful use of these agents is due in large part to their general efficacy to fish, their relative safety to human applicators (Finlayson et al. 2002), and their safety to the environment because of their ability to degrade rapidly (Dawson et al. 1991, Dawson 2003, Hubert 2003). Much of the success enjoyed by energy production inhibitors in fishery management uses can be attributed to physicochemical properties that allow for their rapid uptake by fish across the relatively permeable water-blood barrier of the gills and subsequent rapid and ubiquitous distribution (Gingerich and Rach 1985, Rach and Gingerich 1986) and subsequent loss from the body (Dawson et al. 2002, Vue et al. 2002).

It is clear from the review of current literature that there are a number of new mitochondrial complex I inhibitor ligands that currently could be considered as potential general insecticide candidates (Nicolaou et al. 2000). Such chemicals generally have potency to target receptors that are equal to or greater than rotenone. Insect and fish mitochondria appear to be particularly sensitive to complex I inhibition (Jewess 1994, Degli-Esposti 1998). For this reason, complex I may also be a preferred receptor to target for the development of new piscicides. A number of these identified compounds appear to have complex I inhibition potency sufficient to allow them to be considered further as candidate general fish toxicants. A listing of potential complex I inhibitors and their relative *in vivo* and *in vitro* potencies is presented in Table 7-2.

Table 7-2. Identification of classes of complex I energy production inhibitors, *in vivo* or *in vitro* assay systems, and relative potency for potential candidate fishery management chemicals. LC = lethal concentration; IC = inhibitory concentration; ND = not determined; NA = not applicable.

		***In vivo* assays**			***In vitro* assays**			
Chemical class	**Chemical**	**Assay system[a]**	**Activity LC_{50} (µg/L)**	**Relative potency[b]**	**Assay system[c]**	**Activity IC_{50} (nM/mg)**	**Relative potency[d]**	**References**
Rotenoids	rotenone	GF	50	1	NADH-Q	4.4	1	Fang et al. 1997
	degulin	GF	30	0.6	NADH-Q	6.9	1.57	Fang et al. 1997
Oxadehydrdorotenoids	oxadehydrotenone	GF	≥1,000	≥200	NADH-Q	115	26.1	Fang et al. 1997
	oxadehydrodegulin	GF	≥3,000	≥600	NADH-Q	138	31.4	Fang et al. 1997
Dehydrorotenoids	dyhydrorotenone	GF	≥3,000	≥600	NADH-Q	8,630	1,960	Fang et al. 1997
	dehydrodegulin	GF	≥3,000	≥600	NADH-Q	1,590	361.4	Fang et al. 1997
Annonaceous acetogenins	bullatacin	BS	1.6	0.0327	ND	NA	NA	He et al. 1997
	trilobin	BS	9.7	0.198	ND	NA	NA	He et al. 1997
	trilobacin	BS	8.7	0.178	ND	NA	NA	He et al. 1997
	asiminacin	BS	5.7	0.116	ND	NA	NA	He et al. 1997
	asimicin	BS	26	0.531	ND	NA	NA	He et al. 1997
	motrilin	BS	10	0.204	ND	NA	NA	He et al. 1997
	bullatalicin	BS	150	3.06	ND	NA	NA	He et al. 1997
	rotenone (control)	BS	49	1	ND	NA	NA	He et al. 1997
	rolliniastatin-1	ND	NA	NS	NADH-Q	0.03	0.077	Degli-Esposti et al. 1994
	rolliniastatin-1	ND	NA	NA	NADH-Q	0.75	0.026	Tormo et al. 1999
	rolliniastatin-2	ND	NA	NA	NADH-Q	0.06	0.149	Degli-Esposti et al. 1994
	rolliniastatin-2	ND	NA	NA	NADH-Q	0.61	0.021	Tormo et al. 1999
	otivarian	ND	NA	NA	NADH-Q	0.9	≥1	Degli-Esposti et al. 1994
	corossolin	ND	NA	NA	NADH-Q	6.2	0.215	Tormo et al. 1999

Table 7.2. Continued

Chemical class	Chemical	*In vivo* assays			*In vitro* assays			References
		Assay system[a]	Activity LC_{50} (µg/L)	Relative potency[b]	Assay system[c]	Activity IC_{50} (nM/mg)	Relative potency[d]	
	corossolone	ND	NA	NA	NADH-Q	10.5	0.365	Tormo et al. 1999
	murisolin	ND	NA	NA	NADH-Q	5.3	0.184	Tormo et al. 1999
	annonacinone	ND	NA	NA	NADH-Q	3.7	0.128	Tormo et al. 1999
	rotenone reference	ND	NA	NA	NADH-Q	28.8	1	Tormo et al. 1999
	tripoxyrollin	ND	NA	NA	NADH-Q	19.3	0.67	Tormo et al. 2000
	membrarollin	ND	NA	NA	NADH-Q	0.83	0.029	Tormo et al. 2000
	annonin IV	ND	NA	NA	NADH-Q	0.06	0.857	Friedrich et al. 1994
Piercidin	piercidin-A	ND	NA	NA	NADH-Q	0.036	0.414	Degli-Esposti et al. 1994
	piercidin-A	ND	NA	NA	NADH-Q	0.02	0.286	Friedrich et al. 1994
Vanilloids	capsaicin	NAD	NA	NA	NADH-Q	15	3.67	Wood et al. 1996
Pyridazinones	pyridaben	ND	NA	NA	NADH-Q	77	0.714	Wood et al. 1996
Quinazolines	fenaziquin	ND	NA	NA	NADH-Q	67	0.821	Wood et al. 1996

[a]GF = goldfish; BS = brine shrimp
[b]Potency referenced to rotenone positive control (LC_{50} test chemical/LC_{50} rotenone); potency ratios less than 1 indicate chemicals more toxic than rotenone
[c]Assay system is mitochondrial membrane NADH-ubiquinone reductase extracted from bovine heart
[d]Potency referenced to rotenone positive control (IC_{50} test chemical/IC_{50} rotenone); potency ratios less than 1 indicate chemicals more toxic than rotenone

How could newly identified chemicals be exploited for use as piscicides? These chemicals would need to be obtained and tested against the various target and nontarget fish species. Considerations for candidates should be given to those chemicals with physicochemical properties similar to antimycin and rotenone. That is, they are sparingly soluble in water but readily taken up across the fish gills and rapidly distributed throughout the body. Once the efficacy of one or more of the chemicals is confirmed, the candidate chemical(s) would need to be more fully evaluated as a potential management tool by assessing other characteristics of the chemical including potential mammalian safety, human food safety, and environmental safety concerns. A number of promising candidate chemicals seem to be more toxic than rotenone (Table 7-2). These include certain of the acetogenins as well as the synthetic pyridazinone pyridaben (Nexter®, Sanmite®), and the quinazoline fenazaquin (Matador®). The latter synthetic compounds have been developed as commercial agricultural insecticides and miticides, but there are no current registrations for their use in fishery management. Generally, the development of these commercial products for fishery management purposes would need to be done in close cooperation with a chemical sponsor. Likewise, the development of natural products would need to be undertaken with a sponsor who would supply the chemical.

A second and less expensive initial option in looking for selective toxicants would be to evaluate whether existing, registered ETS/OP piscicides could be used in combination to enhance selectivity to certain problem species. The rationale for this is that the ETS/OP complex receptors for different species may be differentially sensitive to several of the inhibitory ligands. For example, the treatment of certain species with a combination of both a complex I inhibitor ligand and a complex III inhibitor ligand or a complex I inhibitor ligand and an OP uncoupler may be more selective for a certain species than using just a single type of complex inhibitor.

Our laboratory and field experience as well as the literature reviewed to support this report suggest that there is no precedence for the use of combinations of different ETS or ETS/OP inhibitor ligands. It is known that the toxicity of rotenone can be enhanced when it is applied with the mixed function oxygenase inhibitors piperonyl butoxide or sulfoxide (Marking 1977). However, metabolic inhibitors prevent the metabolic degradation of rotenone rather than to additionally selectively block a different receptor site within the ETS. Moreover, use of such metabolic inhibitors would probably reduce rather than enhance the selectivity of toxicants whose potency is reduced by metabolism to less toxic degradation products. The use of multiple OP inhibitor ligands has been used commonly in sea lamprey control applications to enhance the efficacy of the treatment. Bayluscide® is commonly applied in a proportion of 98%:2% (TFM:Bayluscide®) to enhance the toxicity of TFM during sea lamprey control treatments with the effect that it allows less TFM to be used during certain treatments (Howell et al. 1964, Dawson 2003). However, the use of two OP inhibitor ligands has not been successful in enhancing the selectivity of TFM treatments for sea lamprey.

At the present time, it is not clear whether there would be advantages from combining various proportions of different ETS/OP inhibitors to enhance selectivity in fishery management treatments. This is because basic data do not exist for this type of testing. It is known that some interspecific and intraspecific differences exist among some of the electron transport receptor systems for fish species (Chew and Ip 1993, Freund and Kadenbach 1994, Arnold et al. 1997). These differences also may be modified by physicochemical changes in the environment, particularly seasonal temperature changes (Hardewig et al. 1999*a*,*b*, Kikuchi et al. 1999). Ultimately, the sensitivity of the species to the toxicants will be as sensitive as their receptors are to the inhibitory ligands.

Application of multiple ETS/OP inhibitors is an untested and novel approach that may reveal differential sensitivities to target or nontarget species that are not evident when just one specific inhibitor is applied. Moreover, if mixtures of different ETS/OP inhibitor ligands are found to require less of each inhibitor ligand in combination than the concentration of individual ones

used separately, there are immediate advantages from a monetary and practical perspective. First, if less total piscicide is required to effect a successful treatment, substantial savings in costs per treatment could be realized. Second, if less chemical is used for each treatment, detection of each chemical in the mixture by the target species would be more difficult with the result that they would not attempt to avoid the toxicant field.

How would data be developed to confirm or refute such a hypothesis? By applying different proportions of one inhibitor ligand in the presence of a fixed concentration of a second ligand to critical species of interest, it should be clear in a relatively short time whether there is merit to this approach. Conceptually, the 24-hour lethal concentrations to 50% of the test individuals (LC_{50}) would be determined for each inhibitor ligand to appropriate target species as well as to nontarget species of interest. Once established, a fixed concentration of one inhibitor ligand, representing perhaps 50% of the LC_{50}, will be chosen to be mixed with differing proportions of a second inhibitor ligand under conditions of continuous exposure. The proportions of the second inhibitor ligand might range from 10% to 90% of the LC_{50} in 10% increments. Successful combinations of inhibitor ligands would be based on the demonstration of increased selectivity for target over nontarget species.

From the preceding discussion, one can deduce that it is not likely that selective toxicants exist that could be applied immediately to management strategies for the control of invasive species in the southwestern United States. This conclusion stems from a review of the current literature that reveals the lack of available data relating apparent susceptibility of potential target species to specific poisons. At a minimum, selectivity is likely to be based on at least two inter-specific differences, one in the differences of the biochemistry of different species related to their strategies for self-sustenance and a second related to differences in how successful different species are at tolerating potential poisons. Too little information currently exists on the biochemical and pharmacokinetic factors that would act or interact to produce selectively toxic treatments to the problem species of interest.

Science-based evaluations of newer ETS/OP inhibitory ligands suggest that newly discovered chemicals, particularly the annonaceous acetogenins may prove useful as candidate management chemicals for fish. A series of potential candidate electron transport inhibitor ligands have been identified that could serve as the basis for additional evaluation.

As an alternative to full development of a new piscicide, it may be possible to develop specific combinations of currently registered piscicides that would allow for some selective toxicity between target and nontarget fishes of concern. Again, the lack of data precludes identification of any specific candidate combination; however, the advantage to this approach is that all chemicals currently registered for use as piscicides with the EPA could potentially be used in combinations without the development of major sets of additional regulatory data.

Chapter 8. Developing and Registering a Piscicide

by Terrance D. Hubert

It is important that those involved in managing aquatic systems have as many different tools as possible for the control and eradication of nonnative aquatic species. In earlier chapters, it has been noted that only four chemicals are registered as piscicides. While development of additional chemical tools may be worthwhile, it is important to know what is involved before embarking on an effort to develop and register a piscicide.

The need to regulate pesticides became apparent in the late 1940s. In 1947, Congress passed the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) that regulated the licensing and application of pesticides, primarily for agriculture. Initially, the U.S. Department of Agriculture (USDA) was given the responsibility of registering pesticides. The responsibility passed to the EPA when it was created in 1970. Amendments to FIFRA were made in 1980 and 1988, with the latter amendment requiring that all pesticides registered before 1984 undergo a reregistration process. This was largely done because testing methodology had improved significantly, and Congress felt this necessitated repeating the registration process for older chemicals. Finally, Congress passed the Food Quality Protection Act in 1996, which placed emphasis on chemicals used directly on food crops and feed, and required risk assessments on the basis of cumulative effects from pesticides of similar modes of action, provided special consideration for infants, elderly, and other sensitive groups, required the EPA to establish a program to determine the endocrine disrupting characteristics of pesticides, and required reassessments of pesticide tolerances.

It is estimated that from initial discovery through developmental research to final product, the development of a pesticide can take 8 to 10 years and cost $35 to $50 million (American Crop Protection Association 2001). Registration of the pesticide, which is a critical subcomponent of the development process, may require more than 100 different tests and can cost up to $10 million (USDA 2002). Appendix E lists the current guidelines for studies required for the registration of a pest control product. The number and types of tests required depends on the intended use. For instance, pesticides applied to ornamental plants in an enclosed environment will be subjected to less testing than those applied to food crops raised outdoors. This is because the risk associated with potential exposure in the former circumstance is lower than in the latter.

There are three types of registrations that may be granted by the EPA depending on the circumstances. The most common registration is a full, or Section 3(c), registration (EPA 1996*a*). Section 3 registrations require a full battery of data to support the registration and are renewed on an annual basis. This type of registration is usually obtained by the product manufacturer, although there are circumstances in which a third party would obtain such a registration for a use not supported by the manufacturer's registration.

The second type of registration is known as a Special Local Needs, or Section 24(c), registration (EPA 1996*a*). These types of registrations generally cover situations where individual states apply for registration of an additional use of a federally registered pesticide, or a new end-use product to meet special local needs. For example, Florida has a special local needs registration to apply the molluscide Bayluscide® to ornamental ponds to control snails. In most instances, because this involves a currently registered pesticide, minimal additional data requirements are necessary to register a pesticide for a special local need. Generally, data submitted to support the federal registration are sufficient to support the special local needs registration. Applications for special local needs registrations must be accompanied by an unreasonable adverse effects assessment (defined later in this chapter). The state registration may be disapproved by EPA if the use is not covered by the necessary tolerances or has been previously denied, disapproved, suspended, or canceled by the administrator of EPA. Special local needs registrations are also renewed on an annual basis.

The final type of registration is a Section 18 Emergency Exemption (EPA 1996*b*). Section 18 registrations are sought when a control need is identified in which registered pesticides will not be effective. Section 18 requests most frequently involve pesticides registered for other uses. Occasionally, however, requests are made for pesticides for which registrations have been cancelled. In situations where an emergency exemption is required, the EPA has the authority to grant an exemption from the provisions of FIFRA to a state or federal agency. Also, Section 18 regulations allow a state to issue a crisis exemption for the use of a pesticide when there is not sufficient time to formally request a specific exemption or, if formal application has been made, for the EPA to complete the review of the request.

All data submitted to support the registration of a pesticide, regardless of the intended use, must meet strict standards of record-keeping and documentation known as Good Laboratory Practice (GLP) guidelines. Failure to comply with these guidelines not only will result in rejection of the submitted data, but can also result in fines and/or imprisonment for the offending parties. It is therefore important to carefully review the record-keeping practices of laboratories under consideration for conducting registration-related research.

Development of a pesticide is generally a lengthy process and involves the broad steps of (1) developing a treatment strategy, (2) developing a specific chemical, (3) developing formulations of that chemical, (4) producing, and (5) registering the chemical and formulations of the chemical. In the pages that follow, the components of each of these steps will be discussed.

8.1 Developing a Treatment Strategy

Selecting Critical Life Stage for Control

It is important in developing a chemical control strategy to have a sound understanding of the biology of the organism to be controlled. Thorough study of the organism's life cycle, breeding habits, and habitat preferences may identify a life stage that is particularly susceptible to chemical control. Identification of the larval stage of the sea lamprey as being the most

vulnerable was pivotal in the development of a control strategy for sea lampreys in the Great Lakes (see Chapter 11 for a thorough discussion of sea lamprey control in the Great Lakes).

Selecting Candidate Chemicals

Sixty years ago, labor-intensive screening of thousands of chemicals was necessary to identify a taxon-specific chemical to control nonnative fishes (e.g., 6,000 chemicals were screened to find effective lampricides for sea lamprey). Today, models based on the actions of specific classes of chemicals are available to help identify candidates, and requirements for laboratory screening are reduced. In addition to biological activity and effectiveness, ease of handling, safety, and cost should be considered when selecting potential piscicides (Appendix D).

Toxicity Screening

Once the candidate chemicals have been selected, toxicity screening is initiated to define an effective concentration range over which mortality of the target life stage can be achieved (Lennon and Walker 1964). The types of toxicity tests that can be used in this phase are described in a guide from the American Society of Testing Materials (1980). The number of concentrations initially tested is a matter of convenience. Six concentrations, each differing by a factor of 10, is an appropriate starting point. If no mortality is observed at the highest concentration or total mortality is observed at the lowest concentration, the range should be adjusted and a new test conducted. This procedure is repeated until mortality is observed at the highest concentration and not at the lowest concentration. Effective concentrations are then refined by further toxicity testing on the target organism within this concentration range. Toxicity testing on phylogenetically diverse nontarget organisms is done to determine which of these may be sensitive to the chemical at the concentrations effective on the target organism. If any nontarget organisms are determined to be sensitive at the concentrations toxic to the target organism, then subsequent toxicity screening is conducted to determine if there is a concentration range over which mortality of the target organism may be achieved with minimal mortality to nontarget organisms.

8.2 Active Ingredient Development

Decision to Develop

The decision to develop a particular chemical or group of chemicals as selective piscicides should be based primarily on sound science, although economic considerations will also play a role. Research to register the product with the EPA will cost millions of dollars. Since most piscicides in use today have been developed with public funds, good stewardship of public monies must play a central role in the decision-making process.

Safety Considerations

Perhaps the most important consideration in the development of any piscicide is safety. From a human safety perspective, the chemical must be safe to those who apply the piscicide as well as to those who may come into contact with it following applications. Additionally, nontarget organisms exposed to the piscicide or to its degradation products should not be adversely affected. The piscicide label, the document that describes precisely how the piscicide is to be used, provides explicit instructions on the application methods, dose or application rates, and specific instructions on its safe use. Safety considerations include, but are not limited to, protective clothing for applicators, applicator training, instructions and warning statements

regarding specific hazards, restrictions on water usage during and after treatment, environmental warnings, proper storage and disposal of containers, and procedures for handling spills.

Registration Process

Once the decision to develop a pesticide has been made, the process of registration with the EPA begins with a series of complex, long-term research studies (Appendix E). These studies are designed to provide data related to product chemistry, animal toxicology, residues in food and feed, environmental fate, ecological effects, and efficacy. Although the list of studies is extensive, it is possible through modeling that the requirements for some studies may be satisfied or waived. For example, data from studies such as the physical and chemical properties of the active ingredient may be used in models that predict the environmental fate of the piscicide. The results could reduce the number of studies required, for example, in the Series 850 guidelines (Appendix E).

The EPA places submitted data into two categories: data submitted to support the registration of the active ingredient of the pesticide (generic data) and data submitted to support the registration of a specific formulation of the active ingredient (product-specific data). It is critical that studies to support the registration of the active ingredient and formulations be conducted according to GLP standards**.**

Field Testing and Experimental Use Permits

A critical component of the registration process is field testing. This usually begins late in the registration process because field testing generally requires an experimental use permit and data generated during the registration phase are used to support the application for the permit. Field testing occurs on large-scale plots under normal conditions and should cover all proposed uses. Data from field trials must be submitted to the EPA and are also subject to GLP standards. It is at this point in the piscicide development process that a manufacturing source for the active ingredient and formulations is explored if one does not already exist. Manufacturing process development studies are conducted once a manufacturer is identified. This is in preparation for full production of the pesticide once the registration has been granted by the EPA. Data from the process development studies are also submitted to the EPA and, as with all other data, are subject to GLP standards.

Product Chemistry, Toxicological, and Environmental Assessments

Tests conducted to satisfy product chemistry requirements center on the physical characteristics of the active ingredient and the formulated products. For example, tests include solubility in water and organic solvents, color, melting point, boiling point, octanol-water partition coefficient, and storage stability. Exactly which tests are required depends on the nature of the active ingredient and the formulation and the manner in which the formulation will be used. For example, a test to determine viscosity would not be required if the product is a solid.

Toxicological assessments in mammals to ensure human safety and minimize harm to other nontarget organisms are made to determine the acute effects of single doses, the chronic effects from long-term exposures, mutagenic effects, and carcinogenic effects. Acute studies examine the toxicity from oral exposure, dermal exposure, and inhalation. Acute eye and dermal irritation studies are also generally required. Subchronic tests involve 90-day feeding studies and dermal exposure studies that run from 21 to 28 days. Developmental and reproduction studies are also conducted. Finally, there is a battery of studies conducted to determine potential mutagenic, carcinogenic, and neurotoxic effects.

Environmental testing determines the fate of the chemical in water and soil. Some examples of environmental fate studies are hydrolysis, aerobic or anaerobic aquatic or soil metabolism, and photolysis. Studies of this type are generally conducted with radiolabeled material so that the fate of the parent chemical and its degradates can be followed. Use of radiolabeled chemicals can be costly depending on the ease of their synthesis.

Residue Chemistry and Residue Tolerances

Pesticide residue studies are conducted to determine whether residues would persist in an organism that could potentially be consumed by humans. In the case of registration of a piscicide, residue studies in fish or shellfish are generally required. Livestock and plant metabolism studies may also be required if water from a treated stream or pond could potentially be used for irrigation or watering livestock. If it is practical to place use restrictions on treated pond or stream water, the livestock or plant metabolism studies may be waived by the EPA. As a general rule, the first set of these studies should focus on determining the qualitative nature of the residues in the exposed organisms. Once this is known, field studies are conducted to determine levels of the residues that might be expected from a typical treatment. An assessment of the biological activity of the residues is made, and studies are conducted on those residues that might cause toxicity. The EPA will then set residue tolerances for the food portion of the organism on the basis of those studies. It is the responsibility of the manufacturer or registrant to demonstrate that the residues in a commodity are at levels that provide a reasonable margin of safety for human consumption. Monitoring is conducted and any food or feed commodities having residues that exceed the tolerance are destroyed. For a piscicide, it is not likely that residue tolerances would be set unless the piscicide is used on a contained food fish that will be shipped to market. Tolerance enforcement is the responsibility of the FDA.

Risk Assessment

Risks from the use of pesticides (American Crop Protection Association 2001) are assessed by the equation:

$$\text{Risk} = \text{Hazard} \times \text{Exposure}$$

Toxicology studies provide estimates of the hazards and the residue studies provide estimates of the exposures. In determining the risk associated with pesticide use, the EPA estimates the Reference Dose, also known as the Acceptable Daily Intake (ADI). This factor is arrived at by taking the No Observable Effect Level determined from animal feeding studies and dividing by a safety factor, usually 100 or greater. The ADI is taken as the amount of residue that can be ingested by the average person every day for a lifetime with a reasonable expectation of no ill effects. Typically the ADI is set well below levels that affect the most sensitive test animals. Considering that residue tolerances are also set such that residue exposures from all sources fall well below the ADI, a significant margin of safety is incorporated into the risk estimate.

The Federal Registration Package

The process of conducting the appropriate tests to support the registration of a pesticide takes 6 to 7 years and typically results in the accumulation of several thousands of pages of data. Registration packages are reviewed by the scientific and administrative branches of the EPA's Office of Pesticide Program, and the process of review can take 6 months to 1 year for each individual piece of the submission (e.g., product chemistry, toxicology, etc.). While the review is in progress, the registrant begins preparations for pesticide production. A product label will be approved once the data supporting the registration are judged to be adequate by the EPA.

Registration of Pesticide by States

The process of pesticide registration by state agencies was reviewed for the states of Arizona, New Mexico, Nevada, and Utah. In registering a pesticide, New Mexico, Nevada, and Utah do not conduct full data reviews (New Mexico Statutes 1978, Nevada Pesticides Act 1955, Utah Pesticide Control Act 1979). Rather, these states rely on the assessment of the EPA that makes its Registration Eligibility Decisions available to the public on its Web site. For each of these states, registration of a pesticide requires payment of an annual registration fee, ranging from $35 to $70, along with a completed application form containing information regarding the registrant's name and address, the name of the pesticide, the EPA registration number, and a complete copy of the pesticide label. Statutes of all states contain clauses that indicate that the state may request additional information or data in making its assessment.

Registration of a pesticide in Arizona requires more detailed applications than in New Mexico, Nevada, or Utah. Pesticide registration in Arizona is regulated under two separate statutes, which include the Arizona Revised Statute Title 3 on Agriculture (Arizona Revised Statutes 1988*a*) and Title 49 on the Environment (Arizona Revised Statutes 1988*b*). The Arizona Department of Agriculture generally requires information that is similar to the states of New Mexico, Nevada, and Utah in granting a registration along with a $100 registration fee. Federal, state, and county offices are exempt from paying the registration fee.

In contrast to New Mexico, Nevada, and Utah, Arizona has a specific statute governing pesticides in groundwater that falls under Title 49. In this section of the Arizona Revised Statutes, there are additional rules governing the registration of pesticides written in Section 2, Article 6, Water Quality Control: Pesticide Contamination Prevention (Arizona Revised Statutes 1988*b*). The intent of these statutes is to determine the potential of a pesticide and/or its residues to contaminate groundwater. As a consequence, data on water solubility, vapor pressure, octanol-water partition coefficient, soil adsorption coefficient, Henry's Law constant, and all dissipation data including hydrolysis, photolysis, aerobic and anaerobic soil metabolism, and field dissipation are required. With the exception of studies to determine Henry's Law constant, most of the above data will probably have been submitted to the EPA to support a pesticide registration and can therefore be easily obtained for submission to Arizona regulatory agencies. In addition to these data, any other data that were submitted to the EPA to support a pesticide registration may also be requested under Arizona statute. If any of these data do not exist or if the registrant does not provide them, the pesticide automatically is placed on the groundwater protection list. A pesticide registrant is subject to a penalty of up to $10,000 for each day a groundwater protection data gap exists. While the pesticide is on the groundwater protection list, the director of the Department of Environmental Quality has the authority to regulate the use of the pesticide.

8.3 Formulation Development

Safety Considerations

As with the development of the active ingredient in a pesticide product, the safety of a formulation is a critical consideration. Similar safety considerations that apply to active ingredient development also apply to selecting formulants. As with active ingredients, formulants are required to undergo a testing process similar to, but not as extensive as, active ingredients. The EPA maintains a list of accepted inert ingredients for pesticide formulations (http://www.epa.gov/opprd001/inerts/lists.htm).

Field Testing and Experimental Use Permits

The type of formulation developed will depend on the intended use and how the pesticide is best applied. Generally, more than one formulation of the pesticide is developed for application in different environments.

Once a formulation has been developed, it must undergo additional field testing under experimental use permits as required for active ingredient development. This testing is designed to establish that the proposed formulation is efficacious and will not result in adverse effects under typical use conditions.

Toxicological Testing and Product Chemistry

Registration of a specific formulation of a pesticide does not require the formulation to undergo the same battery of tests as the active ingredient. Tests on the formulation are generally limited to acute toxicology and product chemistry testing to determine formulation characteristics, such as viscosity (if the product is a liquid), flammability, corrosiveness, or explodibility.

Risk Assessment

Once the required data are compiled, they are submitted to the Registration Division of the EPA for review along with a proposed label for the formulation. The EPA reviews the submission to ensure that the formulants are on the registered inert ingredients list and that the proposed use will not result in an unacceptable risk either to applicators or nontarget organisms. The EPA reviews the proposed label and provides guidance regarding specific statements concerning safety to humans and nontarget organisms that must appear on the label. Once the label has been approved, the product is cleared for sale and use.

8.4 Production

Identification of Sponsor

A sponsor, as defined by GLP guidelines, can be (1) a person who initiates and supports a study by provision of financial or other resources; (2) a person who submits a study to the EPA in support of an application for a research or marketing permit; and (3) a testing facility, if it both initiates and actually conducts the studies (40 CFR Part 160). Therefore, the sponsor of a pesticide can be either the manufacturer of a chemical or a third party. Not many chemical manufacturers produce piscicides. In most circumstances, a product that is found to be an efficacious piscicide has been developed for other uses, such as an herbicide. Manufacturers of such chemicals are not usually motivated to register the product for use as a piscicide because it is a minor use and is not profitable and because more tests are required for a chemical used on water. Guiding the registration of a piscicide consequently falls on the party interested in the registration from financial and technical perspectives. Once identified, the sponsor has the responsibility to secure and provide funding to develop and register the piscicide and monitor all testing facilities involved in the conduct of registration studies for regulatory compliance and for study progress. The sponsor also has the responsibility of securing funding to produce the active ingredient and formulations. Once registered, the sponsor is responsible for maintaining the registrations of the active ingredients and formulations with the EPA and the states.

Manufacturing

The producer of a piscicide may be willing to manufacture the piscicide and formulations of the piscicide to the specifications of the party interested in the registration. If not, then it will be necessary for the registrant to identify an additional facility that can manufacture the formulation. It is usually wise, depending on the volume of chemical that needs to be acquired, to have more than one manufacturer of the active ingredient under contract so that a constant source is available and costs can be controlled.

Labels and Product Classification

Registrations of products fall into two broad classifications: manufacturing-use products (MUP) and end-use products (EUP). Manufacturing-use products may either be the active ingredient or a formulation, if that formulation is used in the production of yet another formulation. The product label for such a material will specifically state that the product is an MUP and can only be used in the production of another product. End-use products are formulations that are only used to control pests and may not be used in the production of another formulation unless a specific registration and label have been developed for that purpose. For example, Bayluscide® 70% WP has two registrations, one for use in sea lamprey control (EUP), and one for use in the production of Bayluscide® 3.2% Granular Formulation (MUP).

Registration Maintenance

Once an active ingredient and formulations of the active ingredient have been registered, activities turn toward registration maintenance. The registrant remains in contact with the EPA to pay annual fees, to renew the registrations, and provide any additional information that the EPA may require. One important aspect of registration maintenance is the monitoring and reporting of unreasonable adverse effects of the pesticide that falls under Section 6(a)(2) of FIFRA. The EPA has defined unreasonable adverse effects as "any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide" (EPA 1998*a*). Information provided to the EPA under the adverse effects rule is critical. While such information could result in the suspension or cancellation of a product, it is more likely that it will be used to modify the terms and conditions of the registration on the basis of a review of the risks and benefits.

The burden of submission of adverse effects information falls solely on the registrant of a product, and only information that is additional and factual must be submitted. Any pertinent information that comes to the attention of the registrant directly, or to any party under contract to the registrant so that the registrant might reasonably be expected to receive the information, must be submitted. For example, if a university study finds that a pesticide causes tumors in an avian species and the registrant, or an agent for the registrant, becomes aware of the information, then a 6(a)(2) report must be filed with the EPA. The information must be factual. For instance, if someone is alleged to have become ill after swimming in a pond treated with a pesticide and the allegation is reported by a neighbor or friend, that in itself is not sufficient to warrant a 6(a)(2) report. On the other hand, if the person is treated medically for the condition and the symptoms are consistent with expected toxicity, a 6(a)(2) report to the EPA is required provided the incident is reported by the attending physician to an appropriate authority.

Costs to maintain pesticide registrations vary from year to year and are based on appropriation legislation. For example, in 2003 the legislation authorized the EPA to collect $21.5 million in pesticide maintenance fees (J. Jones, EPA, personnel communication). Consequently, the fee to a company for the first registration of a product was set at $1,675, and $3,350 was charged for

each subsequent product registered. So if Company A has three registered products, the fee would be $1,675 + (2 × $3,350) or $8,375. Fee caps are also set by the appropriation legislation, and for this year the caps were set at $70,000 for the first 50 registrations and a maximum of $121,000.

8.5 Laboratories for Development of Regulatory Data

There are more than 2,000 laboratories in the United States that generate regulatory data for submissions to the EPA (D. Garvin, Society of Quality Assurance, personal communication). Laboratories that have submitted data in support of registrations to the EPA are listed in Table 8-1. Because of the breadth and diversity of data required to register a pesticide, there is no single laboratory that can conduct all of the required studies. Most laboratories have expertise in one particular field. Because of the great number of testing laboratories that can conduct GLP studies, a detailed list of the laboratories and their areas of specialization is not provided.

Whichever laboratories are chosen to perform the required studies, it is imperative that a careful review of the laboratories' capabilities and study proposals be conducted. Because the studies will be submitted to regulatory agencies, it will be necessary to review the quality assurance capabilities and GLP conformance of the laboratories. Laboratories that can conduct the appropriate field studies for environmental or residue studies are less easily identified. The additional effort required to conduct studies in the field that conform to GLP is not usually undertaken by most contract laboratories.

8.6 Time Line and Cost Estimates

Figure 8-1 shows an approximate time line for the stages of developing and registering a pesticide. Actual times will vary depending on the chemical selected and the registration requirements. As stated above, conducting all the studies required to register a pesticide can take 8-10 years and can cost up to $10 million. To register a piscicide, the time line may be closer to 5 years and the cost closer to $5 million. If the active ingredient is one that is already registered, the actual final time required and cost associated with registration will depend on the availability of data from the current registrant. While it is desirable to form a cooperative agreement with the producer of a chemical to register their product as a piscicide, by law they are required to cooperate and supply the data if requested.

Table 8-1. Alphabetical listing of analytical and toxicology laboratories that have had data submitted to the U.S. Environmental Protection Agency. This list is only a small portion of the estimated 2,000 testing laboratories in the United States. This list does not represent an endorsement by either the U.S. Geological Survey or the U.S. Environmental Protection Agency.

Name	Address	Phone number	FAX number
	Analytical Laboratories		
ABC Laboratories, Inc.	7200 East ABC Lane, Columbia, Missouri 65202	573.474.8579	573.443.9033
Adpen Laboratories	11757 Central Parkway, Jacksonville, Florida 32224	904.645.9169 888.428.3784	904.641.8423
Analytical Development Corporation	4405 Chestnut Street, Suite D, Colorado Springs, Colorado 80907-3875	719.260.1711	719.260.0695
Compliance Services International	1112 Alexander Avenue, Tacoma, Washington 98421	253.272.6345	253.272.6241
Midwest Research Institute	425 Volker Boulevard, Kansas City, Missouri 64110	816.753.7600	816.753.8420
Morse Laboratories, Inc.	1525 Fulton Avenue, Sacramento, California 95825	916.481.3141	916.481.2959
National Food Laboratory	6363 Clark Avenue, Dublin, California 94568-3097	925.828.1440	925.833.9239
North Coast Laboratories	5680 West End Road, Arcata, California 95521	707.822.4649	707.822.6831
	Toxicology Laboratories		
Argus Research Laboratories	935 Horsham Road, Horsham, Pennsylvania 19044	215.443.8710	215.443.8587
Battelle Memorial Institute	505 King Avenue, Columbus, Ohio 43201	614.424.7948	614.424.3268
Bell Laboratories	3647 Kinsman Boulevard, Madison, Wisconsin 53704	608.241.0202	608.241.9631
Bio Research	1071 North Fulton Avenue, Fresno, California 93728	559.455.5660	559.455.5661
Biocon, Inc.	15801 Crabbs Branch Way, Rockville, Maryland 20855	301.762.3202	800.826.8426
Celsis Laboratories, Inc., New Jersey Division	165 Fieldcrest Avenue, Edison, New Jersey 08837	732.346.5100	732.346.5115
Chemical Industry Institute of	6 Davis Drive, PO Box 12137, Research Triangle Park,	919.558.1341	919.558.1300

Table 8-1. Continued

Name	Address	Phone number	FAX number
Toxicology	North Carolina 27709-2137		
Consumer Product Testing, Inc.	70 New Dutch Lane, Fairfield, New Jersey 07004-3404	201.808.7111	201.808.7234
Cosmopolitan Safety Evaluation, Inc.	PO Box 71, Stateville Quarry Road, Lafayette, New Jersey 07848	973.383.6253	973.383.0383
Covance Laboratories	9200 Leesburg Pike, Vienna, Virgnia 22182	703.893.5400	703.759.6947
Covance Laboratories	3310 Kinsman Road, Madison, Wisconsin 53704	608.241.4471	608.241.7227
Fermenta Animal Health, Inc.	1512 Webster Court, Fort Collins, Colorado 80524	970.221.2050	970.221.5049
Primedica Redfield Laboratories	100 East Boone Street, PO Box 308, Redfield, Arkansas 72132	501.397.2813	501.397.2002
Genesis Laboratories	10122 NE Frontage Road, Wellington, Colorado 80549	970.568.7059	970.568.3293
Gibraltar Laboratories	122 Fairfield Road, Fairfield, New Jersey 07004-2405	973.227.6882	973.227.0812
Huntingdon Life Sciences	PO Box 2360, Mettlers Road, East Millstone, New Jersey 08875-2360	732.873.2550	732.873.3992
IIT Research Institute	10 West 35th Street, Chicago, Illinois 60616-3799	312.567.4883	312.567.4842
Inhausen Research Institute	2601 South Lemay, Suite 7-505, Fort Collins, Colorado 80525-2247	970.221.1090	970.221.4730
MB Research Laboratories	PO Box 178, Steinsburg and Wentz Roads, Spinnerstown, Pennsylvania 18968	215.536.4110	215.536.1816
MPI Research Laboratories	54943 North Main Street, Mattawan, Michigan 49071	616.668.3336	616.668.4151
OREAD Biosafety, Inc.	400 Farmington Avenue, Farmington, Connecticut 06032	860.674.6300	860.676.9443
Product Investigations, Inc.	151 East 10th Avenue, Conshohocken, Pennsylvania 19428	610.825.5855	610.825.7288

Table 8-1. Continued

Name	Address	Phone number	FAX number
Product Safety Laboratories, Inc.	725 Cranbury Road, East Brunswick, New Jersey 08816	732.254.9200	732.254.6736
Research Triangle Institute	PO Box 12194, 3040 Cornwallis Road, Research Triangle Park, North Carolina 27709-2194	919.990.8347	919.541.6003
Ricerca, Inc.	PO Box 1000, 7528 Auburn Road, Painesville, Ohio 44077-1000	216.357.3722	216.354.6276
SGS US Testing	75 Passaic Avenue, Fairfield, New Jersey 07004	973.575.5252	973.244.1694
SRI International	333 Ravenswood Avenue, Menlo Park, California 94025	650.859.2412	650.859.3344
Sitek Research Laboratories	15235 Shady Grove Road, Suite 303, Rockville, Maryland 20850	301.926.4900	301.926.8891
Springborn Laboratories	640 North Elizabeth Street, Spencerville, Ohio 45887	419.647.4196	419.647.6560
Stillmeadow, Inc.	12852 Park One Drive, Sugarland, Texas 77478	281.240.8828	281.240.8448
TKL Research	4 Forest Avenue, Paramus, New Jersey 07652	201.587.0500	201.587.0209
Tox Monitor Laboratories	33 West Chicago Avenue, Oak Park, Illinois 60302	708.345.6970	708.382.0591
Toxikon Corporation	15 Wiggins Avenue, Bedford, Massachusetts 01730	617.275.3330	617.271.1137
White Eagle Toxicology Laboratories	2003 Lower State Road, Doylestown, Pennsylvania 18901	215.348.3868	215.348.5081
WIL Research Laboratories	1407 Montgomery Township, Road 805, Ashland, Ohio 44805-9281	419.289.8700	419.289.3650

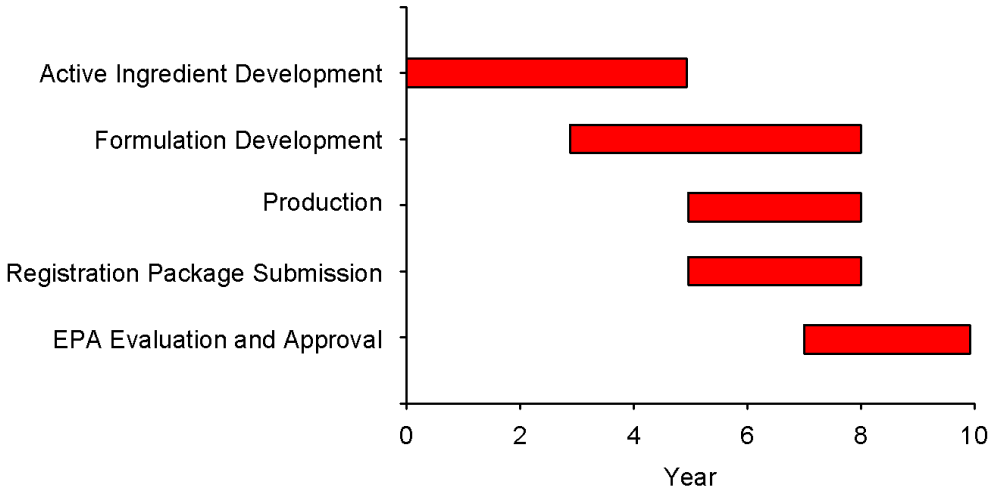


Figure 8-1. Time line for development and registration of a piscicide.

Chapter 9. Developing an Integrated Pest Management Strategy

by Terrance D. Hubert and Verdel K. Dawson

The concept of integrated pest management has been around in various forms for several centuries. It was probably in the late 1950s, however, when the concept started to evolve from a casual combination of techniques into a cohesive strategy of pest management (Forney 1999). The evolution of integrated pest management has been driven primarily by agriculture, and few examples of a complete integrated pest management system for aquatic pests exist. Published definitions of integrated pest management are therefore naturally agriculturally oriented. The USDA defines integrated pest management as follows:

> "a management approach that encourages natural control of pest populations by anticipating pest problems and preventing pests from reaching economically damaging levels. All appropriate techniques are used, such as enhancing natural enemies, planting pest-resistant crops, adapting cultural management, and using pesticides judiciously" (USDA 1994).

In his book on integrated pest management, Dent (1995*a*) states that there are several principles that form the framework of an integrated pest management program. These principles are crop husbandry, ecology, socioeconomics, ecological genetics, principles of control, and control technologies. Crop husbandry, which is changed to resource husbandry for this review, is the practice of growing and harvesting to provide a viable resource in as economically efficient a manner as possible. Ecology is generally defined as the interactions that determine the distribution and abundance of organisms. Socioeconomics describes the aspects of human behavior involved with choices between alternatives on the basis of resources. Ecological genetics examines the changes in genetic composition of populations on the basis of environmental interactions. Principles of control are a move away from the classification of control measures on the basis of their characteristics and a move toward a more functional classification on the basis of the criteria affecting the selection and the use of the control measures. Control technologies are, of course, the various specific methods of control that make up an integrated pest management program.

The first step toward developing a focused integrated pest management strategy is to determine the type and form of integrated pest management system to achieve the required pest control goals (Dent 1995*b*). In doing so, the following questions must be answered: (1) who will be using the integrated pest management control techniques, (2) on what scale will the program be

conducted, (3) what control measures will be used, (4) in what way will the control measures be applied, (5) what will be the perceived benefits, and (6) over what time scale will these perceived benefits be realized? The answers to these questions will determine how research on the integrated pest management program is to proceed and how the integrated pest management system is developed.

Another critical aspect of developing an integrated pest management strategy is the availability of resources (Dent 1995*c*). The availability of human, institutional, temporal, and financial resources will ultimately determine what can or cannot be done as part of the integrated pest management system. Human-resources subcomponents include finding individuals with the appropriate skills, knowledge, and experience to participate in an integrated pest management control program. Subcomponents of the institutional category are vehicles/machinery, land, facilities, and equipment, whereas financial category subcomponents include running costs, consumables, capital, salaries, overhead, and travel.

There are varying opinions regarding the components of an integrated pest management system. Dent (1995*d*) lists pesticides, host plant resistence, biological control, cultural control, and interference methods as components of control. Host-plant resistence and interference methods, i.e., the use of semiochemicals (defined as any of a class of substances produced by organisms, especially insects, that participate in regulation of their behavior in such activities as aggregation of both sexes, sexual stimulation, and trail following; Parker 1994), could be grouped within biological control, and interference methods could also be grouped under chemical control since it is chemical based. Forney (1999) suggests that biological control, cultural control, strategic control, and chemical control are the four major components of an integrated pest management control system and places the use of semiochemicals into the biological control category. For the purposes of this discussion, integrated pest management control systems will be divided into three components: chemical, biological, and physical control.

9.1 Chemical Control

Pesticides have been used in pest control for about 60 years. The effectiveness of pesticides combined with their low cost makes them an attractive part of a control strategy. Drawbacks have included persistence in the environment, deleterious effects on nontarget organisms, and development of chemical resistence in insects. To address the first two harmful effects, research has focused on developing a new generation of more environmentally benign pesticides. On the basis of past experience with invasive species, it is unlikely that an effective integrated pest management strategy can be developed that does not rely to some degree on the use of pesticides.

Rotenone and antimycin are two examples of chemicals that can play key roles in an integrated management of nonnative fishes. In Australia, common carp have contributed to declining water quality, bank erosion, and the disappearance of native species (Carp Control Coordinating Group 2000). Rotenone has been used as part of the national management strategy in this control program (Harris 1995). Also, the use of rotenone in fisheries management in California has been outlined in good detail by Finlayson et al. (2000). Schneider and Lockwood (1997) demonstrated the utility of antimycin in an 8-year study designed to thin out small bluegills from selected lakes in Michigan and enhance the numbers of bluegill larger than 15 cm. The study was conducted on 16 lakes in the southern portion of the state. Antimycin in combination with stocking of walleye, antimycin in combination with catch and release, and walleye stocking only were the strategies tested. Study results indicated that the best responses were obtained by using antimycin in combination with catch and release**.** New piscicides and new formulations of existing piscicides will continue to be avenues of growth in chemical control strategies.

9.2 Biological Control

Over time, biological control has come to mean the use of living organisms as pest control agents. For this review, we expand biological control to include the use of semiochemicals and biochemicals (e.g., pheromones). Dent (1995*b*) suggests that there are five types of biological control strategies: introduction, augmentation, inoculation, inundation, and conservation. Examples of successful biological control involve the introduction of a nonnative natural enemy to control an accidentally introduced pest. Augmentation involves increasing populations of natural enemies present at a given site year-round. One example of augmentation to manage fish populations is the introduction of walleye to complement the use of antimycin to improve bluegill populations in selected Michigan lakes (Schneider and Lockwood 1997). Young walleye were used either alone or in combination with antimycin treatments to thin bluegill populations. In contrast, inoculation is used in situations where seasonal control is desired. The natural enemy is absent from a given area and cannot survive long term under normal circumstances. In this situation, natural enemies are planted at the beginning of the season to prevent buildup of the pest. Inundation involves large releases of native or introduced natural enemies in response to pest levels that have reached damaging proportions. Inundative control is usually a short-term measure. Stocking large numbers of predatory fish is a commonly used biological control method to provide partial control of an undesired species of fish (e.g., attempted control of Eurasian ruffe in Duluth Harbor; Mayo et al. 1998). Finally, conservation involves the use of techniques to conserve populations of natural enemies so that a developing pest population can be controlled.

Biopesticides are materials derived from natural sources, such as animals, plants, bacteria, and certain minerals (EPA 2002). Baking soda, which is used as a fungicide (Kuepper et al. 2002), and canola oil, which is registered by the EPA as an insecticide (EPA 1998*b*), are examples. According to the EPA (2002), biopesticides fall into three major categories: (1) microbial pesticides, (2) plant-incorporated-protectants, and (3) biochemical pesticides. Examples of microbial pesticides include fungi that kill certain weeds or specific insects. Probably the best known example of a plant-incorporated-protectant is incorporation of the Bt® pesticidal protein from *Bacillus thiurengsis* into plant genetic material resulting in the plant's own ability to produce the protein. Biochemical pesticides, or semiochemicals, are naturally occurring substances that control pests by nontoxic mechanisms.

Chemical attractants and repellents have been proposed as means of keeping fish out of specific areas or as means of congregating populations for easier removal (Dawson et al. 1998, Hogue 1999). Specific types of attractants and repellents that have recently received a lot of attention are pheromones. These are species-specific chemicals that can be secreted as attractants to aid in mating or as repellents in the case of alarm pheromones (Maniak et al. 2000, Li et al. 2002). Pheromones could be used to interrupt mating behavior or to lure pest fishes to traps.

Some chemicals that are not naturally occurring also fall under the category of biological control. Some chemicals that have been developed to cause the sterilization of males or females fall into this category. One such chemical is bisazir that is currently being used in the sea lamprey sterile male release program to contribute to the reduction of sea lamprey populations in the Great Lakes (Hanson and Manion 1978). Adult males are sterilized by exposure to bisazir and then released to compete with fertile males during spawning (Figure 9-1). Sterilization can also be achieved by exposure to radiation.

Figure 9-1. U.S. Fish and Wildlife Service technician preparing an adult spawning phase male sea lamprey for sterilization with bisazir.

Genetic manipulations of organisms also fall under the category of biological control. Production of monosex populations of fish is a potential management tool for undesired fishes. This result can be produced by one of two means. The first means is through a process called gynogenesis (development of an ovum after penetration by a spermatozoan but without incorporation of the paternal genome in the zygote). Gynogenesis can be achieved by irradiation of milt and by exposing eggs to thermal shock or hydrostatic pressure (Stanley et al. 1975). Another means of producing monosex fish populations is the use of "daughterless" technology (Carmody 2003, Stucky 2003). Daughterless technology is a strategy in which a promotor is used to activate the daughterless gene to express only in females. The gene triggers the inhibition of production of a key enzyme required for the fish to develop into a female. The fish defaults to a male, and consequently the population is reduced because fewer and fewer females are produced. This approach is being investigated for the control of common carp and Northern Pacific seastar (*Asterias amurensis*) in Australia (Joint Standing Committee on Conservation/Standing Committee on Fisheries and Aquaculture 1999).

Fertility control is being proposed as a fishery management tool in which an immuno-contraceptive agent would provide species-specific management. The target reproductive protein (or antigen) must be specific, that is, show no cross-reaction with nontarget species. The antigen would be delivered in a bait that contains the antigen or a nondisseminating pathogen specific to the species to be controlled (Hinds and Pech 1997).

Specific viruses, such as *Rhabdovirus carpio* that causes the disease Spring Viraemia in carp, is another biological control mechanism that is under investigation (Crane and Eaton 1997). To be effective for this purpose, an infectious agent must be (1) species specific, (2) not capable of

genetic adaptation to new hosts, (3) not affected by environmental conditions, and (4) highly virulent with predictable outbreaks of the disease.

Another area of biological control being debated as a possible fishery management tool involves molecular biological techniques including chromosomal manipulation, gender manipulation (by way of hormones and transgenic methods) and the introduction of inducible fatality genes by way of transgenic methods (Grewe 1997). There is likely to be resistance to gaining approval of these techniques by the public and the scientific community until more is learned about the ecological ramifications of the release of transgenic fish.

9.3 Physical Control

Physical control of undesired species includes management practices, such as the addition of structures to keep the species from infesting a given area and physical removal of individuals of the undesired species. Water-level manipulation can be an effective physical-control strategy when undesired species emigrate differentially from desirable species during the drawdown. This technique has also been used to destroy egg masses of undesired species, such as northern pike, after their deposition in littoral shallows (Harris 1995). Barriers are another example of physical control that may be used in an integrated pest management program. The advantages of high- and low-velocity barrier screens have been described (Miller and Laiho 1997). Barriers of these types were under consideration for control of nonnative fishes in the upper Colorado River. Also considered were electrical, acoustical, and light barriers. An electrical barrier has been installed in the Illinois waterway near Chicago, Illinois, in an attempt to prevent the movement of the invasive round goby from the Great Lakes into the Mississippi River drainage as well as to prevent the upstream migration of Asian carp into the Great Lakes. Two electrical barriers have also been installed on two Central Arizona Project distributary canals to prevent Colorado River fishes from moving upstream into the Gila River drainage (Clarkson 2003). Physical barriers are an important part of the program to control sea lamprey in the Great Lakes (Great Lakes Fishery Commission [GLFC] 2001) and have played an important role in recovery efforts for western trout species (Rinne and Turner 1991). However, barriers have drawbacks as well, related to initial construction costs, maintenance costs, environmental impacts, and preventing desirable fishes from upstream migration.

Examples of other potential physical-control techniques include netting, electrofishing, traps, and explosives. In Lake Davis, California, where northern pike have reduced rainbow trout populations, purse seining was used as one method of control (Lee 2001). The mesh size allowed for the capture of northern pike approximately 20 cm or larger and nontarget species were safely returned to the water. Generally, electrofishing has been thought of as a means of sampling fish for population estimates. However, this method of collecting fish has also been used as a control method in Australia's efforts to control common carp (Harris 1995). The Wisconsin Department of Natural Resources used a combination of chemical treatment with rotenone and placement of traps to control common carp in the Horicon Marsh (Wisconsin Department of Natural Resources 1999), and trap nets have been used to remove bullhead, common carp, and goldfish from diked wetlands on Lake Erie (Wiggins 1999). Detonation cords have been suggested as a possible method of removing nonnative fish stocks, but no examples of this have been reported (Shepard, in press). Physical removal is another approach to controlling undesirable fishes. Targeted fishing or overharvesting of specific species of fish either recreationally or commercially has been used to regulate fish populations, but it has not resulted in elimination of a species. In southeastern Australia, events called "Carpathons" were sponsored, and commercial fishing was encouraged as a means of control of common carp (Harris 1995).

Another important component of nonnative species control is educating the public about the destruction caused by invasive species and how to prevent the spread of the organism. In Australia, part of the National Management Strategy for Carp Control concerns educating the public on the impact of common carp on community assets and resources and how these impact the individual and then encouraging them to participate in eradication and control efforts (Carp Control Coordinating Group 2000). In the United States, the effort to control the spread of the zebra mussel has used an education program sponsored by the U.S. Fish and Wildlife Service and the Great Lakes Sea Grant Network that describes the life cycle of the mussels and emphasizes the importance of making sure that boats that have been in waters infested with zebra mussels are thoroughly cleaned before moving them to another body of water**.** The Alaska Department of Fish and Game has advised the public on rules and regulations regarding fish transport and stocking laws, particularly to stop the illegal stocking of northern pike (Alaska Department of Fish and Game 2001). The University of Minnesota Sea Grant Program has prepared a small brochure that describes the threat posed by the round goby and what the public can do to control its spread**.** In some instances, federal or state agencies have enlisted the assistance of private enterprises to assist in the education process. Mercury Marine, manufacturer of outboard motors, has published a brochure on curbing the spread of nonnative species.

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 ($)					Total cost
		1	2	3	4	5	
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).

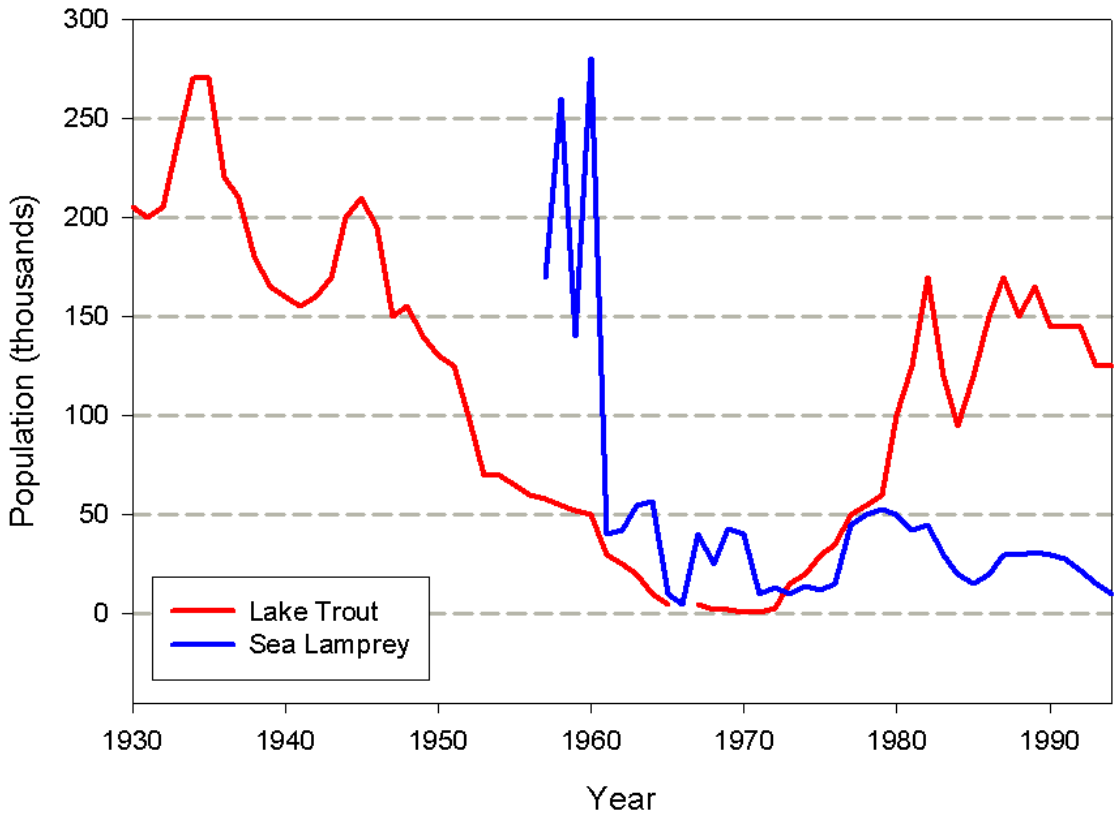


Figure 11-1. Abundance of lake trout (1930-1996, no data collected in 1966) and sea lamprey (1956-1996) in Lake Superior. Lake trout were declining significantly before control of sea lampreys began in the early 1960s (from the Great Lakes Fishery Commission).

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.

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.

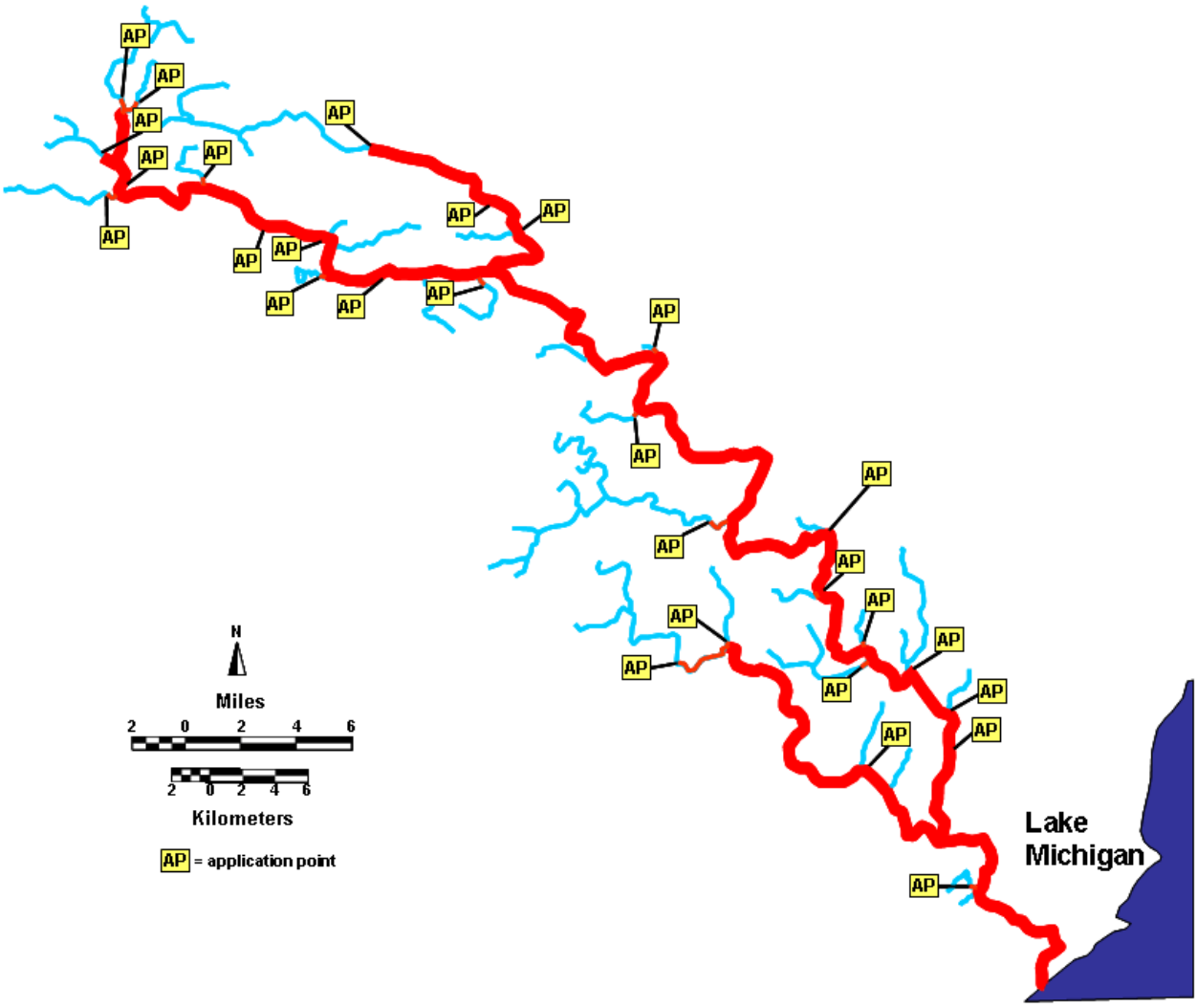


Figure 11-2. Lampricide treatment plan for the Ford River, Upper Peninsula of Michigan, in 2000. Red areas detail treated areas of the watershed. AP = Application Point

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®

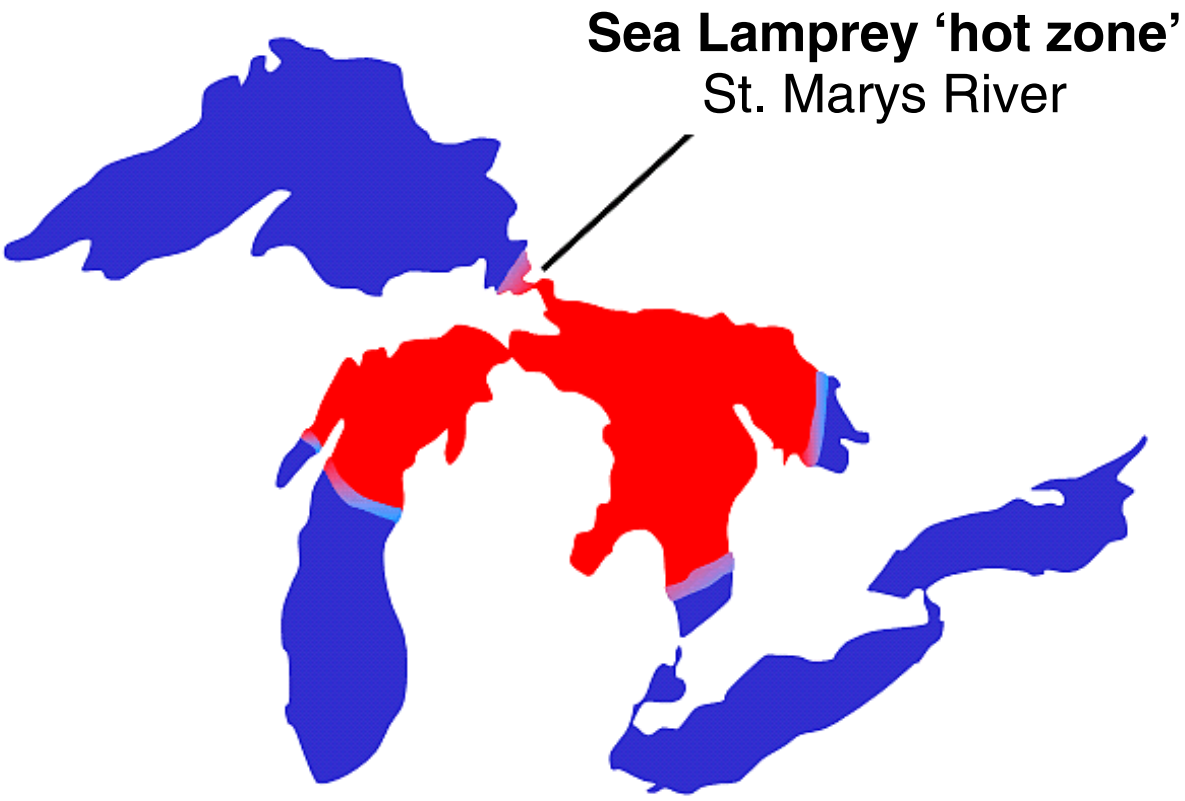


Figure 11-3. Map of the zone of influence by parasitic sea lampreys produced from the St. Marys River.

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).

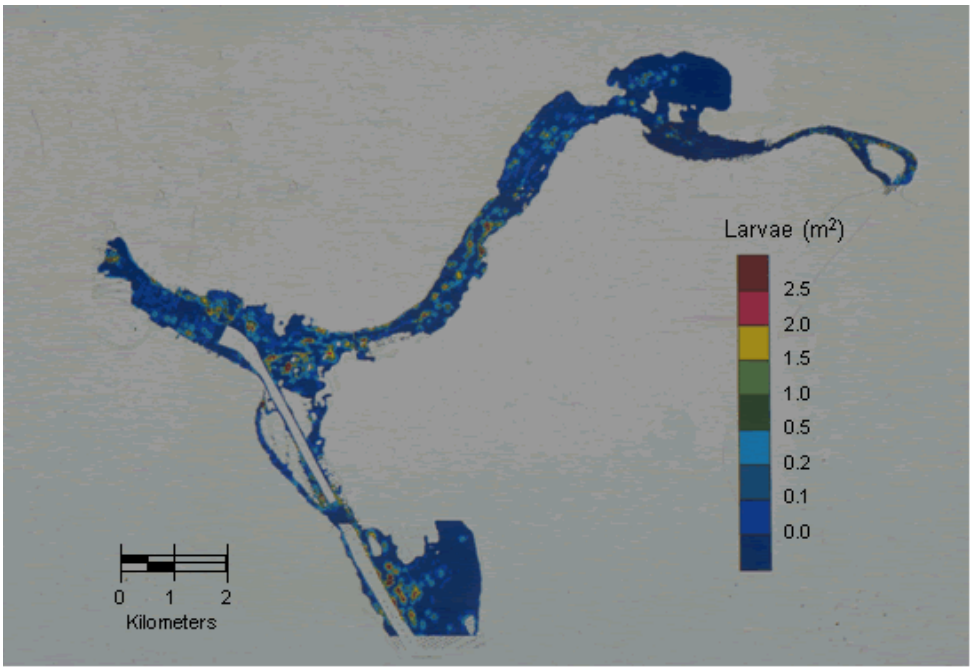


Figure 11-4. Map of the St. Marys River showing the areas in which high abundances of larval sea lamprey were detected before treatment in 1999.

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).

Chapter 14. Summary

by Verdel K. Dawson

Many of the ecosystems in the southwestern United States, including those in the Gila River basin in Arizona and New Mexico, have been degraded by introductions of nonnative fishes, and the native fish species have been compromised. A significant complication in the attempts at reclamation of these systems is the fact that many of the native fish species of concern have little recreational or commercial value, and therefore, lack the societal support enjoyed by native fish species in other regions of the country. For example, when sea lamprey began to destroy the multibillion dollar commercial/recreational lake trout fishery in the Great Lakes, there was considerable support from the United States and Canadian governments to develop a program for controlling this invasive species. On the other hand, the spikedace and loach minnow do not enjoy the same level of recreational or commercial value as the lake trout and therefore lack public support for their protection. Ironically, some of the nonnative species that are competing with and preying on the native species, were introduced to the area specifically because they were regarded as desirable in other regions of the country.

Usually the degraded aquatic systems in the southwestern United States will require reclamation of habitat that has been altered by human activity and removal or substantial reduction of nonnative fishes. In this report, characteristics of the life stages, habitat preferences, and physicochemical tolerances of native fishes of concern were compared with those of harmful nonnative fishes to aid in identification of vulnerable conditions for nonnative species around which control strategies could be developed. The geographic ranges of native and nonnative fishes of concern were mapped to identify areas inhabited solely by native or nonnative species, or to identify key intersection areas between native species of concern and nonnative species. This information could be critical in the development of integrated pest management strategies. Also, knowledge of life-history characteristics, such as spawning periods, may be valuable for timing of those management efforts.

Knowledge of the mode of action of candidate piscicides and structure-toxicity relationships can be useful for optimizing selectivity of chemicals or combinations of chemicals. The identification of specific energy production inhibitors may provide leads to the development of new chemical tools for selectively managing fish populations. While this field of endeavor is in relative infancy regarding piscicides, there are considerable advancements being made in the field of agricultural chemicals that may have application in the development of fishery chemicals.

Eradication of undesired fishes began almost 100 years ago. The use of piscicides has increased since then as more nonnative species were being introduced and as better toxicants were becoming available. At least 45 chemicals have either been used as piscicides, or are currently in various stages of development. A rating system was devised to evaluate the potential of these chemicals to be useful to fishery managers in resolving some of the problems caused by

nonnative fishes. The ratings were based on taxon selectivity, ease of application, toxicity to nontarget organisms, safety to humans, persistence in the environment, tendency to bioaccumulate, cost, and registration status. Only five of the chemicals achieved ratings of 75 or greater out of a possible score of 100. They included the four toxicants currently registered by the EPA for use as piscicides (antimycin, rotenone, TFM, and Bayluscide®) and the candidate selective piscicide, Squoxin.

Delivery systems have been developed to meet specific management needs and include a variety of formulations and application techniques. Piscicides are generally formulated as either liquids or solids that include inert ingredients to help make them soluble in water. Solid formulations include wettable powders, soluble bars, and granules. Granules are designed either to release the active ingredient as it sinks through the water column or may contain an outer coating that allows for a delayed release of the chemical. Recently, toxic baits have been developed where a toxicant is impregnated into a bait that is consumed by target organisms that are congregated and actively feeding in an isolated area.

Fishery managers have come to realize that the piscicide "silver bullet" does not currently exist. Therefore, research and development of additional chemical tools would seem to be desirable. However, the use of piscicides is closely regulated by the EPA as mandated by Congress. It is estimated that development and registration of a pesticide can take 8 to 10 years and cost $35 to $50 million. Over 100 different tests can be required to register a pesticide; many tests must be conducted under the constraints of a Good Laboratory Practices program. In developing a new piscicide, it is important to have an understanding of the biology of the organism to be controlled. Then chemicals are selected for toxicity screening on the basis of prior knowledge of biological activity of structural classes of chemicals and safety to nontarget organisms. Once a chemical has been selected for development, a series of laboratory and field experiments must be conducted to determine efficacy, residue chemistry, environmental safety, product chemistry, etc., and the results must be submitted for EPA's review. A manufacturer and sponsor must be identified, labels must be developed and approved, and registrations must be maintained.

Before conducting a piscicide treatment, a cost-benefit analysis of the treatment should be conducted. Not only should the cost of the chemical be considered, but also pre- and post-treatment surveys, environmental assessments and impact statements, travel, equipment, labor, permits, analytical support, on-site toxicity tests, advance notification, etc. The costs should be balanced against the benefits of the treatment. Benefits of a treatment are more difficult to assess, especially estimating the benefits of protecting or restoring a threatened or endangered species. This usually takes the form of evaluating the impact of various control options on the ecosystem.

New taxon-specific piscicides needed to help manage the environmental problems caused by nonnative fishes in the southwest are not available. The existing class of registered piscicides are all energy production inhibitors. They all have physicochemical properties that allow their rapid uptake by fish across the gills and subsequent rapid distribution and loss from the body. There are a number of new mitochondrial complex I inhibitor ligands that are possible candidate piscicides, however, fish toxicity data are needed to evaluate their potential. A possible option for developing selective piscicides would be to evaluate the relative toxicities of various combinations of existing general piscicides to target and nontarget fishes.

The concept of pharmacokinetic modeling has been proposed as a mechanism for predicting differences in toxicity between species by evaluating distribution or elimination characteristics of

chemicals. More complex models called physiologically based pharmacokinetic models have been used for risk assessment of toxicity. These models are based on the specific physiology of the species and physicochemical characteristics of the compound. However, pharmacokinetic data have not been developed for registered or candidate piscicides and development of physiologically based pharmacokinetic models in fish is in its scientific infancy, so the use of these models to identify species-specific piscicides is premature at this time.

The use of chemicals is still the most direct method of reducing pest numbers, and it is often one of the first methods considered for control. However, it is not likely that the present arsenal of approved selective piscicides would be effective for controlling nonnative fishes in the southwestern United States because the composition of native and nonnative species is different from most areas where selective piscicides are being used. The development and registration of a new selective piscicide specifically for use on nonnative fish species in the southwestern United States would be time-consuming and considerably expensive. That does not mean that fishery managers should just throw up their hands and concede defeat. We recommend that the problems resulting from the invasion of nonnative fishes should be divided into two categories: (1) short-term emergency situations that require immediate action, and (2) longer-term issues that have the luxury of being monitored while research and development are conducted on new and innovative management tools.

The emergency situations should be addressed primarily with the use of one of the currently registered piscicides (antimycin, rotenone, TFM, or Bayluscide®). 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. Therefore, effective use of these chemicals would most likely be as general toxicants rather than as selective toxicants. If critical 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 the reclamation treatment. Unfortunately, the lampricides, TFM and Bayluscide®, 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. Therefore, additional permits would be required, such as an emergency exemption or a special local needs (Section 24[c]) permit to use either lampricide in the southwestern United States. Antimycin and rotenone, however, are currently registered as piscicides for use throughout the United States, and their treatment costs are similar. Unless complete eradication of nonnative species can be achieved and reinfestation can be prevented, piscicides probably will have to be reapplied indefinitely to keep nonnative populations in check.

Fish toxicants have long been considered the best rehabilitation tool available for fishery management (Prevost 1960, Hooper et al. 1964, Klar and Schleen 2000). However, there have been many treatment failures reported in the literature. Lopinot (1975) summarized the use of piscicides in the midwestern United States and reported that during 1963-72 about 82% of the treatments were considered successful. Meronek et al. (1996) reviewed 250 fish control projects and concluded 43% were successful, 29% unsuccessful, and 28% as having insufficient data to determine success or failure. There obviously needs to be improvements made in the piscicides, formulations, and methods of application that are available to fishery managers. Greater success in fishery management could probably be achieved if chemical control was considered only as one tool of many to be used in an integrated pest management approach. This would involve a system comprised of chemical, biological, and physical controls. Creative integration of multiple pest management techniques has been successfully used in agriculture and its importance is now being realized in management of aquatic pests. In addition to the use of piscicides, other management tools should be included as part of an integrated management program. Techniques

that should be considered include the use of water-level manipulations, barriers, targeted overharvest, stocking predators, sterilants, toxic baits, and gynogenesis.

In situations where populations of native fishes are not imminently imperiled by nonnative species, there may be time for longer-term solutions to be developed. These situations should be monitored to evaluate the extent of any ecological impacts and the rates of resulting ecosystem decline. While these systems are being monitored, efforts should be directed toward development of potential future management techniques. These might include the development and use of selective piscicides, attractants and repellants, immuno-contraceptive agents, viruses, chromosomal manipulations, gynogenesis, and transgenics.

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Glossary

<	less than
>	greater than
°C	degrees Centigrade
2,4-D®	(2,4-dichlorophenoxy)acetic acid
ADI	Acceptable Daily Intake
ADP	adenosine diphosphate
ATP	adenosine triphosphate
Bayluscide®	2-aminoethanol salt of 2',5-dichloro-4'-nitrosalycylanilide
Bt®	*Bacillus thiurengsis*
CFR	Code of Federal Regulation
Complex I	NADH:ubiqinone oxidoreductase
Complex II	Succinate:ubiquinone oxidoreductase
Complex III	Ubiquinol:ferrocytochrome c oxidoreductase
Complex IV	ferrocytochrome c:oxygen oxidoreductase
Complex V	F0F1-ATP synthase/oxidative phosphorylation uncoupling agents
DANEX-80	80% dimethyl-1,2,2-trichloro-1-hydroxyethylphosphonate
dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-endo-1,4-exo-5,8-dimethanonapthalene
DDVP	Vapona® or Dichlorvos
DMF	dimethyl formamide
DDT	1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane
Endosulfan or Thiodan®	1,4,5,6,7,7-hexachloro-5-norbornene-2,3-dimethanol cyclic sulfite
EPA	U.S. Environmental Protection Agency
ETS	electron transport system
EUP	end-use products
FDA	U.S. Food and Drug Administration
FAD	Flavin Adenine Diphosphate
FADH2	Reduced Flavin Adenine Diphosphate
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GD-174	2-(digeranylamino)-ethanol
GLFC	Great Lakes Fishery Commission
GLP	Good Laboratory Practice
ha	hectare
HTH	calcium hypochlorite
km	kilometers
Juglone	5-hydroxy-1,4-napthoquinone
L	liter
L/s	liters per second
LC	lethal concentration
LC_{50}	lethal concentrations to 50% of the test species
LC_{100}	lethal concentrations to 100% of the test species
m	meter
m^3/sec	cubic meter per second
mg/L	ppm (parts per million)
MMF	monomethyl formamde
MUP	manufacturing-use products
NADH	Reduced nicotinamide adenine diphosphate

OP	oxidative phosphorylation
PB	piperonyl butoxide
PCIP	polychlorpinene
PEG	polyethylene glycol
phosphamidon	dimicron
Phostoxin®	aluminum phosphine
P_i	organic phosphate
Salicylanilide I	2',5-dichloro-3-tert-butyl-6-methyl-4'-nitrosalicylanilide
Squoxin	1,1'-methylenebis(2-naphthol)
Sumithion®	O,O-dimethyl-O-[3-methyl-4-nitrophenyl] phosphorodithioate
TFM	3-trifluoromethyl-4-nitrophenol
thanite	isobornyl thiocyanoacetate
µg/L	microgram per liter (parts per billion)
UMESC	Upper Midwest Environmental Sciences Center
USDA	U.S. Department of Agriculture

Appendix A. Common and Scientific Names of All Fish Species Used Throughout this Report Organized by Family from Less to More Derived Characters and Alphabetically Within Family by Common Name

Table A-1. Common and scientific names of all fish species used throughout the body of this report listed from the least to the most derived families.

Family	Common name	Scientific name
Petromyzontidae	Sea lamprey	*Petromyzon marinus*
Anguillidae	American eel	*Anguilla rostrata*
Clupeidae	Gizzard shad	*Dorosoma cepedianum*
Channidae	Koravai	*Channa* sp.
	Snakehead	*C. punctata*
Cyprinidae	Utah chub	*Gila atraria*
	Common carp	*Cyprinus carpio*
	Goldfish	*Carassius auratus*
	Grass carp	*Ctenopharyngodon idella*
	Loach minnow	*Tiaroga cobitis*
	Northern pikeminnow	*Ptychocheilus oregonensis*
	Punti	*Puntius* sp.
	Red shiner	*Cyprinella lutrensis*
	Rohu	*Labeo rohita*
	Silver barb	*Puntius gonionotus*
	Silver carp	*Hypopthalmichthyes molitrix*
	Spikedace	*Meda fulgida*
Catostomidae	Utah sucker	*Catostomus ardens*
	White sucker	*Catostomus c. commersonnii*
Ictaluridae	Channel catfish	*Ictalurus punctatus*
	Flathead catfish	*Pylodictus olivaris*
Esocidae	Chain pickerel	*Esox niger*
	Northern pike	*E. luscius*
Bagridae	Tengra	various
Clariidae	Walking catfish	*Clarias* sp.
Osmeridae	Rainbow smelt	*Osmerus mordax*
Galaxiidae	Black mudfish	*Neochanna diversus*

Table A-1. Continued

Family	Common name	Scientific name
Salmonidae	Brook trout	*Salvelinus fontinalis*
	Brown trout	*Salmo trutta*
	Lake trout	*Salvelinus namaycush*
	Rainbow or steelhead trout	*Oncorhynchus mykiss*
	Yellowstone cutthroat trout	*Oncorhynchus clarki bouvieri*
Poeciliidae	Mosquitofish	*Gambusia affinis*
	Plague minnow	*G. holbrooki*
	Guppy	*Lebistes reticulatus*
	Gila topminnow	*Poeciliopsis occidentalis*
Sybranchidae	Cuchia	*Monopterus cuchia*
Moronidae	White perch	*Morone americana*
Centrarchidae	Bluegill	*Lepomis macrochirus*
	Green sunfish	*L. cyanellus*
	Largemouth bass	*Micropterus salmoides*
	Pumpkinseed	*Lepomis gibbosus*
	Rock bass	*Ambloplites rupestris*
Percidae	Yellow perch	*Perca flavescens*
	Walleye	*Stizostideon vitreum*
	Ruffe	*Gymnocephalus cernuus*
Nanidae	Nandus	*Nandus nandus*
Cichlidae	Tilapia	*Oreochromis niloticus*
Anabantidae	Climbing perch	*Anabas testudineus*

Appendix B. Life-history and Taxonomic Information for Native and Nonnative Fishes of Concern

Species-specific information on life history, habitat, biology and physicochemical tolerances are presented by life stage in separate tables (Tables B-1-B-12). In instances where the life-history information was reported without reference to a specific life stage, the information was placed into the adult category. These tables are not comprehensive. Also included is a summary of these data (Table B-13) and data obtained elsewhere that was used to develop a data matrix (Table B-14) analyzed by a series of one-way analyses of variance to determine differences in the species characteristics of native and nonnative fishes of concern in the Gila River basin.

Included in Appendix B–

Table B-1. Taxonomy of native and nonnative southwestern United States fishes of concern

Table B-2. Adult habitat preferences of native and nonnative fishes of concern

Table B-3. Characteristics of the biology of adult native and nonnative fishes of concern

Table B-4. Physicochemical needs for adult native and nonnative fishes of concern

Table B-5. Reproductive life history of native and nonnative fishes of concern

Table B-6. Habitat requirements for successful reproduction of adult native and nonnative fishes of concern

Table B-7. Habitat preferences and diet of juvenile native and nonnative fishes of concern

Table B-8. Physicochemical requirements of juvenile native and nonnative fishes of concern

Table B-9. Habitat preferences, size, and diet of larval native and nonnative fishes of concern

Table B-10. Physicochemical requirements of larval native and nonnative fishes of concern

Table B-11. Habitat requirements and characteristics of embryos of native and nonnative fishes of concern

Table B-12. Embryo physicochemical criteria

Table B-13. Raw data, both summarized from Tables B-1 to B-12 and collected from other sources, used to develop data matrix that was used to evaluate differences between native and nonnative fishes of concern

Table B-14. Data matrix developed from Table B-13 that was used to conduct one-way analyses of variance to determine how native fishes of concern in the Gila River basin differ from those nonnative fishes of concern

List of references. References used to collect life-history information for native and nonnative fishes of concern in Arizona are in the above tables.

Table B-1. Taxonomy of native and nonnative southwestern United States fishes of concern.

Common name	Genus	Species	Order	Family
		Native		
Loach minnow	*Tiaroga*	*cobitis*	Cypriniformes	Cyprinidae
Spikedace	*Meda*	*fulgida*	Cypriniformes	Cyprinidae
Roundtail chub	*Gila*	*robusta*	Cypriniformes	Cyprinidae
Headwater chub	*Gila*	*nigra*	Cypriniformes	Cyprinidae
Gila chub	*Gila*	*intermedia*	Cypriniformes	Cyprinidae
Longfin dace	*Agosia*	*chrysogaster*	Cypriniformes	Cyprinidae
Speckled dace	*Rhinichthys*	*osculus*	Cypriniformes	Cyprinidae
Sonora sucker	*Catostomus*	*insignis*	Cypriniformes	Catostomidae
Desert sucker	*Catostomus*	*clarki*	Cypriniformes	Catostomidae
Razorback sucker	*Xyrauchen*	*texanus*	Cypriniformes	Catostomidae
Gila topminnow	*Poeciliopsis*	*occidentalis*	Cyprinodontiformes	Poeciliidae
Desert pupfish	*Cyprinodon*	*macularius*	Cyprinodontiformes	Cyprinodontidae
		Nonnative		
Channel catfish	*Ictalurus*	*punctatus*	Siluriformes	Ictaluridae
Flathead catfish	*Pylodictis*	*olivaris*	Siluriformes	Ictaluridae
Black bullhead	*Ameiurus*	*melas*	Siluriformes	Ictaluridae
Yellow bullhead	*Ameiurus*	*natalis*	Siluriformes	Ictaluridae
Smallmouth bass	*Micropterus*	*dolomieu*	Perciformes	Centrarchidae
Largemouth bass	*Micropterus*	*salmoides*	Perciformes	Centrarchidae
Green sunfish	*Lepomis*	*cyanellus*	Perciformes	Centrarchidae
Bluegill	*Lepomis*	*macrochirus*	Perciformes	Centrarchidae
Redear sunfish	*Lepomis*	*microlophus*	Perciformes	Centrarchidae
Mosquitofish	*Gambusia*	*affinis*	Cyprinodontiformes	Poeciliidae
Red shiner	*Cyprinella*	*lutrensis*	Cypriniformes	Cyprinidae
Common carp	*Cyprinus*	*carpio*	Cypriniformes	Cyprinidae

Table B-2. Adult habitat preferences of native and nonnative fishes of concern. Numbers in parentheses are references (which can be found at the end of the tables).

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Water body type[b]	Substrate type[c]	Elevation (m)
Loach minnow	lotic (1)	littoral, <0.3 (3), 0.1-0.25 for all life stages (24)	B, 2 (3)	1,2 (1)	1 (1), seasonally associated with filamentous algae (24)	up to ~2,513 (1)
Spikedace	lotic (1)	0.04-0.3, prefer 0.15-0.18, <0.168 in winter (3), 0.2 (11), <1 (31)	B, 3,4 in winter (3), P, 1,5,6 (1), 2 (24)	2 low-moderate gradient (1), low-moderate gradient <1% up to 1.4 m^3/sec (3)	1,2,3 (3)	494-1,373 (1)
Roundtail chub[d]	lotic/lentic (3)	<2 (1), littoral, up to 3.1, prefer deep pools (3), 2+ (24), 0.9-3.1 (21)	1,2,5 (3)	1,2,4 (1), low gradient, up to 1.4 m^3/sec mean annual flow (3)	1,2 (3)	369-2,202, most common between 610 and 1,525 (1), 310-1,830 (3)
Gila chub	lotic (1)	deep pools (3)	1,4 (1)	5,6,7 (1), 4 (24)	3 (1)	830-1,653 (1)
Longfin dace	lotic (1)	<0.3 (3)	B/P (3)	2 usually small (1), coastal streams to headwaters (30), low gradient, up to 1.4 m^3/sec mean annual flow (3)	1,2 (3)	415-2,056, generally <1,500 (1), sea level to 2,300, rarely abundant over 1,500 (30)
Speckled dace	lotic (1)	< 0.5 (1), 0.12-0.16 (3), 0.2-1.5 (17)	1 in headwater creeks, 2,5,6 rarely in lakes (1), B/P 3 (3), 4 during day (17)	1 rarely in 3,6, low-high gradient, up to 1.4 m^3/sec (3)	1,2,3,4 (3)	473-3,000, rarely below 1,500, now only above 1,830 (1), 1,800-2,100 in Arizona (3)
Sonora sucker	lotic/lentic (3)	littoral, <0.3 (3)	B, 1 (3)	1,2 intolerant of lake conditions, low gradient, up to 1.4 m^3/sec mean annual flow (1)	1,2 (3)	369-2,663 (1)
Desert sucker	lotic (1)	<0.3 (3)	B (1), 1,2 (3)	1,2 (1), low gradient, up to 1.4 m^3/sec mean annual flow (3)	1,2,4 (1)	146-2,696 (1)

Table B-2. Continued

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Water body type[b]	Substrate type[c]	Elevation (m)
Razorback sucker	lotic/lentic (3)	littoral, limnetic, 1.2-3, 15 in reservoirs (3), 1.5-2.7 (21), 0.3-3.4, use shallow 0.9-0.99 in May and June and 1.6-2.16 in other months (38)	B, 1,3,5,6 (3), 3,4 flooded areas in spring (38)	1,2,3,4 (3)	1,2,4 (1), sand and gravel not used (21)	55-1,525 (1)
Gila topminnow	lotic (1)	shallow (24)	P, 3 (1), 4, below riffles (3), 7 (36)	6,7 (1), 1,2 (3), 5 (36)	3 (1)	403-2,291, most <1,525 (1)
Desert pupfish	lotic (1)	shallow (1)		2,5,7 (1)	4 (1)	366-<1,500 (1)
Channel catfish	lotic/lentic (2,3)	littoral/limnetic (2), 0.3-7.6 (3), up to 15 (4)	B (2,6), 1 day, 2 night (2)	1,2,3,4 (2,3), low-moderate gradient, 28-140 m^3/sec (3)	1,4 (2)	up to 1,829 (3)
Flathead catfish	lotic/lentic (4)	deep pools (3)	B/P, 1 day, 2 night (6)	1,3,4 (4,6), low moderate gradient (4)		
Black bullhead		littoral, 0.3-1.5 (3), up to 10 (4)	1,2,3,7 (2,3,6)	2,3,4 (2,6), low gradient (2)	1,2,3,4 (2)	
Yellow bullhead	lotic/lentic (3)	0.5-1.2 (2)	1,3 (4,6)	1,2,3,4 (3,4,6)		
Smallmouth bass	lotic/lentic (3)	littoral/limnetic <0.3-1.5, up to 12 (3), deeper pools in the day and move into shallows at dawn and dusk (2)	P, 1,2,7 (3), near riffles but out of current (6), epilimnion (2)	primarily 2 (7), 1,3,4 (3), in lakes use cooler nonvegetated areas <12 m deep (3), moderate-high gradient (9), low-moderate gradient (3)	1,2,3 (3)	
Largemouth bass	lotic/lentic (3)	littoral/limnetic (3), up to 7 (4)	P, 1,3 (3,4)	1,2,3,4,5 (2,4), low gradient (3)	1,2,3,4 (2)	
Green sunfish	lotic/lentic (3)	littoral/limnetic (3), usually <1.5 (2)	P, 1,3 (3)	1,2,3,4 low gradient (2)		

Table B-2. Continued

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Water body type[b]	Substrate type[c]	Elevation (m)
Bluegill	lotic/lentic (3)	littoral at dawn/dusk, limnetic during day (2,6), up to 7.6 (3)	B/P (4), P (3), 1,3 (2)	1,2,3,4,5 (2,3,4,6,7), low gradient, large and medium streams 1.4-140 m^3/sec (3)	1,2,3,4 (2,3)	
Redear sunfish	lotic/lentic (7)	littoral (9)	B (4), 3,7 (6), 1 (7)	1,2,3,4 (7)	2,4 (4), 3 (6)	
Mosquitofish	lotic/lentic (3)	littoral/limnetic up to 3 (3)	1,3,4,7 (4,5,7,9), B/P (4), P (6)	1,2,3,4,5 (3,4,5,7,9), low gradient, <0.14->140 m^3/sec mean annual flow (3)	3 (4,5,9)	310-2,440, larvae 2,130-2,440 (3)
Red shiner	lotic/lentic (3)	littoral, <0.3 (3)	P (2), B/P (6), 1,3,7 (9), 2 (6)	1,2,3 (2)	1,2,4 (2)	
Common carp	lotic/lentic (2)	primarily littoral, up to 30.5 (3), move into shallows in afternoon/evening (2)	B/P (3,4), 1,4 (6)	1,2,3,4 (2,6), 5 (3), large streams-rivers 28-140 m^3/sec, low-moderate gradient (3)	1,2,3,4 (2)	310-2,130 (3)

[a]B = benthic, P = pelagic, 1 = pool, 2 = riffle, 3 = backwater, 4 = stream margins, 5 = run, 6 = eddy, 7 = slack water
[b]1 = river, 2 = stream, 3 = lake, 4 = reservoir, 5 = marsh, 6 = headwaters, 7 = springs
[c]1 = rock, 2 = sand, 3 = vegetation, 4 = silt/soft
[d]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*

Table B-3. Characteristics of the biology of adult native and nonnative fishes of concern. Numbers in parentheses are references (which can be found at the end of tables).

Common name	Size of mature fish[a] (cm)	Age at maturity (years)	Life span (years)	Feeding trait[b]	Prey items[c]	Migratory
Loach minnow	3.8-<8 (15), rarely exceed 6 (24)	2 (1), 1 (24)	4 (1), few live more than 2 (24)	2 (1)	3 (1)	
Spikedace	<7.5 (1), 4 (12), 4 at 1 year (31)	1 (1), 2 (3)	2 (12), many live only 13 months (24), 1-2 (31)	2 (1), diurnal (31)	1,3,4 (1), primarily 3 (11)	
Roundtail chub[c]	25-30, size that individuals frequently attain (1)	2 males, 3 females (24)	20+ (24)	2 (1)	1,3,4,5 (1), 6,7 (24)	
Gila chub	>7.5 (34), females grow to 25, males seldom reach 15 (1), 15 typically (24)	2-3 (1), 1-3 most at 2-3 (34)	3 (3)	6 (1), crepuscular feeders (24)	1,3,4 (1), 5 (3),	
Longfin dace	rarely exceeds 6.5 SL[d] (1), 4.2 SL (30)	1 (30)		6 (1), diurnal feeder (30)	3,5,6 (1), primarily 6 (3)	
Speckled dace	rarely >7.6 (1)	2 females (45)		6 (1), 2 (3)	3,5,7 (1), primarily benthic insects, 3,5,6 (3)	
Sonora sucker	80 maximum (1)			6 (1)	3,5, aufwuchs (1), 6,7 (3)	some move into tributaries to spawn (1)
Desert sucker	10-28 SL (1)			5 (1)	5,6, aufwuchs (1)	

Table B-3. Continued

Common name	Size of mature fish[a] (cm)	Age at maturity (years)	Life span (years)	Feeding trait[b]	Prey items[c]	Migratory
Razorback sucker	100 maximum (1), 40 (38), 50 males and 54 females (40)	4 (1)	40+ (1)	6 (1)	3,5,6 (1), 7 (3)	some migrate long distances to spawning grounds (38)
Gila topminnow	adult size: males ~2.5 SL, females 3.0-4.5 SL (1)	a few weeks to several months (1)	1 (1)	6 (1)	3,5,6,7 (1)	
Desert pupfish	1.5-7.5 (35)	6 weeks if conditions are favorable (1), most during second summer (35)	seldom >1 (1)	6 (1)	3,4,5,6,7 (1)	
Channel catfish	33.7 (42)	4-5 (6), 2-3 in southern extent of range (2)	few >8 (2), usually 6-7 (6)	6 (2,3,4,6)	all (2,3,4,6)	yes, move upstream in spring (2)
Flathead catfish	46 (2,6)	4-5 (2,6)	20 maximum (4)	1 (2,3,6)	1,2 (2,3,6), 3 (4)	
Black bullhead	11 (42), 16 (43)	2-4 (2)	10 (4)	6 (2), largely nocturnal (2,4)	3,4,5,6,7 (2,4)	
Yellow bullhead	23 (42)	3 (2)	6,7 (42)	6 (2), 1 primarily (3)	all (2,3)	
Smallmouth bass	24.3-29 (6), 26-36 (2)	3-4 (2)	10-12 (6)	1 (2)	1,2,3,4 (2)	largely non-migratory (2), migrate up tributaries to spawn (8)
Largemouth bass	25-30 (2)	3-4 (2)	13 (42)	1 (2,4,6)	1,2,3 (2,4,6)	
Green sunfish	7.6 (2)	2 (7), as early as 16 weeks in the lab (2)	5 (4)	6 (2)	1,2,3,4,5,7 (2)	yes, up tributaries in spring (2)

Table B-3. Continued

Common name	Size of mature fish[a] (cm)	Age at maturity (years)	Life span (years)	Feeding trait[b]	Prey items[c]	Migratory
Bluegill	16 (42)	first summer in southern extent of range, 2 to 3 in northern extent of range (2)	11 maximum (4)	6 (2,3,4,6)	3,4,5,6,7 (2,3,4,6)	yes, to warm water in spring (2)
Redear sunfish	13 (42)	2 (6)	5 (7)	4 (6)	3, primarily snails (6)	
Mosquitofish	males 1.9-3.8, females 3.2-5.7 (10)	3 months (6)	3 (4)	6 (4,5,6)	1,3,5,6 (4,5,6)	no (4)
Red shiner	2.4-7.5 SL (5), >4 (2)	males 2, females 3 (6), 1(7)	3 (6), 2.5 (43)	6 (2)	3,5,7 (2)	
Common carp	28 age 2 to 36 age 3 (6)	males 2, females 3 (2)	9-15 (2)	6 (2,3)	3 primarily, 5,6,7 (2,6)	not highly migratory (6), not migratory (4), yes in lakes (3)

[a]Total length
[b]1 = piscivore, 2 = insectivore, 3 = zooplanktivore, 4 = molluscivore, 5 = herbivore, 6 = omnivore
[c]1 = fish, 2 = crayfish, 3 = aquatic inverts, 4 = terrestrial inverts, 5 = algae, 6 = detritus, 7 = vegetation
[d]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*
[e]SL = standard length

Table B-4. Physicochemical needs for adult native and nonnative fishes of concern. Numbers in parentheses are references (which can be found at the end of the tables).

Common name	Dissolved oxygen (DO; mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	pH	Total dissolved solids (ppm)	Turbidity tolerance	Comments
Loach minnow		>34 lethal (23)	0.24-0.79 (3), average 0.573 (24)					tolerates changing water conditions and competition with exotic fishes better than most native cyprinids (3), has a reduced air bladder that allows them to exist in high velocity habitats with minimal energy expenditure (3)
Spikedace		>34 lethal (23)	<0.95 (3), mean 0.3 (11)				found in clear streams (3)	abundance at any one site is extremely variable from year to year (1)
Roundtail chub[a]		CTM[b] 30.5-39.5, minimum <1-7.7, (3), >34 lethal (23)	typically <0.2 (24), 0-0.96 (21)					adults occupy pools <2 m deep that are adjacent to swifter riffles and runs (1)
Gila chub		>34 lethal (23)	sluggish (1)					
Speckled dace	highly tolerant to supersaturated water (3), 1.1-1.5, LD_{50}[c] 1.4 (27)	<15 cold >27 warm, prefer 15.8, CTM 30.5-36.8 (3)	fast, strong, 0.4 (3)					does not fair well in the presence of nonnative predatory fish, not in danger of extinction (1)
Longfin dace	0.6-1.3, LD_{50} 1.0 (27)	>34 (23)	0.15-0.35 (3)				clear water (3)	remarkable ability to disperse into new habitats, appearing a few hours or days after flow reestablishes in formerly dry stream channels; can survive in small volumes of water beneath mats of filamentous algae, then

Table B-4. Continued

Common name	Dissolved oxygen (DO; mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	pH	Total dissolved solids (ppm)	Turbidity tolerance	Comments
								reproduce a few days after summer rains rejuvenate stream; found in intermittent low desert streams to cool high elevation streams (1)
Sonora sucker		warm water to trout streams (1), >34 lethal (23)	<0.3 (1)					found in warm rivers, trout streams, has an affinity for gravelly rocky pools, or at least deep quiet pools (1)
Desert sucker	comparatively low tolerance to reduced DO (1)	survive 32+, prefer 17.5 within modal bounds ranging from 10 to 21 (1), <15 cold >27 warm (3)	0.3-0.46 (3)					
Razorback sucker		>0-32, 22-25 optimum (1), avoid 8.0-14.7 and 27.4-31.6 (3), some mortality at 34+ (39)	0.3 (3), <0.3, preferred 0.15 (21), 0.03-0.3 in winter, 0.5 in summer (38)					predation is limiting factor in Lake Mohave (3)
Gila topminnow	2.2-11.0 (1)	0-37.8 (1), 37.2-38.4 CTM (28), typically found in >20 (24)	moderate current (1), slow (24)	tap sea water (1)	6.6-8.9 (1)			prefer shallow warm water with moderate current and dense vegetation (1), restricted to waters that do not freeze (3), more abundant after floods than mosquitofish (36)

Table B-4. Continued

Common name	Dissolved oxygen (DO; mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	pH	Total dissolved solids (ppm)	Turbidity tolerance	Comments
Desert pupfish	can survive low DO (3), 0.1-0.4, LD_{50} 0.2 (27)	35+ (1)		tolerate 3 times seawater (1)			associated with areas of clear water (1)	when breeding males are territorial and unintentionally guard eggs, in soft substrate males dig small pits in search of food and guard these pits (1), endangered (3)
Channel catfish	0.95-1.08 at 25-35°C lethal (2), 5-7 <5 low, >7 high (3)	10-32 (4), collected in 37.8 (2), 35 lethal when acclimated at 7.2 (3), prefer 21.1 (2)	<0.15-0.48 (3)	may enter brackish (5), <0.5-30 (3)	6-8 (4), <5 is strongly acidic (3)	<5,000 (3)	prefer clean, well oxygenated water (2,4), tolerate high turbidity, saprophilic[d], saprophobic[e] (3)	dH[f] 4-30 (4), alkalinity 30->200 (3), larvae survival is low in clear water (6)
Flathead catfish		optimum 31.5-33.5 (2)						
Black bullhead		lethal 35-39 (2,3), 18-29 optimal (3)	<0.04, <0.15 (3)		6.5-8.0 (4), 3.4, 5.0 acidic (3)	<5,000 (3)	more tolerant of turbidity, warm water, and agricultural, industrial, and domestic human-made organic chemicals than the other bullhead species (2)	dH 4-25 (4), largely nocturnal (2,4)
Yellow bullhead	0-0.3 winter (2)		gentle-fast (2), prefer calm (6)				prefer clear water (6)	
Smallmouth bass	0.96 at 21.1°C lethal (2), 5-7 moderate, <5 low (3)	10-30 (4), prefer 21.1-26.7 (2)	fast flowing (5)		avoid <6 (3)	<5,000, 100-350 optimal (3)	saprophobic, little tolerance for turbidity (3)	winter in larger, deeper waters with gradients of <1.3 m/km (8)

Table B-4. Continued

Common name	Dissolved oxygen (DO; mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	pH	Total dissolved solids (ppm)	Turbidity tolerance	Comments
Largemouth bass	3.1 at 15°C was lethal, 0.6-2.3 in winter (2)	lethal 35.6-38 (2)	slow or standing (2)	brackish, 24.4 (2), >11.8 decreases adult abundance, >50 not conducive to spawning (3)	7-7.5 (4), <5 or >10 not conducive to spawning (3)	<5,000, 100-350 optimal (3)	intolerant of turbidity (6), saprophobic (3)	dH 10.0 (4), diurnal (3), bass tapeworm considered a significant parasite that causes sterility (2)
Green sunfish	3.6 winter threshold, died if 1.5 for 48 hours (2)	survive 33-36, prefer 28.2 (2)	<0.3 (3)		tolerated changes from 7.2 to 9.6, 6.0-8.1 at 17-19.5°C with 4-9 ppm DO (2), <5 strongly acidic (3)	<5,000 (3)	most silt tolerant sunfish except for the orange-spotted, tolerate extreme turbidity, temperatures, DO, current velocity (6), saprophobic (3)	dH 10-15 (4), the first to penetrate up streams during high water and repopulate intermittent streams, diurnal, crepuscular (3), builds nest after rise in mean water temperature (2)
Bluegill	0.6-0.8 toleration threshold, supersaturation is lethal (2), <5 is low (3)	0-36 (4), collected in 35-41, some mortality at 36.1 (2)	calm to moderately swift (2,3)	collected in 4.5 (2), <0.5 (3)	endure 4.0-10.35 (2), 7-7.5 (4)		cannot tolerate constant high turbidity (6)	dH 10-15 (4), often the first to die in winter kill lakes, supersaturation of DO seems to cause rapid mortality (2)
Redear sunfish		less tolerant of low temperatures than many other species (7)		occasionally found in brackish water (5)			more tolerant of silt than many other species (7)	subject to winter kill (8), most abundant in clear artificial lakes (7)
Mosquitofish	5-7,<5 low, >7 high, tolerate low levels (3), 0.5 (28)	18-24 (4), 15-27, <15 cold, >27 warm, >37.3 or <4	<0.15-0.3 (3)	<0.5-30 (3)	6.0-8.0 (4)		prefer clear water with vegetation (8), saprophilic, tolerates turbidity (3)	dH 5-19 (4), does not adapt to extremely cold environments (3)

Table B-4. Continued

Common name	Dissolved oxygen (DO; mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	pH	Total dissolved solids (ppm)	Turbidity tolerance	Comments
		lethal (3), 36.4-38.8 CTM (28)						
Red shiner	1.5 (16), critical oxygen concentration 1.2-2.0 (19)	15-25 (4), taken in 39.5 (2), prefer 27	moderate flow (7), slow flow (3), 0.062 (32)	10 (16)	7-7.5 (4), 5-10 (16)		tolerant of high turbidity (2)	absent in clear high gradient streams (5), avoided highly alkaline conditions in the field (18)
Common carp	tolerate low (can use atmospheric) and supersaturation (2), <5 low, >7 high (3)	-0.7 is the lower lethal temperature, 31-35.7 is the upper lethal temperature dependent on acclimation temperature (2), 3-35 (4)	avoid swift water except during spawning (2)	up to 17 (2)			thrive in turbid rivers (4), tolerate high turbidity, saprophilic (3)	need meso-eutrophic conditions (3), last survivor in oxygen depleted waters (2)

[a]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*
[b]Critical thermal maxima (CTM)—the maximum temperature at which a species can survive indefinitely (28)
[c] LD_{50}—the lethal dosage or amount of a toxin necessary to cause death in 50% of the recipients
[d] Saprophilic—ability to tolerate human-made organic chemicals (3)
[e] Saprophobic—unable to tolerate human-made organic chemicals (3)
[f]dH = degrees of hardness (carbonate hardness) where 1 dH = 17.86 ppm

Table B-5. Reproductive life history of native and nonnative fishes of concern. Numbers in parentheses are references (which can be found at the end of the tables).

Common name	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Season[b]	Water body type[c]	Substrate type[d]	Strategy[e]	Periodicity
Loach minnow	littoral, 1.0 (3), 0.1-0.25 (24)	B, 2 (3)	WN (1), SP, and FL (24)	2 (1)	1 cobble, gravel (1)	7 nest cavities open to downstream side of rocks (1)	
Spikedace	<1.5 (3), 0.15 (12), shallow (24)	2 (3), P (12)	SP,SM (1), when discharge is decreasing and temperature is increasing (31)	2 (1)	2 (1), 1 (3)	2,6 (3), 2 (13)	1-2 age one usually once per year, age two twice per year (1)
Roundtail chub[f]	shallow (33)	1,2 (24), 6 (33)	SP, early SM early as spring runoff subsides (1)	2 (1)	1,3 (1)	2 (1)	
Gila chub			late SP into SM (1), late WN into SM (3)		3 (1)	3 (1)	
Longfin dace	0.15-0.20 (3), mean 0.085 (30)	B, 1 (14), 3,5 (30)	primarily SP but may spawn throughout year (1), WN,SP,SM (14)	1,2 (1), nest near mouths of streams (30)	1,3 (3), 2 (14), areas free of detritus and plant debris (30)	2,6 saucer-shaped nest spawner (14)	twice per year (30)
Speckled dace	0.025-0.1 (45)	2 (3)	two periods, SP and late SM (1)	1,2 (1)	1 course substrate (1)	8 nest spawner (3)	twice per year (1)
Sonora sucker		2 (3)	late WN through mid-SM (1)	2,3 (1)	1 (1)	2 (1)	
Desert sucker		2 (1)	late WN and early SP (1), SP (3)	2 (1)	1,2,4 (1)	2 (1)	

Table B-5. Continued

Common name	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Season[b]	Water body type[c]	Substrate type[d]	Strategy[e]	Periodicity
Razorback sucker	littoral/limnetic, 0.3-7.6 (3), most <2.0 (38), 0.7-1.0 (39)	4 (1), 3,6 (38)	late WN through early SP (1), SP with rising water levels and temperatures (39)	1,4 (1)	1,2 (3)	2,6 (3)	
Gila topminnow			year-round in warm waters (3)			viviparous, live bearer (22)	up to 15 broods/year (36)
Desert pupfish	<1.0 (35)		SP,SM, year-round if temperatures stay warmer (3)			1 some unintentional guarding (1), 1 (4)	
Channel catfish	1.8-7.6 (3)	B, 4 (2)	SP,SM (2,3,6)	1 (2)	1,4 if turbid (2)	7 (22)	annual (3)
Flathead catfish	1.8-7.6 (3)	4 (2)	SP,SM (2,3)			7 (6)	
Black bullhead	littoral, 0.3-1.5 (3)	1,3,4 (2,3)	SP (2,6), SP through SM (3)	low gradient (3)	2,3,4 (2)	8 (22)	annual (3)
Yellow bullhead	0.6 (2)	4 (2)	SP through SM (2)	3 (2)	3 (2)	7 (22)	
Smallmouth bass	littoral nest built in <4.0 (3)	B, 1,6,7 (3)	SP through SM (6)	2, low gradient (3)	1, 2,3 (3)	8 nest spawner (22)	1 to >3 per year (3)
Largemouth bass	0.2-7.6 average 0.6 (2,3,6)	1 (3)	SP,SM (6), SP in NM (3)	low gradient (3)	1,2,3 (2,6), prefer sand and gravel (3)	nest spawner guarder-phytophil (22)	annual (3)
Green sunfish	littoral/limnetic, 0.04-3.55, up to 61 (3), usually <0.35 (2)	B (3), 1 (7), 3 (6)	SP through SM (2)	2,3,4 (2)	1,2,3,4 (3)	8 nest spawner (22), nest in colonies (2)	

Table B-5. Continued

Common name	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Season[b]	Water body type[c]	Substrate type[d]	Strategy[e]	Periodicity
Bluegill	up to 1.5 (3)	B, 1,3,7 (3)	SP,SM ripe females collected year round in cooling pond (2)	1,2,3,4 (2,3)	1,2,3,4 (2,3,6)	8 nest spawner (22), in colonies of 40-50 nest (2)	>3 per year (3)
Redear sunfish		B, 1, 7 (7)	SP,SM second nesting in August (6)	2,4 (6), 3 (2)	4 (6)	8 nest spawner (22), nest in colonies (6)	
Mosquitofish	up to 1.5 (3)	P, 1,3,7 (3)	SP through SM (3)	low gradient (3)	3,4 (3)	viviparous, live bearer (22)	3 to 4 broods per year (5,6)
Red shiner	littoral (3)	1,7 (7), 2 (3)	SP,SM peak, FL (2,6),	2,3 (3)	1,2,4, over sunfish nest (2,6)	5 (2,6)	>3 per year (3)
Common carp	littoral, 0.8-1.83 (2)	3,7 (2)	SP,SM (2,6)	2,3,4,5, floodplain (2)	3 (2,3,4), 1 (6)	3 need freshly flooded vegetation (22)	annual, can last several weeks (2)

[a]B = benthic, P = pelagic, 1 = pool, 2 = riffle, 3 = backwater, 4 = stream margins, 5 = run, 6 = eddy, 7 = slack water
[b]SP = spring (Mar-Jun), SM = summer (Jun-Sep), FL = fall (Sep-Dec), WN = winter (Dec-Mar)
[c]1 = river, 2 = stream, 3 = lake, 4 = reservoir, 5 = marsh, 6 = headwaters, 7 = springs
[d]1 = rock, 2 = sand, 3 = vegetation, 4 = silt/soft
[e]1 = nonguarder litho-pelagophil, 2 = nonguarder lithophil, 3 = nonguarder phytophil, 4 = nonguarder pelagophil, 5 = nonguarder phyto-lithophil, 6 = nonguarder psammophil, 7 = guarder spelophil, 8 = guarder lithophil
[f]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*

Table B-6. Habitat requirements for successful reproduction of adult native and nonnative fishes of concern. Numbers in parentheses are references (which can be found at the end of the tables).

Common name	Temperature (°C)	Current velocity (m/sec)	Total dissolved solids (ppm)	Turbidity/pollution tolerance	Comments
Loach minnow	18-20 (1), 10-12 in the laboratory (29), 16-20 (24)				
Spikedace	<15 cold >27 warm (3)	moderate (24)			
Roundtail chub[a]	20 (3), 15-22 (24)	moderate (3)			water temperature most significant in triggering spawning (3)
Gila chub	20-24 optimal (24)				
Longfin dace	23.4 average, 14.2-29.7 (30)	0.07±0.04, and in 0 flow (30)			spawn a few days after summer rains rejuvenate streams (1)
Speckled dace	12-18 (3)	swift (1)			
Sonora sucker		flowing (3)			
Desert sucker		flowing (3)			
Razorback sucker	10-20, 20 optimum (3), 9.5-22, peak at 10-15 (26)	standing water (3), 0.74 (38), 0.3 (39)			
Gila topminnow					
Desert pupfish	middle-upper 20s (35)				
Channel catfish	26.7 optimal (2), 15-29 (2,3)	standing or flowing water (3)			
Flathead catfish	22.2-23.9 (2), 21-29 (3)				
Black bullhead	20 (3)	<0.15 (3)	<5,000 (3)		

Table B-6. Continued

Common name	Temperature (°C)	Current velocity (m/sec)	Total dissolved solids (ppm)	Turbidity/pollution tolerance	Comments
Yellow bullhead					
Smallmouth bass	12.8-23.9 (2), 15.5 (6), 15-27 <15 cold (3)	out of current (6)	<5,000 (3)	saprophobic[b], little tolerance for turbidity (3)	
Largemouth bass	in New Mexico starts at 14-15 (3), 16.7-18.3, and in waters with mean annual temperatures of 25.5 (2)	out of current or waves (3)			
Green sunfish	15-28 (2), >21 (6), 15-31, >27 warm (3)	<0.15, low gradient, prefer <0.1, tolerate up to 0.25 (3)	<5,000 (3)		
Bluegill	15.0-26.7 (3), prolonged periods >20.0 may extend season (2)				
Redear sunfish					
Mosquitofish	15-27, >27 warm (3)	<0.15 (3)			
Red shiner	15.6-29.4 (2,3)	flowing or standing (3)		tolerate turbidity (3)	
Common carp	18.3-23.9 (2), 15-27 (3)				

[a]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*
[b]Saprophobic—no ability to tolerate organic pollution (3)

Table B-7. Habitat preferences and diet of juvenile native and nonnative fishes of concern. Numbers in parentheses are references (which can be found at the end of the tables).

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Substrate type[b]	Water body type[c]	Size total length (cm)	Feeding trait[d]	Prey items[e]
Loach minnow	lotic (3)	littoral, <0.3 (3), 0.1-0.25 (24)	B (3)	1 (3)	2 (1)	2.9-3.7 (15)	2 (3)	3 (3)
Spikedace	lotic (1)	<0.3 (3), 0.16 (11), average depth 0.19 (24)	P, 3,4 (3)	1,2,3,4 (3)	2 (1)	2.6-3.5 (11)		3 (24)
Roundtail chub[f]	lotic (3)	0.3-1.5 (3), 0.9-1.5 (21)	4 (1), 2 (3)	1,2 (3)	2 (3)	<5 (1)	2,6 (1)	3,4,5 (1)
Gila chub	lotic (1)		1,2,3,4 (1)	3 (1)	2,5,6 (1)		6 (1)	3,4,5 (1), 6,7 (24)
Longfin dace				3 (3)				
Speckled dace			B/P (25)				6 (25)	3,5,6 (25)
Sonora sucker	lotic (1)		4 (1)		2 (1)		6 (1)	3,5 (1)
Desert sucker	lotic (3)		1,4 (3)		2 (3)		2 (3)	3 (3)
Razorback sucker	lotic (38)		3,6,7 (38)				limited information (38)	5,6 (38)
Gila topminnow								
Desert pupfish								
Channel catfish	lotic (3)	shallow (3)	1,2 (2,3,6)	1,2 (2)	1,2 (3)		6 (2)	1,2,3,7 (2,3)
Flathead catfish			2 (2,4)	1,2 (2,4)	2 (3)		2 (2,3)	3 (2,3)
Black bullhead		littoral, shallow (2)	1,2,3 (3)		ponds, 2 (3)		2,3 (3)	3,4, plankton (3)
Yellow bullhead				1,3 (3)			6 (3)	all (3)
Smallmouth bass	lotic/lentic (2)	littoral/limnetic <0.3-1.5, up to 12 (3)	P, 2 (3)	1,3 (3)	2 low-moderate gradient (3)		primarily 2 (2)	1,2,3,4 (2)

Table B-7. Continued

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Substrate type[b]	Water body type[c]	Size total length (cm)	Feeding trait[d]	Prey items[e]
Largemouth bass	lotic/lentic (3)	shallow (3)	P, 1 (3)	3 (3)	ponds, 2 (3)		primarily 2 (2,3)	1,3 (2,3,6)
Green sunfish	lotic/lentic (3)		P, 1,3 (3)	1,3 (3)	ponds, 2 (3)		primarily 3 (3)	3,4 (3)
Bluegill	lotic/lentic (2,3)	littoral/limnetic, <0.3-1.5 (3)	1,3 (3)	1,2,3,4 (3)	1,2,3 (2)		2,3 (3)	3 (3)
Redear sunfish								
Mosquitofish	lotic/lentic (3)	littoral/limnetic, up to 3 (3)	1,3,4,7 (4,5,7,9), B/P (4), P (6)	1,2,3,4 (3,4,5,7,9)	3 (4,5,9)		6 (3)	3,5 (3)
Red shiner								
Common carp							6 (3)	3,5 (3)

[a]B = benthic, P = pelagic, 1 = pool, 2 = riffle, 3 = backwater, 4 = stream margins, 5 = run, 6 = eddy, 7 = slack water
[b]1 = rock, 2 = sand, 3 = vegetation, 4 = silt/soft
[c]1 = river, 2 = stream, 3 = lake, 4 = reservoir, 5 = marsh, 6 = headwaters
[d]1 = piscivore, 2 = insectivore, 3 = zooplanktivore, 4 = molluscivore, 5 = herbivore, 6 = omnivore
[e]1 = fish, 2 = crayfish, 3 = aquatic inverts, 4 = terrestrial inverts, 5 = algae, 6 = detritus, 7 = vegetation
[f]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*

Table B-8. Physicochemical requirements of juvenile native and nonnative fishes of concern. Numbers in parentheses are references (which are at the end of the tables).

Common name	Dissolved oxygen (mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	Total dissolved solids (ppm)	Turbidity/pollution tolerance
Loach minnow			0.27-0.67 (3)			
Spikedace		21-27 (3)	<0.15 (3), 0-0.58, mean 0.49 (24)			
Roundtail chub[a]			0-0.61 (21)			
Gila chub			moderate velocities (24)			
Longfin dace						
Speckled dace						
Sonora sucker						
Desert sucker			move to swifter water as they mature (3)			
Razorback sucker						
Gila topminnow		37.4-38.3 CTM[b] (28)				
Desert pupfish						
Channel catfish	5.0-7.0 moderate (3)	36.6-37.8 lethal (2)				
Flathead catfish						
Black bullhead		35-39 lethal (3)	low gradient, <0.15 (3)		<5,000 (3)	
Yellow bullhead			avoid strong currents (3)			prefer clear water (3,6)
Smallmouth bass	5.0-7.0, <5.0 low (3)		moderate gradient (3)		<5,000 (3)	saprophobic[c], little tolerance for turbidity (3)

Table B-8. Continued

Common name	Dissolved oxygen (mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	Total dissolved solids (ppm)	Turbidity/pollution tolerance
Largemouth bass	<5.0 low, 5.0-7.0 moderate (3)	21-27, >27 warm (3)	low gradient (3)			
Green sunfish		prefer 28.2 avoid >31 or <26 (3)	low gradient, prefer <0.1, tolerate up to 0.25 (3)		<5,000 (3)	
Bluegill	5.0-7.0, <5.0 is low (3)	prefer 31.2 (2), 15-27 (3)	low gradient, large and medium streams 1.4-140 m^3/sec (3)	<0.5 (3)		
Redear sunfish						
Mosquitofish	5.0-7.0, <5.0 low, >7.0 high (3)	15-27, <15 cold, >27 warm (3), 37.4-38.3 CTM (28)		<0.5-30 (3)		
Red shiner						
Common carp				17 (2)		

[a]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*
[b]CTM = critical thermal maxima
[c]Saprophobic—no ability to tolerate organic pollution (3)

Table B-9. Habitat preferences, size, and diet of larval native and nonnative fishes of concern. Numbers in parentheses are references (which are provided at the end of the tables).

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Substrate type[b]	Water body type[c]	Size total length (cm)	Duration	Feeding trait[d]	Prey items[e]
Loach minnow	lotic, seek out low velocity sites (3)	littoral, depth <0.3 (3), 0.1-0.25 (24)	B, 4 (3)	1 (3)	2 (1)	<0.28 (15), 0.54 (24),		2 (3)	3 (3)
Spikedace		<0.30 (3), mean 0.08 (11), <0.3 (24)	3,4 (3)	1,2,3 (3), 2,4 (1)	2 (1)	≤0.25 (11), 0.5-0.7 (24),			
Roundtail chub[f]			3 until reach 25-50 mm (1), 4 (3)					6 (1)	3,5 (1)
Gila chub		shallow (24)		3 (24)		0.7-0.8 (3)			
Longfin dace						0.64 average (30)			
Speckled dace			B/P (25)				remain in nest 7-8 days (1)	6 (25)	3,5,6 (25)
Sonora sucker	lotic, margins of streams (1)					0.5 (3)		6 (1)	crustaceans, protozoans (1)
Desert sucker	lotic, in quiet water along banks (1)		1 (1), 4 (3)						
Razorback sucker	lotic/lentic (38)	littoral (41)	4 (1), 3 flooded bottomlands essential (3), 4 (38)		1,2,4 (38)	0.7-0.9 (38), 0.7-1.0 (46)		2,3 (38)	4,5 (38)
Gila topminnow									
Desert pupfish									
Channel catfish			B, 1,2 (6)		1 (2), low gradient (3)	0.64 minimum (2), 0.6-0.98 (44)	several weeks (2), remain in nest 7 days, then school for several weeks (2)	6 (2,3)	3,5,6 (2,3)

Table B-9. Continued

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Substrate type[b]	Water body type[c]	Size total length (cm)	Duration	Feeding trait[d]	Prey items[e]
Flathead catfish		shallow (2)	2 (2)	beneath stone or cover (2)		1.1 (2)			
Black bullhead		near surface in deep water (2)	P, 1,2,3 (2,3)	3,4 (3)	ponds, 2 low gradient (3)	0.9-1.0 (44)		3 (6)	3, plankton (6)
Yellow bullhead						0.28 (44), 0.6-0.8 (44)		2 (2)	3,4 (2)
Smallmouth bass	lotic/lentic (2)		P, 1,2 (3)	1,2,3 moderate density (3)	2,3 (2), low gradient (3)	0.4-1.0 (44)	6-15 days in nest, guarded 2-9 days up to 28 days (2)	primarily 3 (2)	1,3 (2)
Largemouth bass	lotic/lentic (3)		P, 1 (3), B,P (2)	3 (3)	ponds, 2 low gradient (3)	0.3 upon hatching (2), 0.3-0.6 (44)	B for 6-7 days, then P for 31 days (2)	3 (3,6)	3 (3,6)
Green sunfish	lotic/lentic (3)	littoral, <0.3 (3)	P, 1,3 (3)	1,2,3 (3)	2,3 (2), low gradient (3)	0.35-0.37 upon hatching, 0.6 at swim up (2), 0.3-0.6 (44)	5-6 days to swim-up (2)	3 (2)	3 (2)
Bluegill		littoral at first migrate from nest to limnetic area after absorb yolk sac (2,3), up to 1.5 (3)	P, 1,3 (3)	1,2,3,4 (3)	1,2,3 (2), low gradient, 28-140 m^3/s (3)	0.2-0.3 at hatching, 0.5-0.55 at 3 days (2), 0.2-0.5 (44)	31 days at 23.5°C (4)	3 (3)	3,5 (3)
Redear sunfish						0.5 (44)			
Mosquitofish	lotic/lentic (3)	littoral/limnetic <1.5 (3)	1,3,4,7 (4,5,7,9), B/P (4), P (6)	1,2,3,4 (3,4,5,7,9)	3 (4,5,9), low gradient, <140->140 m^3/sec mean annual flow (3)	0.74, 0.8-1.0, 0.7 (47)	larval stage short (3)	6 (3)	3,5 (3)

Table B-9. Continued

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/pelagic[a]	Substrate type[b]	Water body type[c]	Size total length (cm)	Duration	Feeding trait[d]	Prey items[e]
Red shiner						0.33 (2)			
Common carp		littoral/limnetic (2), <3 (3)	B (2)	3 (2)	2,3 (2)	0.3-0.64 (2), 0.3-0.8 (44)	1-2 days attached/near vegetation, in 4-5 days yolk sac is absorbed and they move to bottom, spend most of summer in deeper water (2)	6 (3)	3,5 (3)

[a]B = benthic, P = pelagic, 1 = pool, 2 = riffle, 3 = backwater, 4 = stream margins, 5 = run, 6 = eddy, 7 = slack water
[b]1 = rock, 2 = sand, 3 = vegetation, 4 = silt/soft
[c]1 = river, 2 = stream, 3 = lake, 4 = reservoir, 5 = marsh, 6 = headwaters
[d]1 = piscivore, 2 = insectivore, 3 = zooplanktivore, 4 = molluscivore, 5 = herbivore, 6 = omnivore
[e]1 = fish, 2 = crayfish, 3 = aquatic inverts, 4 = terrestrial inverts, 5 = algae, 6 = detritus, 7 = vegetation
[f]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*

Table B-10. Physicochemical requirements of larval native and nonnative fishes of concern. Numbers in parentheses are references (which are at the end of the tables).

Common name	Dissolved oxygen (mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	Total dissolved solids (ppm)	Turbidity/pollution tolerance
Loach minnow			< 0.15 (3), average 0.73 (24)			
Spikedace			slow <0.05 (3), 0.08 (11)			
Roundtail chub[a]						
Gila chub						
Longfin dace						
Speckled dace						
Sonora sucker						
Desert sucker			quiet (3)			
Razorback sucker						
Gila topminnow						
Desert pupfish						
Channel catfish	5.0-7.0 moderate (3)	36.6-37.8 lethal (2), 15-27, >27 warm (3)	<0.15-0.3 (3)	<0.5-30 (3)	<5,000 (3)	
Flathead catfish						
Black bullhead		35-39 lethal (3)	<0.15 (3)		<5,000 (3)	
Yellow bullhead						
Smallmouth bass	5.0-7.0 moderate <5.0 low (3)	15-27 (3)			<5,000 (3)	saprophobic[b], little tolerance for turbidity (3)
Largemouth bass	<5.0 low, 5.0-7.0 moderate (3)	15-27, >27 warm (3)		>16.6 decreases growth (3)		
Green sunfish		15-27, >27 warm (3)	<0.15, <0.05 optimal (3)		<5,000 (3)	

Table B-10. Continued

Common name	Dissolved oxygen (mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	Total dissolved solids (ppm)	Turbidity/pollution tolerance
Bluegill	5.0-7.0 moderate (3)	21-27 (3)		<0.5 (3)		
Redear sunfish						
Mosquitofish	5.0-7.0, <5.0 low, >7.0 high (3)	15-27, <15 cold, >27 warm (3)	<0.15-0.3 (3)			
Red shiner						
Common carp		15-27 (3)				

[a]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*
[b]Saprophobic—no ability to tolerate organic pollution (3)

Table B-11. Habitat requirements and characteristics of embryos of native and nonnative fishes of concern. Numbers in parentheses are references (which are at the end of the tables).

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/ pelagic[a]	Substrate type[b]	Water body type[c]	Size total length (mm)	Duration to hatch	Egg typed	Fecundity (number of eggs)
Loach minnow	lotic (3)	littoral, <0.3 (3), 0.1-0.25 (24)	B, 2 (3)	1 (1)	2 (1)	1.55 (1), 1.3-1.8 (53)	5-6 days at 18-20°C (1)	1 (1)	150-1,200 (1), 145-300 (24)
Spikedace	lotic (1)	littoral (1)		1,2,3,4 (3)		1.5-1.8 (12)	probably 4-7 days (11)	1,2 (24)	100-300 (1), 100-800 (3), 319 for age 2, 101 for age 1 (24)
Roundtail chub[d]	lotic (1)	littoral (1)	1,5 (3)	1 (3)		0.48-1.69 (3)	4-7 (3)	1 (3)	600-45,125 (3), 33,400 for a 30-cm female (24)
Gila chub							4-7 days at 18°C (3)	1 (23)	
Longfin dace	lotic (1)	<0.3 (3)		2,3 (3), 4 (20)	2 (20)	2.3 (30)	3-4 days need, 4 days at >24°C (3)	2, non-adhesive (23)	80 or less mature ova (30)
Speckled dace	lotic (1)	littoral (1)	B (3)	1 (3)	1 (37)	1 (37), 1.5 (54)	5-7 days at 16-19°C (3)	1 (23)	174, 514 for a 47- and 71-mm fish, respectively (3)
Sonora sucker	lotic/lentic (3)	littoral (1)	2 (1)			1.5 fertilized (3)	6 (3)	2 (1), 1 (23)	
Desert sucker	lotic (1)	littoral (1)						1 (23)	
Razorback sucker	lotic (1)	littoral (1)	B (3)			2.3-2.8 hardened (55)	a few days (1)	1,2 (1)	75,000-144,000 (3)
Gila topminnow									11-15 live young (1)
Desert pupfish							a few days (1)		
Channel catfish			B, 4 (2)	1,4 (2)	1 (2)	3.2 without chorion (2)	5-10 days at 21.1-29.4°C (2), 7 days (6)	2 (3)	2,660-52,000 (2)
Flathead catfish						3.7 (2)	5-14 days (3), 6-9 days at 23.9-27.8°C (2)		4,076-58,972 (2,3)

Table B-11. Continued

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/ pelagic[a]	Substrate type[b]	Water body type[c]	Size total length (mm)	Duration to hatch	Egg typed	Fecundity (number of eggs)
Black bullhead		littoral, 0.3-1.5 (3)	B, 1,3 (3)	3,4 (3)	low gradient (3)	0.8-1.6 (2), 3.0 (3)	1-14 days (3)	1,2 (3)	3,500 (4), 2,000-6,000 (56), 2,500-3,500 (43)
Yellow bullhead						2.8 (52)	5-10 days (2), 5-14 days (3)	1 (2)	860-7,000 (3)
Smallmouth bass	lotic, downstream of obstructions (6), lentic (2)	littoral, 0.3-1.5 (3)	B, 1,7 (3)	1,2,3 (3)	2 (3)	2.5 (6)	1-14 days (3), 9.5 days at 12.8°C, <2 days coupled with rising water temperatures that level off at 23-25°C (2)	1,2 (3)	2,000-20,800 (3), 4,896-5,364 for 33-to 41-cm females (2)
Largemouth bass		0.3-7.6 (3)	B, 1 (3)	2,3 (3)	low gradient (3)	1.4-2.0 (2,3)	1-7 days (2,3,6), 2 days at 19°C (2)	1,2 (2)	55,000 (42), 2,000-20,000 (2)
Green sunfish	lotic/lentic (3)	littoral/limnetic, <0.3-61.0 (3)	B, 1,3 (3)	1,2,3,4 (3)	2,3 (3)	0.8-1.4 (2)	1.4-2.33 days at 24-27°C, 3-7 days (3)	1,2 (2)	2,000-10,000 (3)
Bluegill	lotic/lentic (3)	littoral up to 1.5 (3)	B, 7 (3)	1,2,3,4 (3)	1,2,3 (2), low gradient, 1.4-140 m^3/sec (3)	1.09-1.4 (2)	1.3, 1.4, 3 days at 27.3, 26.9, and 22.2°C, respectively (2), 10 days, 2-3 days at >21°C (3)	1,2 (2)	1,900-46,000 (2), 7,200-38,000 (3)
Redear sunfish	lotic/lentic (7)								49,750 (42)
Mosquitofish						3.4 (52)	24-30 days (4,5)		30 live young/ brood (9), 1-315 embryos (5,6), 1-300 (58)
Red shiner						1.3-1.7 (58)	5-7 days (3)		485-684 (2), 1,000 (42), 500-1,000 (43)

Table B-11. Continued

Common name	Lotic/lentic	Littoral/limnetic depth (m)	Benthic/ pelagic[a]	Substrate type[b]	Water body type[c]	Size total length (mm)	Duration to hatch	Egg type[d]	Fecundity (number of eggs)
Common carp	lotic/lentic (3)	littoral, <3.0 (3)	B, 7 (3)	3 (3)	1,2,3,4 (2,6), 5 (3), large streams-rivers 28-140 m^3/sec, low-moderate gradient (3)	0.9-2.0 (2), 1.5-2.1 (52)	3-16 days, 3-5 days at 20°C (2)	1,2 (2)	100,000-2,200,000 (2), 300,000 for a 47-cm female (4)

[a]B = benthic, P = pelagic, 1 = pool, 2 = riffle, 3 = backwater, 4 = stream margins, 5 = run, 6 = eddy, 7 = slack water
[b]1 = rock, 2 = sand, 3 = vegetation, 4 = silt/clay
[c]1 = river, 2 = stream, 3 = lake, 4 = reservoir, 5 = marsh, 6 = headwaters
[c]1 = adhesive, 2 = sink
[d]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*

Table B-12. Embryo physicochemical criteria. Numbers in parentheses are references (which are at the end of the tables).

Common name	Dissolved oxygen (mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	Total dissolved solids (ppm)	Turbidity/ pollution tolerance	Comments
Loach minnow			< 0.43 (3), flow important (24)				
Spikedace		15-27 (3)					
Roundtail chub[a]			moderate (3)				
Gila chub		15-21 (3)					
Longfin dace							eggs are buried in pit walls and not guarded (20)
Speckled dace							
Sonora sucker							
Desert sucker							
Razorback sucker		15-21, 20 best, die at 5, 10, or 30 (3)					
Gila topminnow							female has two broods developing simultaneously with one more advanced than the other (24)
Desert pupfish							
Channel catfish	1.7 lethal (2)	21-27, >27 warm, need >15.5 (3)	<0.15 (3)	limited spawning if >2, tolerate up to 16 (3)			
Flathead catfish							
Black bullhead		20-27, optimal 20-22, lethal 35-39 (3)	<0.15 (3)	>0.8 impairs development (3)	<5,000 (3)		
Yellow bullhead							

Table B-12. Continued

Common name	Dissolved oxygen (mg/L)	Temperature (°C)	Current velocity (m/sec)	Salinity (ppt)	Total dissolved solids (ppm)	Turbidity/ pollution tolerance	Comments
Smallmouth bass		15-27 (3), 12.5-25 (2)			<5,000 (3)	saprophobic[b], little tolerance for turbidity (3)	
Largemouth bass		15-27 (3)		>1.5 decreases survival (3)			
Green sunfish		21-27 (3)	<0.15, <0.10 optimal (3)		<5,000 (3)		
Bluegill	5.0-7.0 moderate (3)	21-27 (3)		<0.5 (3)			
Redear sunfish							
Mosquitofish							
Red shiner		34-35 may be lethal (3)					
Common carp		15-21 (3)					water-level drawdown is effective in killing eggs and sac fry by exposing to air (2)

[a]Headwater chub *Gila nigra* is a recently described species subsumed in the existing literature under the roundtail chub *Gila robusta*
[b]Saprophobic—no ability to tolerate human-made organic chemicals (3)

Table B-13. Raw data, both summarized from Tables B-1 to B-12 and collected from other sources, used to develop data matrix that was used to evaluate differences between native and nonnative fishes of concern. Numbers in parentheses are references (which are at the end of the tables).

Common name	Family	Native or exotic	Lentic or lotic	Mature fish length (mm)	Age at maturity (years)	Longevity (years)	Prey type
Channel catfish	ictaluridae	exotic (BOR)	both (2, 3)	337 (42)	4-5 (6), 2-3 (2)	8 (2), 6-7 (6)	fish, crustaceans, clams, snails
Flathead catfish	ictaluridae	exotic (BOR)	both (4)	460 (2, 6)	4-5 (2, 6)	20 (4)	fish, crayfish, insects, invertebrates
Black bullhead	ictaluridae	exotic (BOR)	both (42)	110 (42), 160 (43)	2-4 (2)	10 (4)	invertebrates, terrestrial insects, algae, detritus, vegetation
Smallmouth bass	centrarchidae	exotic (BOR)	both (3)	243-290 (6), 260-360 (2)	3-4 (2)	10-12 (6)	fish, crayfish, invertebrates, terrestrial insects
Largemouth bass	centrarchidae	exotic (BOR)	both (3)	250-300 (2)	3-4 (2)	13 (42)	fish, crayfish, invertebrates
Green sunfish	centrarchidae	exotic (BOR)	both (3)	76 (2)	2 (7)	5 (4)	fish, crayfish, invertebrates, terrestrial insects, algae, vegetation
Bluegill	centrarchidae	exotic (BOR)	both (3)	160 (42)	2-3, 1 (2)	11 (4)	invertebrates, terrestrial insects, algae, detritus, vegetation
Redear sunfish	centrarchidae	exotic (BOR)	both (7)	130 (42)	2 (6)	5 (7)	invertebrates, especially snails
Mosquitofish	poeciliidae	exotic (BOR)	both (3)	32-57 (10)	00.4 (6)	3 (4)	fish, invertebrates, algae, detritus
Red shiner	cyprinidae	exotic (BOR)	both (3)	24-75 SL[a] (5), >40 (2)	3 (6), 1 (7)	3 (6), 2.5 (43)	invertebrates, algae, vegetation
Common carp	cyprinidae	exotic (BOR)	both (2)	280-360 (6)	3 (2)	9-15 (2)	invertebrates, algae, detritus, vegetation
Loach minnow	cyprinidae	native (BOR)	lotic (1)	38-<80 (15); rarely >60 (24)	2 (1), 1 (24)	4 (1) , 2 (24)	insects
Spikedace	cyprinidae	native (BOR)	lotic (1)	<75 (1), 40 (12), 40 (31)	1 (1), 2 (3)	2 (12), 1.1 (24), 1-2 (31)	fish, invertebrates, terrestrial insects
Roundtail chub	cyprinidae	native (BOR)	both (3)	250-300 (1)	3 (24)	20+ (24)	fish, invertebrates, terrestrial insects, algae, detritus, vegetation
Gila chub	cyprinidae	native (BOR)	lotic (1)	>75 (34), 150 typically (24)	2-3 (1), 1-3 (34)	3 (3)	fish, invertebrates, algae, insects
Longfin dace	cyprinidae	native (BOR)	lotic (1)	65 SL (1), 42 SL (30)	1 (30)	No data	detritus, invertebrates, algae, zooplankton
Speckled dace	cyprinidae	native (BOR)	lotic (1)	76 rarely (1)	2 (45)	No data	invertebrates, algae, vegetation; detritus
Sonora sucker	catostomidae	native (BOR)	both (3)	800 (1)	No data	No data	invertebrates, algae; plants, detritus
Desert sucker	catostomidae	native (BOR)	lotic (1)	100-280 SL (1)	No data	No data	algae, detritus
Razorback sucker	catostomidae	native (BOR)	both (3)	400 (38), 540 (40)	4 (1)	40 + (1)	invertebrates, algae, detritus; vegetation
Gila topminnow	poeciliidae	native (BOR)	lotic (1)	30-45 SL (1)	0.4 (1)	1 (1)	invertebrates, algae, detritus, vegetation
Desert pupfish	cyprinodontidae	native (BOR)	lotic (1)	15-75 (35)	0.2 (35), 1 (2)	1 (1)	invertebrates, terrestrial insects, algae, detritus, vegetation

Table B-13. Continued.

Common name	Upper water temperature (°C)	Egg diameter (mm)	Incubation (days)	Fecundity	Hatchling (mm)
Channel catfish	35 (3)	3.2 (2)	5-10 (2), 7 (6)	2,660-52,000 (2)	6.4 (2), 6-9.8 (44)
Flathead catfish	33.5 optimum (2)	3.7 (2)	5-14 (3), 6-9 (2)	4,076-58,972 (2, 3)	11 (2)
Black bullhead	35-39 (2, 3)	0.8-1.6 (2), 3.0 (3)	1-14 (3)	3,500 (4), 2,500-3,500 (43)	9-10 (44)
Smallmouth bass	32 (48)	2.5 (6)	1-14 (3), 9.5 (2)	2,000-20,800 (3), 4,896-5,364 (2)	4-10 (44)
Largemouth bass	35.6-38 (2)	1.4-2.0 (2, 3)	1-7 (2,3,6), 2 (2)	55,000 (42), 2,000-20,000 (2)	3 (2), 3-6 (44)
Green sunfish	survive 33-36 (2)	0.8-1.4 (2)	1.4-2.3, 3-7 (3)	2,000-10,000 (3)	3.5-3.7 (2), 3-6 (44)
Bluegill	38.5-41.4 (49)	1.09-1.4 (2)	1,3, 1.4, 3 (2), 10, 2-3 (3)	1,900-46,000 (2), 7,200-38,000 (3)	2-3 (2), 2-5 (44)
Redear sunfish	36 (49)	1.4 (50)	No data	42,750 (42)	5 (44)
Mosquitofish	>37.3 lethal (3), CTM 36.4-38.8 (28)	3.4 (44)	24-30 (4,5)	30/brood (9), 1-315 embryoes (5, 6), 1-300 (47)	7.4, 8-10, 7 (47)
Red shiner	taken in 39.5 (2)	1.3-1.7 (47)	5-7 (3)	485-684 (2), 1,000 (42), 500-1,000 (43)	3.3 (2)
Common carp	31-35.7 (2)	0.9-2.0 (2), 1.5-2.1 (44)	3-16, 3-5 (2)	100,000-2,200,000 (2), 300,000 (4)	3-6.4 (2), 3-8 (44)
Loach minnow	>34 lethal (23)	1.55 (1)	5-6 (1)	150-1,200 (1), 145-300 (24)	2.8 (15), 5.4 (24)
Spikedace	>34 lethal (23)	1.5-1.8 (12)	4-7 (11)	100-300 (1), 100-800 (3), 319, 101 (24)	2.5 (11), 5-7 (24)
Roundtail chub	CTM 30.5-39.5 (3), >34 lethal (23)	0.48-1.69 (3)	4-7 (3)	600-45,125 (3), 33,400 (24)	No data
Gila chub	>34 lethal (23)	No data	4-7 (3)	No data	7-8 (3)
Longfin dace	>34 lethal (23)	2.3 (30)	3-4 (23)	80 (30)	No data
Speckled dace	CTM 30.5-36.8 (3)	1 (37)	5-7 (3)	174, 514 (45)	No data
Sonora sucker	>34 lethal (23)	1.5 (3)	6 (3)	No data	5 (3)
Desert sucker	survive 32+ (1)	No data	No data	No data	No data
Razorback sucker	some mortality 34+ (39)	2.3-2.8 (46)	Few days (1)	75,000-144,000 (3)	7-9 (38), 7-10 (46)
Gila topminnow	CTM 37.2-38.4 (28)	No data	No data	11-15 live (1)	No data
Desert pupfish	35+ (1)	No data	Few days (1)	No data	No data

[a]SL = standard length
[b]CTM = critical thermal maximum

Table B-14. Data matrix developed from Table B-13 that was used to conduct one-way analyses of variance to determine how native fishes of concern in the Gila River basin differ from those nonnative fishes of concern.

Common name	Family	Native or exotic	Habitat	Mature length	Age at maturity	Longevity	Diet breadth	Upper temperature	Egg diameter	Incubation time
Channel catfish	50	1	3	337	3.5	7.3	2	35	3.2	7.3
Flathead catfish	50	1	3	460	4.5	20	3	No data	3.7	8.5
Black bullhead	50	1	3	165	3	10	5	37	2.1	7.5
Smallmouth bass	130	1	3	288	3.5	11	4	32	2.5	8.5
Largemouth bass	130	1	3	275	3.5	13	3	36.8	1.7	3.6
Green sunfish	130	1	3	76	2	5	6	36	1.1	3.5
Bluegill	130	1	3	160	1.8	11	5	39.3	1.3	3.6
Redear sunfish	130	1	3	130	2	5	1	36	1.4	No data
Mosquitofish	115	1	3	45	0.4	3	4	37.5	3.4	27.0
Red shiner	34	1	3	50	2	2.8	3	39.5	1.5	6.0
Common carp	34	1	3	320	3	12	4	33.2	1.7	7.0
Loach minnow	34	2	1	59	1.5	3	1	34	1.6	5.5
Spikedace	34	2	1	40	1.5	1.5	3	34	1.7	6.5
Roundtail chub	34	2	3	275	3	20	6	34.5	1.1	6.5
Gila chub	34	2	1	113	2.3	3	4	34	No data	6.5
Longfin dace	34	2	1	54	1	No data	4	34	2.3	3.5
Speckled dace	34	2	1	76	2	No data	4	33.7	1	6.5
Sonora sucker	36	2	3	800	No data	No data	4	34	1.5	6.0
Desert sucker	36	2	1	190	No data	No data	2	32	No data	No data
Razorback sucker	36	2	3	470	4	40	4	34	2.6	3.5
Gila topminnow	115	2	1	38	0.4	1	4	37.8	No data	No data
Desert pupfish	117	2	1	45	0.6	1	5	35	No data	3.5

Table B-14. Continued.

Common name	Fecundity	Larval length	Spawning seasons	Parental care	Human use	History introduction	History invasive
Channel catfish	27,330	7.2	2	4	32	1	2
Flathead catfish	31,524	11	2	4	9	2	2
Black bullhead	3,250	10	2	5	27	1	1
Smallmouth bass	8,265	7	2	5	18	1	1
Largemouth bass	33,000	3.8	2	5	25	1	1
Green sunfish	6,000	4.1	2	5	18	1	2
Bluegill	23,275	2.5	2	5	23	1	1
Redear sunfish	42,750	5	2	5	12	1	2
Mosquitofish	154	7.8	2	6	15	1	1
Red shiner	778	3.3	3	1	5	2	2
Common carp	725,000	5.1	2	1	27	1	1
Loach minnow	449	4.1	3	4	2	2	2
Spikedace	287	4.3	2	1	2	2	2
Roundtail chub	28,131	No data	2	1	2	2	2
Gila chub	No data	6	4	2	2	2	2
Longfin dace	80	6.4	3	3	2	2	2
Speckled dace	344	No data	2	4	4	2	2
Sonora sucker	No data	5	3	1	2	2	2
Desert sucker	No data	No data	2	1	2	2	2
Razorback sucker	109,500	8.3	2	1	2	2	2
Gila topminnow	13	No data	4	6	2	2	2
Desert pupfish	No data	No data	4	3	5	2	2

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Appendix C. Technical Data for Chemicals Either Registered with the U.S. Environmental Protection Agency, Used As, or Proposed to Be Used as Fish Toxicants

Included are the names and formulations of each chemical, their primary and secondary uses or proposed uses, mode of action, toxicity to a variety of taxa, safety hazard, persistence in the environment, and registration status.

Ammonia

Alternative names: Anhydrous ammonia, urea
Chemical formula: NH_3
Formulation: Liquid under pressure
Primary use: Fertilizer
Secondary use: Control of aquatic weeds; fish toxicant
Mode of action: Corrosive action in gastrointestinal tract; alkalosis
Toxicity to fish: Highly toxic; toxicity is pH dependent at low concentrations
Toxicity to birds: No information available
Toxicity to invertebrates: No information available
Toxicity to mammals: Moderately toxic
Safety hazard: Liquid under pressure; inhalation of leaking fumes; rupture of lines
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Antimycin

Alternative names: Fintrol®-5, Fintrol®-15, and Fintrol®-concentrate
Chemical formula: $C_{28}H_{40}N_3O_9$
Formulation: Controlled-release coating on sand grains and water-soluble liquid
Primary use: Registered fish toxicant in the United States and Canada
Secondary use: Fungicide; miticide
Mode of action: Irreversible inhibitor of cellular respiration
Toxicity to fish: Extremely toxic to freshwater and marine fishes
Toxicity to birds: Highly toxic to quail
Toxicity to mammals: Highly toxic to mouse, rat, rabbit, guinea-pig, dog, and lamb
Safety hazard: Conjunctivitis; protect eyes with safety glasses
Persistence in environment: Nonpersistent
Registration status: Registered as a fish toxicant in the United States and Canada

Aqualin

Alternative names: Acrolein, r-propenal, acrylic aldehyde
Chemical formula: C_3H_4O
Formulation: Liquid
Primary use: Industrial; military in poison gas mixture
Secondary use: Fish toxicant
Mode of action: Irritant; lacrimator
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: Toxic
Safety hazard: Highly volatile and flammable; avoid contact with liquid and vapors

Persistence in environment: None
Registration status: Not registered as a fish toxicant in the United States

Bayluscide®

Alternative names: Bayer 73, Yomesan
Chemical formula: $C_{15}H_{15}Cl_2O_5N_3$
Formulation: Wettable powder; granular timed-release; liquid (formulation not yet registered)
Primary use: Molluscicide
Secondary use: Registered fish toxicant in the United States and Canada
Mode of action: No information available
Toxicity to fish: Extremely toxic
Toxicity to birds: No information available
Toxicity to mammals: Moderately toxic
Safety hazard: Prevent oral or dermal contact; avoid inhalation
Persistence in environment: Nonpersistent
Registration status: Registered as a fish toxicant for restricted use in the United States and Canada

Baythroid®

Alternative names: Synthetic pyrethroid; cyano(4-fluoro-3-phenoxyphenyl)methyl-3(2,2-dichloroethanyl)-2,2-dimethyl-cyclopropanecarboxylate
Chemical formula: $C_{22}H_{19}O_3NCl_2F$
Formulation: No information available
Primary use: Agricultural insecticide
Secondary use: Experimental crayfish or fish toxicant
Mode of action: No information available
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: LC_{50} (mg/kg) for rats were oral, 1,015; dermal, >5,000
Safety hazard: Prevent oral or dermal contact; avoid inhalation; wear protective clothing
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Bleaching powder and urea

Alternative names: Calcium hypochlorite and ammonia
Chemical formula: $Ca(ClO)_2 \bullet H_2O : NH_3$
Formulation: No information available
Primary use: Industrial uses and fertilizer
Secondary use: Fish toxicant
Mode of action: Oxidizing agent
Toxicity to fish: Highly toxic
Toxicity to birds: No information available

Toxicity to mammals: No information available
Safety hazard: Avoid inhalation of fumes; protective clothing recommended
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Calcium carbide

Alternative names: Acetylenogen
Chemical formula: CaC_2
Formulation: Crystals
Primary use: Generating acetylene gas; other industrial purposes
Secondary use: Fish toxicant
Mode of action: Inflation in gut
Toxicity to fish: No information available
Toxicity to birds: No information available
Toxicity to mammals: No information available
Safety hazard: No information available
Persistence in environment: None
Registration status: Not registered as a fish toxicant in the United States

Calcium hypochlorite

Alternative names: Bleaching powder, chlorine
Chemical formula: $Ca(ClO)_2 \bullet H_2O$
Formulation: Powder
Primary use: Industrial processes
Secondary use: Disinfectant; fish toxicant
Mode of action: Oxidizing agent
Toxicity to fish: Extremely toxic
Toxicity to birds: No information available
Toxicity to mammals: Highly toxic
Safety hazard: Avoid inhalation of fumes; explosive in some formulations
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Copper sulfate pentahydrate

Alternative names: Bluestone, blue citriol, cupric sulfate pentahydrate
Chemical formula: $CuSO_4 \bullet 5\ H2O$
Formulation: Crystal; powder
Primary use: Herbicide; industrial
Secondary use: Medical and veterinary; fish toxicant
Mode of action: Strong irritant on mucous membranes
Toxicity to fish: Extremely toxic

Toxicity to birds: Slightly toxic
Toxicity to mammals: Practically nontoxic
Safety hazard: Keep well away from foodstuffs, animal feed, and their containers
Persistence in environment: Persistent and cumulative in soft water
Registration status: Not registered as a fish toxicant in the United States

Croton seed powder

Alternative names: No information available
Chemical formula: No information available
Formulation: Powder
Primary use: Fish toxicant in China
Secondary use: No information available
Mode of action: Vesicant, purgative
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: Highly toxic
Safety hazard: Powerful vesicant
Persistence in environment: No information available
Registration status: Not registered as a fish toxicant in the United States

Cunaniol

Alternative names: Cunani
Chemical name: Polyacetylenic alcohol
Formulation: Aqueous extract of leaves from *Clibadium sylvestre*
Primary use: Fish toxicant
Secondary use: No information available
Mode of action: No information available
Toxicity to fish: Extremely toxic
Toxicity to birds: No information available
Toxicity to mammals: No information available
Safety hazard: No information available
Persistence in environment: No information available
Registration status: Not registered as a fish toxicant in the United States

DANEX-80

Alternative names: Dimethyl-1,2,2-trichloro-1-hydroxyethylphosphonate
Chemical formula: $C_4H_8Cl_3O_4P$
Formulation: Crystal
Primary use: Insecticide
Secondary use: Fish toxicant
Mode of action: Cholinesterase inhibitor

Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: Moderately toxic; rat oral LD_{50} 630 mg/kg
Safety hazard: Protective clothing recommended
Persistence in environment: No information available
Registration status: Not registered as a fish toxicant in the United States

DDVP

Alternative names: Nuvan 100 EC, Vapona®, Herkol, Dichlorvos
Chemical formula: $C_4H_7Cl_2O_4P$
Formulation: Liquid
Primary use: Insecticide
Secondary use: Vermifuge in livestock; fish toxicant
Mode of action: Cholinesterase inhibitor
Toxicity to fish: Highly toxic
Toxicity to birds: Acute oral LD_{50} for mallards is 7.78 mg/kg and for pheasants is 11.3 mg/kg
Toxicity to mammals: Acute oral LD_{50} in rats is 70 mg/kg
Safety hazard: Avoid inhalation and contamination of food
Persistence in environment: About 3 weeks in water
Registration status: Not registered as a fish toxicant in the United States

Dibrom®-malathion

Alternative names: Dibrom®:malathion, Ortho Fish Thinner
Chemical formula: $C_4H_7O_4PBr_2Cl_2 : C_{10}H_{19}O_6PS_2$
Formulation: Liquid
Primary use: Singly as insecticides
Secondary use: Selective fish toxicant (removal of sunfishes from largemouth bass)
Mode of action: Cholinesterase inhibitor
Toxicity to fish: Highly to extremely toxic
Toxicity to birds: No information available
Toxicity to mammals: Slightly toxic
Safety hazard: Protect eyes with safety glasses
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Dieldrin

Alternative names: 1,2,3,4,10,10-hexachloro-exo-6,7-epoxy-14,40,5,6,7,8,8a-octahydro-endo-exo-5,8-dimethanonaphthalene
Chemical formula: $C_{12}H_8Cl_6O$
Formulation: Crystals
Primary use: Insecticide

Secondary use: Fish toxicant
Mode of action: No information available
Toxicity to fish: Highly toxic
Toxicity to birds: Highly toxic
Toxicity to mammals: Highly toxic; rat oral LD_{50} 46 mg/kg
Safety hazard: Avoid direct contact; may be absorbed by ingestion, inhalation, or through skin
Persistence in environment: Persistent
Registration status: Manufacture and use discontinued in the United States

Endosulfan

Alternative names: Thiodan®, Thionex®, Malix, Malic, Thimul, Cyclodan; 1,4,5,6,7,7-hexachloro-5-norbornene-2,3-dimethanol cyclic sulfite
Chemical formula: $C_9H_6Cl_6O_3S$
Formulation: Crystals, powder
Primary use: Insecticide
Secondary use: Fish toxicant
Mode of action: No information available
Toxicity to fish: Highly toxic
Toxicity to birds: Acute oral LD_{50} for mallards is 33 mg/kg
Toxicity to mammals: Acute oral LD_{50} for rats is 100 mg/kg
Safety hazard: No information available
Persistence in environment: Moderately persistent
Registration status: Not registered as a fish toxicant in the United States

Endrin

Alternative names: Compound 269, Experimental Insecticide 269, mendrin, nendrin, hexadrin
Chemical formula: $C_{12}H_8Cl_6O$
Formulation: Crystals, powder
Primary use: Insecticide
Secondary use: Fish toxicant
Mode of action: No information available
Toxicity to fish: Extremely toxic
Toxicity to birds: Highly toxic and cumulative toxicity
Toxicity to mammals: Highly toxic; rat oral LD_{50} 18 mg/kg
Safety hazard: Avoid direct contact; may be absorbed by ingestion, inhalation, or through skin
Persistence in environment: Persistent
Registration status: Manufacture and use discontinued in the United States

***Euphorbia antiquorum* extract**

Alternative names: Extract from Indian hedge plant
Chemical formula: No information available

Formulation: Powder
Primary use: Experimental fish toxicant
Secondary use: No information available
Mode of action: No information available
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: No information available
Safety hazard: No information available
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

GD-174

Alternative names: 2-(digeranylamino)-ethanol
Chemical formula: $C_{21}H_{43}NO$
Formulation: Liquid
Primary use: Experimental fish toxicant
Secondary use: Experimental herbicide
Mode of action: No information available
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: Low toxicity
Safety hazard: No information available
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Guthion®

Alternative names: Gusathion, Methyl Guthion, DBD, Bay 9027
Chemical formula: $C_{10}H_{12}N_3O_3PS_2$
Formulation: Crystals, powder, liquid concentrate
Primary use: Insecticide
Secondary use: Selective fish toxicant (removal of centrarchids from bait minnow ponds)
Mode of action: Cholinesterase inhibitor
Toxicity to fish: Extremely toxic
Toxicity to birds: Highly toxic
Toxicity to mammals: Highly toxic; rat oral LD_{50} 11 mg/kg
Safety hazard: Protect eyes with safety glasses
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Ichthyothereol

Alternative names: Cunabi, cunami, cunambi
Chemical formula: $C_{14}H_{14}O_2$
Formulation: Extract from leaves of *Ichthyothere terminalis*
Primary use: Fish toxicant
Secondary use: No information available
Mode of action: Convulsant
Toxicity to fish: Extremely toxic
Toxicity to birds: No information available
Toxicity to mammals: Extremely toxic
Safety hazard: No information available
Persistence in environment: No information available
Registration status: Not registered as a fish toxicant in the United States

Juglone

Alternative names: 5-hydroxy-1,4-napthoquinone; walnut extract
Chemical formula: $C_{10}H_6O_3$
Formulation: Powder
Primary use: Experimental fungicide and bactericide
Secondary use: Folk medicine; experimental fish toxicant
Mode of action: No information available
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: Doses of 5 mg/kg were not toxic to dogs, but 10 mg/kg were fatal
Safety hazard: No hazards identified; protective clothing recommended
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Lime

Alternative names: Quick lime, burnt lime, caustic lime, calcium oxide
Chemical formula: CaO (quicklime); $Ca(OH)_2$ (hydroxide)
Formulation: Crystals or powder
Primary use: Building materials
Secondary use: Pesticides; fish toxicant
Mode of action: Caustic
Toxicity to fish: Highly to moderately toxic
Toxicity to birds: Practically nontoxic
Toxicity to mammals: No information available
Safety hazard: Quick lime may cause severe irritation of skin and mucous membranes
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Limil

Alternative names: No information available
Chemical formula: No information available
Formulation: No information available
Primary use: No information available
Secondary use: Fish toxicant
Mode of action: No information available
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: No information available
Safety hazard: No information available
Persistence in environment: No information available
Registration status: Not registered as a fish toxicant in the United States

Malathion

Alternative names: Malathon, carbophos, karbofos, phyphanon
Chemical formula: $C_{10}H_{19}O_6PS_2$
Formulation: Liquid
Primary use: Insecticide
Secondary use: Ectoparasiticide for livestock; fish toxicant
Mode of action: Cholinesterase inhibitor
Toxicity to fish: Highly to extremely toxic
Toxicity to birds: Slightly toxic
Toxicity to mammals: Slightly toxic
Safety hazard: Poisonous if swallowed; keep well away from foodstuffs and animal feed
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Ozone

Alternative names: Triatomic oxygen
Chemical formula: O_3
Formulation: gas
Primary use: Disinfectant
Secondary use: Fish toxicant
Mode of action: Oxidizing agent
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: High concentration may cause severe irritation of respiratory tract and eyes
Safety hazard: Avoid inhalation
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Phosphamidon

Alternative names: Dimicron, OR-1191, ENT 25515, C 570, ML-97
Chemical formula: $C_{10}H_{19}ClNO_5P$
Formulation: Oil
Primary use: Systemic insecticide
Secondary use: Fish toxicant
Mode of action: Cholinesterase inhibitor
Toxicity to fish: Highly toxic
Toxicity to birds: Highly toxic
Toxicity to mammals: Highly toxic
Safety hazard: Prevent inhalation and skin contamination
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Phostoxin®

Alternative names: Aluminum phosphide, phosphine, Celphos
Chemical formula: AlP
Formulation: Crystal, powder
Primary use: Insecticidal fumigant
Secondary use: Fish toxicant
Mode of action: No information available
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: Phosphine highly toxic
Safety hazard: Avoid inhalation and contact
Persistence in environment: No information available
Registration status: Not registered as a fish toxicant in the United States

Polychlorpinene

Alternative names: PCIP
Chemical formula: No information available
Formulation: Liquid
Primary use: Insecticide
Secondary use: Fish toxicant
Mode of action: No information available
Toxicity to fish: Extremely toxic
Toxicity to birds: No information available
Toxicity to mammals: Toxic
Safety hazard: Absorbs through skin, gut, or respiratory tract
Persistence in environment: Up to 1.5 years in some waters
Registration status: Not registered as a fish toxicant in the United States

Potassium permanganate

Alternative names: Permanganic acid potassium salt, chameleon mineral
Chemical formula: $KMnO_4$
Formulation: Powder
Primary use: Industrial uses
Secondary use: Experimental fish toxicant
Mode of action: Oxidizing agent
Toxicity to fish: Moderately toxic
Toxicity to birds: No information available
Toxicity to mammals: Relatively nontoxic
Safety hazard: Protective clothing recommended
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Rotenone

Alternative names: Noxfish®, Pro-Noxfish®, NuSyn-Noxfish®, Chem-fish Regular, Chem-fish Special, Fish-tox, Derris, Cube', Derrin, Nicouline, Tubatoxin, Timbe Powder
Chemical formula: $C_{23}H_{22}O_6$
Formulation: Liquid, synergized liquid, and powdered plant roots
Primary use: Insecticide
Secondary use: Fish toxicant
Mode of action: Inhibitor of cellular respiration
Toxicity to fish: Extremely toxic
Toxicity to birds: Slightly toxic
Toxicity to mammals: Moderately toxic
Safety hazard: Contact causes irritation of eyes and skin; protective clothing recommended
Persistence in environment: Seldom over 2 weeks; longer in soft or cold water
Registration status: Some formulations are registered for fishery use

Salicylanilide I

Alternative names: Sal I, 2',5-dichloro-e-tert-butyl-6-methyl-4'-nitrosalicylanilide
Chemical formula: $C_{18}H_{18}N_2O_2$
Formulation: Powder
Primary use: Experimental germicide and fish toxicant
Secondary use: None
Mode of action: No information available
Toxicity to fish: Extremely toxic
Toxicity to birds: No information available
Toxicity to mammals: Unknown, however, its structure is closely related to Bayluscide®
Safety hazard: Protective clothing recommended

Persistence in environment: Detoxified within a week
Registration status: Not registered as a fish toxicant in the United States

Saponins

Alternative names: Sapongenin glycosides
Chemical formula: No information available
Formulation: Tea-seed cake
Primary use: Foaming agent in textile and food industries
Secondary use: Fish toxicant
Mode of action: Dissolves red corpuscles
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: Low oral toxicity; powerful hemolytic
Safety hazard: Protective clothing recommended
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Sodium cyanide

Alternative names: Cyanide
Chemical formula: NaCN
Formulation: Cyanogram, Cyan-o-brick, Cyaneggs
Primary use: Fumigant; electroplating
Secondary use: Fish toxicant
Mode of action: Inhibits oxidative enzymes; respiratory failure
Toxicity to fish: Highly toxic
Toxicity to birds: Highly toxic
Toxicity to mammals: Highly toxic
Safety hazard: Deadly poison; protective clothing required
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Sodium fluoride

Alternative names: Chemifluor, Florocid, Lemoflur, Ossalin
Chemical formula: NaF
Formulation: Crystal, powder
Primary use: Insecticide; industrial uses
Secondary use: Fish toxicant
Mode of action: No information available
Toxicity to fish: Moderately toxic
Toxicity to birds: No information available
Toxicity to mammals: Moderate oral toxicity; rat oral LD_{50} 180 mg/kg

Safety hazard: Protective clothing recommended
Persistence in environment: No information available
Registration status: Not registered as a fish toxicant in the United States

Sodium hydroxide

Alternative names: Caustic soda, soda lye, sodium hydrate
Chemical formula: NaOH
Formulation: Lumps, sticks, pellets, ships, and liquid solutions
Primary use: Many industrial uses
Secondary use: Fish toxicant
Mode of action: Corrosive to all tissues
Toxicity to fish: Highly to moderately toxic
Toxicity to birds: No information available
Toxicity to mammals: Slightly toxic
Safety hazard: Protective clothing recommended; avoid inhalation of dust or mist
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Sodium nitrite

Alternative names: Nitrous acid sodium salt
Chemical formula: $NaNO_2$
Formulation: Powder
Primary use: Industrial uses
Secondary use: Fish toxicant
Mode of action: No information available
Toxicity to fish: Highly toxic
Toxicity to birds: No information available
Toxicity to mammals: Rat oral LD_{50} 180 mg/kg
Safety hazard: Protective clothing recommended
Persistence in environment: No information available
Registration status: Not registered as a fish toxicant in the United States

Sodium pentachlorophenate

Alternative names: Santobrite, Dowicide G, PCP
Chemical formula: NaC_6HCl_5O
Formulation: Powder
Primary use: Insecticide; herbicide
Secondary use: Wood preservative; slimicide; fish toxicant
Mode of action: No information available
Toxicity to fish: Extremely toxic
Toxicity to birds: No information available

Toxicity to mammals: Causes lung, liver, and kidney damage
Safety hazard: Avoid contact and inhalation; more toxic in organic solvents
Persistence in environment: Persistent
Registration status: Not registered as a fish toxicant in the United States

Sodium sulfite

Alternative names: No information available
Chemical formula: Na_2SO_3
Formulation: Crystal or powder, Heptahydrate ($Na_2SO_3 \bullet 7H_2O$)
Primary use: Industrial, photographic developers
Secondary use: Medical; fish toxicant
Mode of action: Reducing agent; suffocates fish
Toxicity to fish: Moderately toxic
Toxicity to birds: No information available
Toxicity to mammals: Slightly toxic; mouse LD_{50} 175 mg/kg
Safety hazard: Protective clothing recommended
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Squoxin

Alternative names: 1,1'-methylenedi-2-naphthol, Sonar 300
Chemical formula: $C_{12}H_{16}O_2$
Formulation: Powder, liquid solution, emulsion
Primary use: Industrial uses
Secondary use: Selective toxicant for squawfishes (*Ptychocheilus* spp.)
Mode of action: Vaso-constrictor
Toxicity to fish: Extremely toxic to squawfishes; highly to extremely toxic to salmonids and other fresh-water fishes
Toxicity to birds: No acute effects in domestic ducks at 14.7 mg/kg/day over 7 days
Toxicity to mammals: No acute effects in lambs at 1.2 mg/kg/day over 7 days
Safety hazard: Flammable; use with adequate ventilation
Persistence in environment: Nonpersistent
Registration status: Not currently registered as a fish toxicant in the United States

Sumithion®

Alternative names: Fenitrothion
Chemical formula: O,O-Dimethyl-O-(3-methyl-4-nitrophenyl)phosphorodithioate
Formulation: Yellow oil
Primary use: Insecticide
Secondary use: Fish toxicant
Mode of action: Cholinesterase inhibitor

Toxicity to fish: Moderately toxic
Toxicity to birds: No information available
Toxicity to mammals: Rat oral LD_{50} 250 mg/kg
Safety hazard: Protective clothing recommended
Persistence in environment: No information available
Registration status: Not registered as a fish toxicant in the United States

TFM

Alternative names: 3-trifluoromethyl-4-nitrophenol, Lamprecid®
Chemical formula: $CF_3C_6H_3(NO_2)OH$
Formulation: Crystalline solid, liquid
Primary use: Selective toxicant for larvae of sea lamprey (*Petromyzon marinus*)
Secondary use: No information available
Mode of action: Circulatory collapse; sever hemorrhage of respiratory capillaries
Toxicity to fish: Highly toxic to sea lamprey larvae; highly toxic to teleosts
Toxicity to birds: Moderately toxic
Toxicity to mammals: No acute effects in deer or dairy cattle; acute oral LD_{50} for rabbit is 0.16 g/kg
Safety hazard: Protective clothing recommended when handling concentrated forms of toxicant
Persistence in environment: Nonpersistent
Registration status: Registered as a fish toxicant for restricted use in the United States and Canada

Thanite

Alternative names: Isobornyl thiocyanoacetate
Chemical formula: $C_{13}H_{19}NO_2S$
Formulation: Liquid
Primary use: Insecticide, especially in cattle sprays
Secondary use: Fish-collecting aid, fish toxicant
Mode of action: No information available
Toxicity to fish: Highly to extremely toxic
Toxicity to birds: No information available
Toxicity to mammals: Moderately toxic
Safety hazard: Irritant to eyes and mucous membranes
Persistence in environment: Nonpersistent
Registration status: Not registered as a fish toxicant in the United States

Tobacco waste

Alternative names: Nicotine
Chemical formula: $C_{10}H_{14}N_2$
Formulation: Waste portions of tobacco plant; tobacco dust
Primary use: Fertilizer for fish ponds

Secondary use: Insecticide; fish toxicant
Mode of action: No information available
Toxicity to fish: Highly toxic (active ingredient)
Toxicity to birds: Slightly toxic
Toxicity to mammals: Highly toxic (active ingredient)
Safety hazard: No information available
Persistence in environment: No information available
Registration status: Not registered as a fish toxicant in the United States

Toxaphene

Alternative names: Chlorinated camphene, Hercules 3956, Phenacide, Phenatox®, Cooper-Tox, Melipax-Spritzmittel
Chemical formula: $C_{10}H_{10}Cl_8$
Formulation: Liquid emulsion
Primary use: Insecticide
Secondary use: Fish toxicant
Mode of action: No information available
Toxicity to fish: Extremely toxic
Toxicity to birds: Highly toxic
Toxicity to mammals: Moderately to highly toxic; rat oral LD_{50} 90 mg/kg
Safety hazard: Avoid oral or dermal exposure; protective clothing and respirator recommended
Persistence in environment: Persistent
Registration status: Not registered as a fish toxicant in the United States

Appendix D. Fish Toxicants and Candidate Fish Toxicants

Table D-1. Fish toxicants and candidate fish toxicants rated for their potential use as piscicides based on eight criteria (each of which received a rating from 1 to 5). Higher ratings indicate greater potential. No rating was assigned (indicated by –) if insufficient information was available for any criterion. Overall rating was determined by summing the criteria ratings for each chemical, dividing by the number of points possible, and converting to a percentage. Chemicals receiving overall ratings of 75 or greater are bolded and were considered good potential for use as piscicides.

Toxicant	Selectivity[a]	Ease of Application[b]	Nontarget toxicity[c]	Safety to humans[d]	Environmental persistence[e]	Bioaccumulation[f]	Cost[g]	Registration status[h]	Overall rating
Ammonia (urea)	1	1	4	4	4	4	4	3	63
Antimycin	**3**	**4**	**3**	**3**	**5**	**5**	**2**	**5**	**75**
Aqualin (acrolein)	1	2	3	2	3	3	3	1	45
Bayluscide®	**3**	**4**	**3**	**4**	**4**	**5**	**3**	**5**	**78**
Baythroid®	2	3	3	4	4	4	3	2	63
Bleaching powder and urea	2	4	3	3	4	4	4	2	65
Calcium carbide	3	3	3	3	2	3	3	2	55
Calcium hypochlorite	1	3	2	4	5	5	3	2	63
Copper sulfate pentahydrate	2	4	3	4	2	3	3	3	60
Croton seed powder	1	3	3	4	–	–	4	2	57
Cunaniol	1	3	3	–	–	–	4	2	52
DANEX-80	4	3	3	3	–	–	4	2	63
DDVP	4	3	4	3	4	3	–	2	66
Dibrom®-malathion	4	3	3	3	4	3	3	2	63
Dieldrin	2	3	2	2	1	2	4	1	43
Endosulfan	2	3	3	2	2	2	3	2	48
Endrin	2	3	2	2	2	2	3	1	43

Table D.1. Continued

Toxicant	Selectivity[a]	Ease of Application[b]	Nontarget toxicity[c]	Safety to humans[d]	Environmental persistence[e]	Bioaccumulation[f]	Cost[g]	Registration status[h]	Overall rating
Euphorbia antiquorum extract	4	3	3	–	4	4	4	3	71
GD-174	4	3	4	4	4	4	3	3	73
Guthion®	4	3	2	3	4	3	3	2	60
Ichthyothereol	2	3	2	2	.	3	–	2	47
Juglone	3	3	3	3	4	4	3	3	65
Lime	2	3	4	4	4	5	4	3	73
Limil	2	3	–	–	–	–	–	3	53
Malathion	4	3	3	3	4	3	3	2	63
Ozone	2	2	3	4	4	5	3	4	68
Phosphamidon	4	2	2	2	4	3	–	2	54
Phostoxin®	2	3	3	2	4	–	–	2	53
Polychlorpinene	2	3	2	2	1	3	–	2	43
Potassium permanganate	2	3	3	4	4	4	4	3	68
Rotenone	**2**	**4**	**4**	**4**	**4**	**4**	**3**	**5**	**75**
Salicylanilide I	2	3	3	3	4	4	3	3	63
Saponins	2	3	3	4	4	3	4	2	63
Sodium cyanide	2	3	2	1	3	3	4	1	48
Sodium fluoride	2	3	3	3	.	4	3	3	60
Sodium hydroxide	2	2	3	3	4	5	3	3	63

Table D.1. Continued

Toxicant	Selectivity[a]	Ease of Application[b]	Nontarget toxicity[c]	Safety to humans[d]	Environmental persistence[e]	Bioaccumulation[f]	Cost[g]	Registration status[h]	Overall rating
Sodium nitrite	2	3	3	4	4	5	3	3	68
Sodium pentachlorophenate	2	3	3	2	3	2	–	2	49
Sodium sulfite	3	4	4	4	4	4	3	3	73
Squoxin	**5**	**4**	**4**	**4**	**4**	**4**	**3**	**4**	**80**
Sumithion®	2	3	3	3	.	3	2	3	54
TFM	**5**	**4**	**4**	**4**	**4**	**4**	**3**	**5**	**83**
Thanite	4	3	3	3	4	3	3	3	65
Tobacco waste	2	3	3	3	3	3	4	3	60
Toxaphene	3	3	1	2	1	2	4	1	43

[a]1 means nonselective; 5 means highly selective
[b]1 means difficult to apply; 5 means easy to apply
[c]1 means toxic to nontarget organisms; 5 means relatively nontoxic
[d]1 means dangerous; 5 means safe
[e]1 means persistent; 5 means nonpersistent
[f]1 means piscicide bioaccumulates; 5 means it does not bioaccumulate
[g]1 means very expensive; 5 means relatively inexpensive
[h]1 means probably difficult to obtain registration as a piscicide; 5 means already registered as a piscicide

Appendix E. List of Studies for Pesticide Registration

The following test guidelines show studies required to register a pesticide with the U.S. Environmental Protection Agency. The actual studies required to register a pesticide are determined by the U.S. Environmental Protection Agency based on the registrant's intended use. For example, a pesticide used on ornamental plants will have different requirements than a pesticide used on food crops.

OPPTS Series 810 Test Guidelines

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
	Series 810—Product Performance Test Guidelines				
	Group A—General.				
810.1000	Overview, Definitions, and General Considerations	none	90–1, 90–3 90–30	none	98–001
	Group C—Invertebrate Control Agent Product Performance Test Guidelines.				
810.3000	General considerations for efficacy of invertebrate control agents	none	95–1	none	98–409
810.3100	Soil treatments for imported fire ants	none	95–3	none	98–410
810.3200	Livestock, poultry, fur- and wool-bearing animal treatments	none	95–8	none	98–414
810.3300	Treatments to control pests of humans and pets	none	95–9, 95–30	none	98–411
810.3400	Mosquito, black fly, and biting midge (sand fly) treatments	none	95–10	none	98–419
810.3500	Premises treatments	none	95–11, 95–30	none	98–413
810.3600	Structural treatments	none	95–12	none	98–424

Series 830—Product Properties Test Guidelines

August 1996

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
830.1000	Background for product properties test guidelines	none	none	none	96–310
	Group A—Product Identity, Composition, and Analysis Test Guidelines.				
830.1550	Product identity and composition	none	158.155	none	96–006
830.1600	Description of materials used to produce the product	none	158.160	none	96–007
830.1620	Description of production process	none	158.162	none	96–008
830.1650	Description of formulation process	none	158.165	none	96–009
830.1670	Discussion of formation of impurities	none	158.167	none	96–010
830.1700	Preliminary analysis	none	158.170	none	96–011
830.1750	Certified limits	none	158.175	none	96–012
830.1800	Enforcement analytical method	none	158.180	none	96–013
830.1900	Submittal of samples	none	64–1	none	96–015
	Group B—Physical/Chemical Properties Test Guidelines.				
830.6302	Color	none	63–2	none	96–019
830.6303	Physical state	none	63–3	none	96–020
830.6304	Odor	none	63–4	none	96–021
830.6313	Stability to normal and elevated temperatures, metals, and metal ions	none	63–13	none	96–022
830.6314	Oxidation/reduction: chemical incompatability	none	63–14	none	96–023
830.6315	Flammability	none	63–15	none	96–024
830.6316	Explodability	none	63–16	none	96–025
830.6317	Storage stability	none	63–17	none	96–026
830.6319	Miscibility	none	63–19	none	96–027
830.6320	Corrosion characteristics	none	63–20	none	96–028
830.6321	Dielectric breakdown voltage	none	63–21	none	96–029
830.7000	pH	796.1450	63–12	none	96–030
830.7050	UV/Visible absorption	796.1050	none	101	96–031
830.7100	Viscosity	none	63–18	114	96–032
830.7200	Melting point/melting range	796.1300	63–5	102	96–033
830.7220	Boiling point/boiling range	796.1220	63–6	103	96–034
830.7300	Density/relative density/bulk density	796.1150	63–7	109	96–035
830.7370	Dissociation constants in water	796.1370	63–10	112	96–036
830.7520	Particle size, fiber length, and diameter distribution	796.1520	none	110	96–037
830.7550	Partition coefficient (*n*-octanol/water), shake flask method	796.1550	63–11	107	96–038
830.7560	Partition coefficient (*n*-octanol/water), generator column method	796.1720	63–11	none	96–039
830.7570	Partition coefficient (*n*-octanol/water), estimation by liquid chromatography	796.1570	63–11	117	96–040
830.7840	Water solubility: Column elution method; shake flask method	796.1840	63–8	105	96–041
830.7860	Water solubility, generator column method	796.1860	63–8	none	96–042
830.7950	Vapor pressure	796.1950	63–9	104	96–043

Series 835—Fate, Transport and Transformation Test Guidelines

April 1996

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
	Group A—Laboratory Transport Test Guidelines.				
835.1110	Activated sludge sorption isotherm	none	none	none	96–298
835.1210	Soil thin layer chromatography	796.2700	none	none	96–047
835.1220	Sediment and soil adsorption/desorption isotherm	796.2750	none	106	96–048
	Group B—Laboratory Abiotic Transformation Test Guidelines.				
835.2110	Hydrolysis as a function of pH	796.3500	none	111	96–057
835.2130	Hydrolysis as a function of pH and temperature	796.3510	none	none	96–059
835.2210	Direct photolysis rate in water by sunlight	796.3700	none	none	96–060
835.2310	Maximum direct photolysis rate in air from UV/visible spectroscopy	796.3800	none	none	96–066
	Group C—Laboratory Biological Transformation Test Guidelines.				
835.3100	Aerobic aquatic biodegradation	796.3100	none	none	96–075
835.3110	Ready biodegradability	796.3180, .3200, .3220, .3240, .3260	none	301	96–076
835.3120	Sealed-vessel carbon dioxide production test	none	none	none	96–311
835.3170	Shake flask die-away test	none	none	none	96–297
835.3180	Sediment/water microcosm biogradation test	none	none	none	96–083
835.3200	Zahn-Wellens/EMPA test	796.3360	none	302B	96–084
835.3210	Modified SCAS test	796.3340	none	302A	96–085
835.3220	Porous pot test	none	none	none	96–301
835.3300	Soil biodegradation	796.3400	none	304A	96–088
835.3400	Anaerobic biodegradability of organic chemicals	796.3140	none	none	96–090
	Group D—[Reserved].				
	Group E—Transformation Chemical-Specific Test Guidelines.				
835.5045	Modified SCAS test for insoluble and volatile chemicals	795.45	none	none	96–097
835.5154	Anaerobic biodegradation in the subsurface	795.54	none	none	96–098
835.5270	Indirect photolysis screening test: Sunlight photolysis in waters containing dissolved humic substances	795.70	none	none	96–099
	Groups F-D—[Reserved].				

OPPTS Series 840 Test Guidelines

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
	Series 840—Spray Drift Test Guidelines.				
840.1000	Background for pesticide aerial drift evaluation	none	201–1, 201–4	none	98–319
840.1100	Spray droplet size spectrum	none	201–1	none	98–055
840.1200	Spray drift field deposition	none	201–1	none	98–112

Series 850—Ecological Effects Test Guidelines

April 1996

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
850.1000	Special considerationd for conducting aquatic laboratory studies	none	none	none	96–113
	Group A—Aquatic Fauna Test Guidelines.				
850.1010	Aquatic invetebrate acute toxicity, test, freshhwater daphnids	797.1300	72–2	none	96–114
850.1020	Gammarid acute toxicity test	795.120	none	none	96–130
850.1025	Oyster acute toxicity test (shell deposition)	797.1800	72–3	none	96–115
850.1035	Mysid acute toxicity test	797.1930	72–3	none	96–136
850.1045	Penaeid acute toxicity test	797.1970	72–3	none	96–137
850.1055	Bivalve acute toxicity test (embryo larval)	none	72–3	none	96–100
850.1075	Fish acute toxicity test, freshwater and marine	797.1400	72–1, 3	203	96–118
850.1085	Fish acute toxicity mitigated by humic acid	797.1460	none	none	96–117
850.1300	Daphnid chronic toxicity test	797.1330	72–4	202	96–120
850.1350	Mysid chronic toxicity test	797.1950	72–4	none	96–166
850.1400	Fish early-life stage toxicity test	797.1000	72–4	210	96–121
850.1500	Fish life cycle toxicity	none	72–5	none	96–122
850.1710	Oyster BCF	797.1830	72–6	none	96–127
850.1730	Fish BCF	797.1520	72–6, 165–4	305	96–129
850.1735	Whole sediment acute toxicity invertebrates, freshwater	none	none	none	96–354
850.1740	Whole sediment acute toxicity invertebrates, marine	none	none	none	96–355
850.1790	Chironomid sediment toxicity test	795.135	none	none	96–313
850.1800	Tadpole/sediment subchronic toxicity test	797.1995	none	none	96–132
850.1850	Aquatic food chain transfer	none	72–6	none	96–133
850.1900	Generic freshwater microcosm test, laboratory	797.3050, .3100	none	none	96–134
850.1925	Site-specific aquatic microcosm test, laboratory	797.3100	none	none	96–173
850.1950	Field testing for aquatic organisms	none	72–7, 165–5	none	96–135
	Group B—Terrestrial Wildlife Test Guidelines.				
850.2100	Avian acute oral toxicity test	797.2175	71–1	none	96–139
850.2200	Avian dietary toxicity test	797.2050	71–2	205	96–140
850.2300	Avian reproduction test	797.2130, .2150	71–4	206	96–141
850.2400	Wild mammal acute toxicity	none	71–3	none	96–142
850.2450	Terrestrial (soil-core) microcosm test	797.3775	none	none	96–143
850.2500	Field testing for terrestrial wildlife	none	71–5	none	96–144
	Group C—Beneficial Insects and Invertebrates Test Guidelines.				
850.3020	Honey bee acute contact toxicity	none	141–1	none	96–147
850.3030	Honey bee toxicity of residues on foliage	none	141–2	none	96–148
850.3040	Field testing for pollinators	none	141–5	none	96–150
	Group D—Nontarget Plants Test Guidelines.				
850.4000	Background—Nontarget plant testing	none	120–1	none	96–151
850.4025	Target area phytotoxicity	none	121–1	none	96–152
850.4100	Terrestrial plant toxicity, Tier I (seedling emergence)	none	122–1	none	96–153
850.4150	Terrestrial plant toxicity, Tier I (vegetative vigor)	none	122–1	none	96–163
850.4200	Seed germination/root elongation toxicity test	797.2750	122–1	none	96–154
850.4225	Seedling emergence, Tier II	797.2750	123–1	none	96–363
850.4230	Early seedling growth toxicity test	797.2800	123–1	none	96–347
850.4250	Vegetative vigor, Tier II	797.2750	123–1	none	96–364
850.4300	Terrestrial plants field study, Tier III	none	124–1	none	96–155
850.4400	Aquatic plant toxicity test using *Lemna* spp. Tiers I and II	797.1160	122–2, 123–2	none	96–156
850.4450	Aquatic plants field study, Tier III	none	124–2	none	96–157
850.4600	*Rhizobium*-legume toxicity	797.2900	none	none	96–158
850.4800	Plant uptake and translocation test	797.2850	none	none	96–159
	Group E—Toxicity to Microorganisms Test Guidelines.				
850.5100	Soil microbial community toxicity test	797.3700	none	none	96–161
850.5400	Algal toxicity, Tiers I and II	797.1050	122–2, 123–2	none	96–164
	Group F—Chemical-Specific Test Guidelines.				
850.6200	Earthworm subchronic toxicity test	795.150	none	207	96–167
850.6800	Modified activated sludge, respiration inhibition test for sparingly soluble chemicals	795.170	none	209	96–168
	Group G—Field Test Data Reporting Guidelines.				
850.7100	Data reporting for environmental chemistry methods	none	none	none	96–348

Series 860—Residue Chemistry Test Guidelines

August 1996

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
860.1000	Background	none	170–1	none	96–169
860.1100	Chemical identity	none	171–2	none	96–170
860.1200	Directions for use	none	171–3	none	96–171
860.1300	Nature of the residue—plants, livestock	none	171–4a,b	none	96–172
860.1340	Residue analytical method	none	171–4c,d	none	96–174
860.1360	Multiresidue method	none	171–4m	none	96–176
860.1380	Storage stability data	none	171–4e	none	96–177
860.1400	Water, fish, and irrigated crops	none	171–4f,g,h, 165–5	none	96–178
860.1460	Food handling	none	171–4i	none	96–181
860.1480	Meat/milk/poultry/eggs	none	171–4j	none	96–182
860.1500	Crop field trials	none	171–4k	none	96–183
860.1520	Processed food/feed	none	171–4l	none	96–184
860.1550	Proposed tolerances	none	171–6	none	96–186
860.1560	Reasonable grounds in support of the petition	none	171–7	none	96–187
860.1650	Submittal of analytical reference standards	none	171–13	none	96–016
860.1850	Confined accumulation in rotational crops	none	165–1	none	96–188
860.1900	Field accumulation in rotational crops	none	165–2	none	96–189

870–Health Effects Test Guidelines

Revised June 1996

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
	Group A—Acute Toxicity Test Guidelines.				
870.1000	Acute toxicity testing–background	none	none	none	96–189
870.1100	Acute oral toxicity	798.1175	81–1	401	96–190
870.1200	Acute dermal toxicity	798.1100	81–2	402	96–192
870.1300	Acute inhalation toxicity	798.1150	81–3	403	96–193
870.1350	Acute inhalation toxicity with histopathology	none	none	none	96–291
	Group B—Specific Organ/Tissue Toxicity Test Guidelines.				
870.2400	Acute eye irritation	798.4500	81–4	405	96–195
870.2500	Acute dermal irritation	798.4470	81–5	404	96–196
870.2600	Skin sensitization	798.4100	81–6	406	96–197
	Group C—Subchronic Toxicity Test Guidelines.				
870.3100	90-Day oral toxicity	798.2650	82–1	408	96–199
870.3150	Subchronic nonrodent oral toxicity–90-day	none	82–1	409	98–200
870.3200	Repeated dose dermal toxicity–21/28-Day	none	82—2	410	96–201
870.3250	Subchronic dermal toxicity–90-day	798.2250	82–3	411	96–202
870.3465	Subchronic inhalation toxicity	798.2450	82–4	413	96–204
870.3500	Preliminary development toxicity screen	798.4420	none	none	96–205
870.3600	Inhalation developmental study	796.4350	none	none	96–206
870.3700	Prenatal developmental toxicity study	798.4900	83–3	414	96–207
870.3800	Reproduction and fertility effects	798.4700	83–4	416	96–208
	Group D—Chronic Toxicity Test Guidelines.				
870.4100	Chronic toxicity	798.3260	83–1	452	96–210
870.4200	Carcinogenicity	798.3300	83–2	451	96–211
870.4300	Combined chronic toxicity/carcinogenicity	798.3320	83–5	453	96–212
	Group E—Genetic Toxicity Test Guidelines.				
870.5100	Bacterial reverse mutation test	798.5100, .5265	84–2	471, 472	96–247
870.5140	Gene mutation in *Aspergillus nidulans*	798.5140	84–2	none	96–215
870.5195	Mouse biochemical specific locus test	798.5195	84–2	none	96–216
870.5200	Mouse visible specific locus test	798.5200	84–2	none	96–217
870.5250	Gene mutation in *Neurospora crassa*	798.5250	84–2	none	96–218
870.5265	*The Salmonella typhimurium* reverse mutation assay	798.5265	84–2	471, 472	96–219
870.5275	Sex-linked recessive lethal test in *Drosophila melanogaster*	798.5275	84–2	477	96–220
870.5300	In vitro mammalian cell gene mutation test	798.5300	84–2	476	96–221
870.5375	In vitro mammalian chromosome aberration test	798.5375	84–2	473	96–223
870.5380	Mammalian spermatogonial chromosomal aberration test	798.5380	84–2	483	96–224
870.5385	Mammalian bone marrow chromosomal aberration test	798.5385	84–2	475	96–225
870.5395	Mammalian erythrocyte micronucleus test	798.5395	84–2	474	96–226
870.5450	Rodent dominant lethal assay	798.5450	84–2	478	96–227
870.5460	Rodent heritable translocation assays	798.5460	84–2	none	96–228
870.5500	Bacterial DNA damage or repair tests	798.5500	84–2	none	96–229
870.5550	Unscheduled DNA synthesis in mammalian cells in culture	798.5550	84–2	482	96–230
870.5575	Mitotic gene conversion in *Saccharomyces cerevisiae*	798.5575	84–2	481	96–232
870.5900	In vitro sister chromatid exchange assay	798.5900	84–2	479	96–234
870.5915	In vivo sister chromatid exchange assay	798.5915	84–2	none	96–235
	Group F—Neurotoxicity Test Guidelines.				
870.6100	Acute and 28-day delayed neurotoxicity of organophosphorus substances	798.6450, .6540, .6560	81–7, 82–5, 82–6	418, 419	96–237
870.6200	Neurotoxicity screening battery	798.6050, .6200, .6400	81–8, 82–7, 83–1	424	96–238
870.6300	Developmental neurotoxicity study	none	83–6	none	98–239
870.6500	Schedule-controlled operant behavior	796.6500	85–5	none	98–240
870.6850	Peripheral nerve function	796.6850	85–6	none	98–241
870.6855	Neurophysiology: Sensory evoked potentials	796.6855	none	none	98–242
	Group G—Special Studies Test Guidelines.				
870.7200	Domestic animal safety	none	none	none	96–349
870.7485	Metabolism and pharmacokinetics	798.7485	85–1	417	95–244
870.7600	Dermal penetration	none	85–3	none	96–350
870.7800	Immunotoxicity	none	85–7	none	98–351
	Group H—Health Effects Chemical-Specific Test Guidelines.				
870.8223	Pharmacokinetic test	795.223	none	none	96–250

870–Health Effects Test Guidelines—Continued

Revised June 1996

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
870.8245	Dermal pharmacokinetics of DGBE and DGBA	795.225	none	none	96–251
870.8300	Dermal absorption for compounds that are volatile and metabolized to carbon dioxide	795.226	none	none	96–252
870.8320	Oral/dermal pharmacokinetics	795.228	none	none	96–253
870.8340	Oral and inhalation pharmacokinetic test	795.230	none	none	96–254
870.8355	Combined chronic/toxicity carcinogenicity testing of respirable fibrous particles	798.3320	none	none	99–352
870.8360	Pharmacokinetics of isopropanol	795.231	none	none	96–255
870.8380	Inhalation and dermal pharmacokinetics of commercial hexane	795.232	none	none	96–256
870.8500	Toxicokinetic test	795.235	none	none	96–257
870.8600	Developmental neurotoxicity screen	795.250	none	none	96–258
870.8700	Subchronic oral toxicity test	795.260	none	none	96–259
870.8800	Morphologic transformation of cells in culture	795.285	none	none	96–260

Series 875—Occupational and Residential Exposure Test Guidelines

February 1996

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
	Group A—Applicator Exposure Monitoring Test Guidelines.				
875.1000	Background for application exposure monitoring test guidelines	none	230	none	96–261
875.1100	Dermal exposure—outdoor	none	231	none	96–262
875.1200	Dermal exposure—indoor	none	233	none	96–209
875.1300	Inhalation exposure—outdoor	none	232	none	96–263
875.1400	Inhalation exposure—indoor	none	234	none	96–213
875.1500	Biological monitoring	none	235	none	96–264
875.1600	Application exposure monitoring data reporting	none	236	none	96–265
	Group B—Postapplication Exposure Monitoring Test Guidelines.				
875.2000	Background for postapplication exposure monitoring test guidelines	none	130, 131	none	96–266
875.2100	Foliar dislodgeable residue dissipation	none	132–1	none	96–267
875.2200	Soil residue dissipation	none	132–1	none	96–243
875.2400	Dermal exposure	none	133–3	none	96–269
875.2500	Inhalation exposure	none	133–4	none	96–270
875.2600	Biological monitoring	none	235	none	96–271
875.2800	Descriptions of human activity	none	133–1	none	96–283
875.2900	Data reporting and calculations	none	134	none	96–272

Series 880—Biochemicals Test Guidelines

February 1996

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
	Group A—Product Analysis Test Guidelines.				
880.1100	Product identity and composition	none	151–10	none	96–273
880.1200	Description of starting materials, production and formulation process	none	151–11	none	96–274
880.1400	Discussion of formation of impurities	none	151–12	none	96–275
	Group B—Toxicology Test Guidelines.				
880.3550	Immunotoxicity	none	152–18	none	96–280
880.3800	Immune response	none	152–24	none	96–281
	Group C—Nontarget Organisms and Environmental Testing Test Guidelines.				
880.4350	Nontarget insect testing	none	154–11	none	96–285
880.4425	Dispenser water leaching	none	155–5	none	96–286

Series 885—Microbial Pesticide Test Guidelines

February 1996

OPPTS Number	Name	Existing Numbers			EPA Pub. no.
		OTS	OPP	OECD	712–C–
885.0001	Overview for microbial pest control agents	none	150A	none	96–290
	Group A—Product Analysis Test Guidelines.				
885.1100	Product identity	none	151A–10	none	96–292
885.1200	Manufacturing process	none	151A–11	none	96–293
885.1300	Discussion of formation of unintentional ingredients	none	151A–01	none	96–294
885.1400	Analysis of samples	none	151A–13	none	96–295
885.1500	Certification of limits	none	151A–15	none	96–296
	Group B—Residues Test Guidelines.				
885.2000	Background for residue analysis of microbial pest control agents	none	153A–1	none	96–299
885.2100	Chemical identity	none	153A–4	none	96–300
885.2200	Nature of the residue in plants	none	153A–6	none	96–302
885.2250	Nature of the residue in animals	none	153A–7	none	96–311
885.2300	Analytical methods—plants	none	153A–8a	none	96–301
885.2350	Analytical methods—animals	none	153A–8b	none	96–305
885.2400	Storage stability	none	153A–9	none	96–306
885.2500	Magnitude of residues in plants	none	153A–10	none	96–307
885.2550	Magnitude of residues in meat, milk, poultry, eggs	none	153A–11	none	96–308
885.2600	Magnitude of residues in potable water, fish, and irrigated crops	none	153A–01	none	96–309
	Group C—Toxicology Test Guidelines.				
885.3000	Background–mammalian toxicity/pathogenicity/infectivity	none	152A–1	none	96–314
885.3050	Acute oral toxicity/pathogenicity	none	152A–10	none	96–315
885.3100	Acute dermal toxicity/pathology	none	152A–11	none	96–316
885.3150	Acute pulmonary toxicity/pathogenicity	none	152A–12	none	96–317
885.3200	Acute injection toxicity/pathogenicity	none	152A–13	none	96–318
885.3400	Hypersensitivity incidents	none	152A–15	none	96–320
885.3500	Cell culture	none	152A–16	none	96–321
885.3550	Acute toxicology, Tier II	none	152A–20	none	96–322
885.3600	Subchronic toxicity/pathogenicity	none	152A–21	none	96–323
885.3650	Reproductive/fertility effects	none	152A–30	none	96–324
	Group D—Nontarget Organism and Environmental Expression Test Guidelines.				
885.4000	Background for nontarget organism testing of microbial pest control agents	none	154A–1, 2, 3, 4, 5	none	96–328
885.4050	Avian oral, Tier I	none	154A–16	none	96–329
885.4100	Avian inhalation test, Tier I	none	154A–17	none	96–330
885.4150	Wild mammal testing, Tier I	none	154A–18	none	96–331
885.4200	Freshwater fish testing, Tier I	none	154A–19	none	96–332
885.4240	Freshwater aquatic invertebrate testing, Tier I	none	154A–20	none	96–333
885.4280	Estuarine and marine animal testing, Tier I	none	154A–21	none	96–334
885.4300	Nontarget plant studies, Tier I	none	154A–22	none	96–335
885.4340	Nontarget insect testing, Tier I	none	154A–23	none	96–336
885.4380	Honey bee testing, Tier I	none	154A–24	none	96–337
885.4600	Avian chronic pathogenicity and reproduction test, Tier III	none	154A–26	none	96–342
885.4650	Aquatic invertebrate range testing, Tier III	none	154A–27	none	96–343
885.4700	Fish life cycle studies, Tier III	none	154A–28	none	96–344
885.4750	Aquatic ecosystem test	none	154A–29	none	96–345
	Group E—Environmental Expression Test Guidelines.				
885.5000	Background for microbial pesticides testing	none	155A–1, 2	none	96–056
885.5200	Expression in a terrestrial environment	none	155A–10	none	96–338
885.5300	Expression in a freshwater environment	none	155A–11	none	96–339
885.5400	Expression in a marine or estuarine environment	none	155A–12	none	96–340

Appendix F. Current Labels for All Piscicide Formulations Currently Registered in the United States and Material Safety Data Sheets for the Active Ingredients in Those Piscicide Formulations

Included in Appendix F:

Labels for Registered Piscicide Formulations in the United States

Label for Fintrol® Concentrate (23% antimycin A)

Label for Rotenone Fish Toxicant Powder (7.4% active rotenone)

Label for Prentox® Prenfish™ Fish Toxicant Powder (5% active rotenone)

Synpren-fish® Toxicant (2.5% active rotenone)

Lampricid® (38% active TFM)

TFM Bar (23% active TFM)

Bayluscide® Wettable Powder (70% active niclosamide, aminoethanol salt)

Bayluscide® Granular (3.2% active niclosamide, aminoethanol salt)

Bayluscide® Emulsifiable Concentrate (20.6% active niclosamide, aminoethanol salt)

Material Safety Data Sheets for Registered Piscicide Formulations in the United States

Antimycin A

Prentox® Prenfish™ Fish Toxicant Powder (rotenone)

TFM

Bayluside Technical

Label for Fintrol® Concentrate (23% Antimycin A)

RESTRICTED USE PESTICIDE

Due to Aquatic Toxicity & Need for Highly Specialized Applicator training.

For retail sale to, and use only by, Certified Applicators, or persons under their direct supervision, and only for those uses covered by the Certified Applicators' Certification.

FINTROL®-

CONCENTRATE (ANTIMYCIN A) FISH TOXICANT KIT

(contains Fintrol Concentrate and Fintrol Diluent)

This can contains 1 bottle of FINTROL-Concentrate and 1 bottle of Fintrol-Diluent.

FINTROL CONCENTRATE (8 fl. Oz.)		
Active Ingredients		
Antimycin A	23%	w/w
Inert Ingredients		
Soy lipids	15%	
Acetone	62%	
	100%	w/w

FINTROL DILUENT (8 fl. Oz.)		
Inert Ingredients		
Diethyl Phthalate (surfactant)	30.5%	w/w
Nonoxyl-9 (detergent)	16.7%	
Acetone	52.8%	
	100.0%	w/w

AQUABIOTICS CORP. P.O. BOX 10576. Bainbridge Island, WA 98110
E.P.A. Reg. No 39096-2 E.P.A. Est. No 39096-WA-01

DANGER  **POISON**

Keep out of reach of children

See side panel for other Precautionary Statements.

DIRECTIONS FOR USE

It is a violation of federal law to use this product in a manner inconsistent with its labeling. See "USE DIRECTIONS LEAFLET" for "Fintrol (Antimycin A) Fish Toxicant Kit"

TAKE TIME

OBSERVE LABEL DIRECTIONS

FINTROL-® CONCENTRATE

(antimycin A) (solution 20%)

PRECAUTIONARY STATEMENTS
Hazards to Humans and Domestic Animals

DANGER: Fatal if swallowed. May be fatal if absorbed through skin. Causes substantial but temporary eye injury. Causes skin irritation. Do not breathe spray mist. Do not get in eyes, on skin or on clothing. Wear protective goggles. Wear chemical gloves. Wash thoroughly with soap and water after handling and before eating, drinking or using tobacco. Remove contaminated clothing and wash before reuse.

Environmental Hazards
This product is very highly toxic to fish.

STORAGE AND DISPOSAL
Do not contaminate water, food or feed by storage or disposal. SEE OUTER CAN LABEL FOR PROPER STORAGE, PESTICIDE DISPOSAL AND CONTAINER DISPOSAL

EPA Reg. No. 39096-2
EPA Est. No. 39096-WA-01

Fintrol Concentrate for use with Fintrol (Antimycin) Fish Toxicant Kit

Ingredients	(w/w%)
Active Ingredients	
Antimycin A	23%
Inert Ingredients	
Soy lipids	15%
Acetone	62%
	100%

DANGER

POISON

KEEP OUT OF REACH OF CHILDREN

Aquabiotics Corp.
PO Box 10576
Bainbridge Island, WA

Physical or Chemical Hazards:
Extremely Flammable: Keep away from fire, sparks and heated surfaces.
FIRST AID IF SWALLOWED: Call a physician or Poison Control Center. Drink 1 or 2 glasses of water and induce vomiting by touching back of throat with finger. If person is unconscious, do not give anything by mouth and do not induce vomiting.
IF INHALED: Remove victim to fresh air. If not breathing, give artificial respiration, preferably mouth-to-mouth. Get medical attention.
IF ON SKIN: Wash with plenty of soap and water. Get medical attention.
IF IN EYES: Hold eyelids open and flush with a steady, gentle stream of water for 15 minutes. Get medical attention.
DIRECTIONS FOR USE
It is a violation of federal law to use this product in a manner inconsistent with its labeling. See "USE DIRECTIONS LEAFLET" for "FINTROL (Antimycin A) Fish Toxicant Kit".

FINTROL CONCENTRATE
PRECAUTIONARY STATEMENTS
Hazards to Humans and Domestic Animals

DANGER: Fatal if swallowed. May be fatal if absorbed through skin. Causes substantial but temporary eye injury. Causes skin irritation. Do not breath spray mist. Do not get in eyes, on skin or on clothing. Wear protective goggles. Wear chemical gloves. Wash thoroughly with soap and water after handling and before eating, drinking or using tobacco. Remove contaminated clothing and wash before reuse.

Environmental Hazards
This product is very highly toxic to fish
Physical or Chemical Hazards

Extremely Flammable: Keep away from fire, sparks and heated surfaces.

FIRST AID: IF SWALLOWED: Call a physician or Poison Control Center. Drink 1 or 2 glasses of water and induce vomiting by touching back of throat with finger. If person is unconscious, do not give anything by mouth and do not induce vomiting.

IF INHALED: Remove victim to fresh air. If not breathing, give artificial respiration, preferably mouth-to-mouth. Get medical attention.

IF ON SKIN: Wash with plenty of soap and water. Get medical attention.

IF IN EYES: Hold eyelids open and flush with a steady, gentle stream of water for 15 minutes. Get medical attention.

STORAGE AND DISPOSAL

Do not contaminate water, food or feed by storage or disposal.

Storage: Store only in original containers, in a dry place inaccessible to children and pets. Fintrol Concentrate will thicken if stored at temperatures below 65 F. Before use store overnight above 70 F. Fintrol Concentrate is stable for a minimum of 3 years when stored in unopened original glass bottles.

Pesticide Disposal: Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide, spray mixture, or rinsate is a violation of federal law. If these wastes cannot be disposed of by use according to label instructions, contact your state pesticide or environmental Control Agency or the Hazardous Waste representative at the nearest EPA Regional Office for guidance.

Container Disposal: Triple rinse (or equivalent). Then dispose of in a sanitary landfill or by other approved state and local procedures.

TAKE TIME

OBSERVE LABEL DIRECTIONS

FINTROL DILUENT

FOR USE WITH

PRECAUTIONARY STATEMENTS
Hazards to Humans & Domestic Animals

CAUTION: Harmful if swallowed. Harmful if inhaled. Harmful if absorbed through skin. Causes moderate eye irritation. Avoid contact with skin and clothing. Do not breathe spray mist. Do not get in eyes, on skin or on clothing. Wear protective goggles. Wear chemical gloves. Wash thoroughly with soap and water after handling and before eating, drinking or using tobacco. Remove contaminated clothing and wash before reuse.

Physical or Chemical Hazards:
Extremely Flammable: Keep away from fire, sparks and heated surfaces.

First Aid: See Outer Can Label

EPA Reg. No. 39096-2
EPA Est. No. 39096-WA-01

FINTROL®

(Antimycin)

Fish Toxicant Kit

Ingredients	(w/w%)
Inert Ingredients	
Diethyl Phthalate (surfactant)	30.5%
Nonoxyl-9 (detergent)	16.7%
Acetone	52.8%
	100%

CAUTION
Keep out of reach of children

DIRECTIONS FOR USE
It is a violation of federal law to use this product in a manner inconsistent with its labeling. See "USE DIRECTIONS LEAFLET" for FINTROL (Antimycin A) Fish Toxicant Kit.

STORAGE AND DISPOSAL
Do not contaminate water, food or feed by storage or disposal. SEE OUTER CAN LABEL FOR PROPER STORAGE, PESTICIDE DISPOSAL AND CONTAINER DISPOSAL.

AQUABIOTICS CORP.
P.O. Box 10576
Bainbridge Island, WA 98110

FINTROL DILUENT
PRECAUTIONARY STATEMENTS
Hazards to Humans and Domestic Animals

CAUTION: Harmful if swallowed. Harmful if inhaled. Harmful if absorbed through skin. Causes moderate eye irritation. Avoid contact with skin and clothing. Do not breath spray mist. Do not get in eyes, on skin or on clothing. Wear protective goggles. Wear chemical gloves. Wash thoroughly with soap and water after handling and before eating, drinking or using tobacco. Remove contaminated clothing and wash before reuse.

Physical or Chemical Hazards

EXTREMELY FLAMMABLE: KEEP AWAY FROM FIRE, SPARKS AND HEATED SURFACES.

FIRST AID

IF SWALLOWED: Call a physician or Poison Control Center. Drink 1 or 2 glasses of water and induce vomiting by touching back of throat with finger. If person is unconscious, do not give anything by mouth and do not induce vomiting.

IF INHALED: Remove victim to fresh air. If not breathing, give artificial respiration, preferably mouth-to-mouth. Get medical attention.

IF ON SKIN: Wash with plenty of soap and water. Get medical attention.

IF IN EYES: Hold eyelids open and flush with a steady, gentle stream of water for 15 minutes. Get medical attention.

STORAGE AND DISPOSAL

Do not contaminate water, food or feed by storage or disposal.

Storage: Store only in original containers, in a dry place inaccessible to children and pets. Fintrol Concentrate will thicken if stored at temperatures below 65 F. Before use store overnight above 70 F. Fintrol Concentrate is stable for a minimum of 3 years when stored in unopened original glass bottles.

Pesticide Disposal: Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide, spray mixture, or rinsate is a violation of federal law. If these wastes cannot be disposed of by use according to label instructions, contact your state pesticide or environmental Control Agency or the Hazardous Waste representative at the nearest EPA Regional Office for guidance.

Container Disposal: Triple rinse (or equivalent). Then dispose of in a sanitary landfill or by other approved state and local procedures.

FINTROL®

Fish Toxicant Kit

Use Direction Leaflet

Directions For Use

It is a violation of Federal Law to use this product in a manner inconsistent with its labeling.

FINTROL-CONCENTRATE is designed for use in running water, streams and shallow waters. This liquid form of FINTROL may be applied to lakes and ponds by boat bailer method or spray equipment. Spray methods are useful at depths to 1 foot. Boat bailer and drip tubes, applied at the propeller wash, are used at other depths. Application from an airplane is NOT recommended.

Each can of Fintrol-Concentrate (Antimycin A) Fish Toxicant Kit [containing 240 cc. Fintrol-Concentrate (solution 20%) and 240 cc. Diluent] will, after mixing, make 480 cc., which treats approximately 38 acre-feet of water at 1 p.p.b. (1 part per billion)

AQUABIOTICS CORP.
P.O. Box 10576
10750 Arrow Point Dr. NE
Bainbridge Island, WA 98110

EPA Reg. No. 39096-2
EPA Est. No. 39096-WA-01

Licensed by: Wisconsin Alumni Research Foundation

Trademark licensed by: Ayerst Laboratories, Inc.

Before applying FINTROL to either public or private waters, contact the Director of the State Fish and Game Department or Conservation Department for State and Federal regulations governing the use of fish toxicants in your area.

DESCRIPTION

The active ingredient of FINTROL is antimycin A. When absorbed through the gills of fish, antimycin A kills by interfering with the respiration of body cells. Antimycin A does not repel fish. This is an important advantage, particularly when running waters, bog lakes, and the epilimnion, or upper layer, of large lakes are treated. Fish make no attempt to escape contact with the toxicant by seeking to move into waters that are clear of it. FINTROL'S action is rapid and irreversible.

Sensitivity to FINTROL varies widely among fish species. Hence it may be employed to selectively destroy certain species, without affecting other species concurrently inhabiting the same body of water.

Sensitive:
Gizzard shad, trouts, pikes, carp, minnows, suckers, brook stickleback, white bass, sunfishes, perches, freshwater drum, sculpins.

Least Sensitive:
Shortnose gar, bowfin, goldfish, catfish.

FINTROL also may be used to selectively destroy certain age groups of species; younger fish are more sensitive to FINTROL.

Providing the concentration is correctly estimated, FINTROL can be used effectively at any time of year in either cold, warm, soft, hard, acid, alkaline, clear or turbid (muddy) waters. (See TABLE 1 and instruction for bioassay.)

FINTROL does not impart detectable taste or odor to treated waters. In the usual, recommended concentrations it causes no apparent harm to aquatic plants, insects, or bottom fauna. Since FINTROL'S active ingredient degrades rapidly, the reclaimed waters may be restocked soon after treatment. **(See HOW TO DETERMINE WHEN TREATED WATER MAY BE RESTOCKED.)** There is very little interruption in availability of the waters for recreational, agricultural, industrial, or other purpose.

USES

FINTROL is used to cull undesirable species of fish from freshwater lakes, ponds, and streams. It can be used to eliminate all fish from a body of water (complete kill). Or, it can be used to remove only certain fish species or size groups from mixed populations (selective kill).

A **complete kill** may be achieved with a concentration of anywhere from 5 to 25 p.p.b. of active ingredient. **(See HOW TO DETERMINE THE MOST EFFECTIVE CONCENTRATION.)** FINTROL is particularly advantageous for complete kills because if detoxifies so rapidly the pond can usually be restocked in about a week, or as soon as caged fish survive 48 hours' exposure to the treated waters.

Under optimal circumstances, in ponds managed for sports fishing, **selective kills** may be achieved at concentrations as low as 0.5 to 1.0 p.p.b. However, because these concentrations are extremely low, there is no rule of thumb that can be relied upon to determine them accurately. A BIOASSAY IS ALWAYS REQUIRED TO PINPOINT THE OPTIMAL CONCENTRATION FOR SELECTIVE KILLS. (Literature describing this procedure is available upon request.)

A **selective kill** has these advantages: It can be made without interrupting sport fishing for more than a week or so, and fishing may be gradually improved without restocking. In the past, when bluegill, minnows, or green sunfish dominated a pond managed for bass, the usual solution to the problem was the total removal of all the fish with a fish toxicant. This meant restocking and little or no fishing for one or two years. Now — with FINTROL — this is no longer necessary. Low concentrations of FINTROL will affect small bluegill, green sunfish, and minnows primarily. Only a few of the very small bass will succumb. The bulk of the adult bluegill and green sunfish will not be affected. Thus FINTROL helps to bring about a balanced relationship between the bass and bluegill populations. This improves fishing without interrupting it for any appreciable length of time.

In **catfish farming** FINTROL can be used to *selectively eliminate* the trash fish (scale fish) that commonly reduce the yields and increase the costs of the commercial catfish farmer. It is possible to do this with FINTROL because concentrations that will eliminate scale fish generally will not harm adult catfish. The scale fish most often encountered by the catfish farmer will succumb to anywhere from 5 to 10 p.p.b. of active ingredient (See TABLE 1) whereas, under ordinary circumstances, it takes in excess of 20 p.p.b. to kill catfish. (Caution should be exercised during stress conditions of unusually high water temperature and reduced oxygen content when the sensitivity of fishes to chemicals may increase.)

HOW TO SELECT THE APPROPRIATE FORMULATION

The nature of the water to be treated (its depth and rate of flow) and the character of the surrounding land are factors to be taken into consideration when determining the formulation of FINTROL to employ in a given situation.

HOW TO DETERMINE THE MOST EFFECTIVE CONCENTRATION

For complete kills and also,
for removal of scale fish from catfish ponds.
The concentration of antimycin A required to kill one or more species of fish in any given body of water depends upon: 1) the sensitivity of the species to be eradicated, and 2) the chemical and physical properties of the water at the time of application of the toxicant; the pH and the temperature of the water are the most important of these chemical and physical factors under ordinary circumstances. Therefore, to determine what concentration of antimycin A will be required to kill the undesirable fish in your pond or lake:

1) identify the species to be eradicated,
2) determine the pH and average water temperature by measuring at various sites and depths,
3) refer to TABLE 1 for approximate concentrations.
4) conduct a bioassay to pinpoint the optimal concentration.

TABLE 1 provides a rough estimate of the concentrations required for a **complete kill** under various environmental conditions. However, since water chemistry is subject to sudden alteration by many variables and often unpredictable factors (pollution, heavy algae bloom, weather, drawdown, etc.) it should be realized that such changes may affect the performance of the toxicant. For this reason, measurements of pH and water temperature should always be taken as close to the time of treatment as is feasible.

TABLE 1—FOR ROUGH ESTIMATION OF CONCENTRATIONS* OF FINTROL (ANTIMYCIN A) NEEDED FOR COMPLETE† ERADICATION OF DIFFERENT FISH SPECIES, UNDER VARIOUS COMBINATION OF WATER TEMPERATURE AND WATER pH

TARGET SPECIES	SENSITIVITY OF TARGET SPECIES TO FINTROL (in p.p.b. of active ingredient)	EFFECTIVE CONCENTRATION OF FINTROL* (in p.p.b. of active ingredient)			
		When pH is 8.5 or less		When pH is 8.5 or more	
		water temperature above 60°F.	water temperature below 60°F.	water temperature above 60°F.	water temperature below 60°F
gizzard shad trouts pikes carp minnows suckers brook stickleback white bass sunfishes perches freshwater drum sculpins	5-10	5	7.5	7.5	10
short nose gar bowfin goldfish catfish	15-25	15	20	20	25

***The concentration level suggested by this table should be confirmed by an on-site bioassay.**

† This table is applicable only when a *complete* kill is desired. Do not use it for a selective kill. (See the following section.)

* Fish nomenclature according to American Fisheries Society

Note (columns 1 and 2) that the sensitivity of the target species determines the concentration range. To eradicate sensitive species, it is recommended that the appropriate formulation at FINTROL be applied so that the body of water will have a concentration of from 5 to 10 p.p.b. of antimycin A, depending upon variation in pH and water temperature. For more tolerant species, higher concentrations are recommended. Laboratory Studies indicate that less sensitive fish will succumb at concentrations of from 15 to 25 p.p.b of antimycin A, depending upon variations in pH and water temperature. Columns 3 to 6 show how to adjust for pH and water temperature. Note that, in general, the lower the pH, the less FINTROL required. The higher the water temperature, the less FINTROL required. The ideal situation for a complete kill would combine a highly sensitive species, low pH and high water temperature.

For selective kills in ponds managed for sports fishing

The only way to determine the concentration of FINTROL needed for a selective kill is to perform a bioassay. This involves subjecting both the target and nontarget fish to several concentrations of FINTROL to determine the minimum lethal dose. (A description of the bioassay procedure is available upon request.)

HOW TO CALCULATE THE AMOUNT OF FINTROL TO BE ADDED TO A BODY OF WATER TO OBTAIN A GIVEN CONCENTRATION

To calculate the amount of FINTROL to be added to a body of water for eradication of undesired species, the following steps should be taken:

- Determine the volume of water to be treated in acre-feet. This can be arrived at by multiplying the surface area in acres by the average depth in feet.
- Determine the concentration to be used from Table 1.
- Multiply the number of acre-feet by the value given in Table 2, opposite the desired concentration.
- Divide this number by the total kit volume (480 cc. or 16 oz.) to get number of Fish Toxicant Kits needed.

TABLE 2—RAPID ESTIMATION OF FINTROL-CONCENTRATE REQUIREMENTS

Desired Concentration (p.p.b. active ingredient)	Amount of FINTROL-CONCENTRATE per acre-foot	
	cc*	oz.(approx.)
1 p.p.b	12.3	½
2 p.p.b.	24.6	¾
3 p.p.b.	36.9	1¼
4 p.p.b.	49.2	1½
5 p.p.b.	61.5	2
6 p.p.b.	73.8	2½
7 p.p.b.	86.1	2¾
8 p.p.b.	98.4	3¼
9 p.p.b.	110.7	3¾
10 p.p.b.	123.0	4

*Obtained by multiplying 12.3 cc. by the p.p.b.

Note: 1 measuring teaspoon = 5 cc.; 1 measuring tablespoon = 15 cc.; ¼ standard measuring cup = 60 cc.; ½ standard measuring cup = 120 cc.; 1 standard meas. cup = 240 cc.

Sample calculation:

To treat 75 acre-feet at 3 p.p.b., use:

75 x 36.9 cc = 2,767 cc. of FINTROL-CONCENTRATE / 480 cc. = 5.8 Kits, or

75 x 1¼ fl. oz. = 93¾ fl. oz. of FINTROL-CONCENTRATE / 16 oz = 5.8 kits).

METHODS OF APPLICATION

IMPORTANT: DURING APPLICATION OF FINTROL, ALL PERSONS IN THE IMMEDIATE VICINITY SHOULD WEAR PROTECTIVE GOGGLES AND PROTECTIVE GLOVES

Liquid formulation: Directions for mixing: Add the Diluent [blue label] to the FINTROL CONCENTRATE (solution 20%) [Green label] in the oversize mixing container. Cap tightly and invert 2 to 3 times to mix thoroughly. Further dilute with AT LEAST five (5) gallons of water to insure that the acetone contained in FINTROL-CONCENTRATE will not affect rubber parts on any equipment that might be used to apply it. After water has been added, apply within eight (8) hours. [Note: The solution obtained by mixing the Diluent with FINTROL-CONCENTRATE (solution 20%) retains potency for up to seven (7) days. But once water has been added to this solution, it must be used within eight (8) hours to ensure potency.]

After appropriate dilution with water, the liquid formulation of FINTROL can be applied to lakes and ponds by the boat bailer method or spray equipment. Spray methods are useful at depths to one foot. Boat bailer and drip tubes when applied at the propeller wash are useful at greater depths. Pinpoint applications to shoal areas and small, isolated ponds can readily be made with backpack sprayers. (See CAUTION on use of PROTECTIVE GOGGLES AND PROTECTIVE GLOVES.)

In streams, FINTROL-CONCENTRATE is most often applied through drip stations established to meter the toxicant at a precalculated rate. Information on the use of such equipment may be obtained from state and/or federal agencies, experienced in stream treatment.

It is recommended that all applications of FINTROL be made at daybreak or as soon as there is enough light to work by.

PRECAUTIONS

Fish killed with antimycin A should not be consumed by man or animals. Treated waters must not be used for drinking by man or animals, or for crop irrigation, until fingerling rainbow trout or fingerling bluegills survive 48 hours' exposure in livecars in the treated waters.

Leftover portions of mixed liquid formulation retain potency for up to seven (7) days. But once water has been added to FINTROL-CONCENTRATE, it must be used within eight (8) hours to ensure potency.

Due to its acetone component, FINTROL-CONCENTRATE is flammable: keep away from heat and flame.

HOW TO DETERMINE WHEN TREATED WATER MAY BE RESTOCKED

Since antimycin A degrades rapidly following application, waters can usually be restocked about one week following treatment with FINTROL. Place livecars containing a sensitive species of fish in the treated water. It is recommended that these fish be fingerling rainbow trout or fingerling bluegills if the water temperature is between 35° and 68° F. When the water temperature exceeds 68° F, only fingerling bluegills should be used. If the fish survive for 48 hours, the water may be restocked.

HOW TO DETOXIFY FINTROL WITH POTASSIUM PERMANGANATE ($KMnO_4$)

If it should be necessary to detoxify FINTROL in the outflow of a pond to prevent killing fish downstream, apply potassium permanganate at 1 part per million (1 p.p.m.) to the outflow. (More potassium permanganate may be needed if the stream has a high permanganate demand). Drip systems of hose-and-clamp or carburetor types can be employed to continuously dispense a solution of potassium permanganate into the water at the discharge outlet.

To evaluate the effectiveness of the detoxification process, place livecars containing fingerling rainbow trout or fingerling bluegills approximately 100 yards downstream from the site of $KMnO_4$ introduction. The water is considered detoxified if the fish survive for at least 48 hours in the livecar.

To detoxify FINTROL-treated streams, apply $KMnO_4$ at 1 p.p.m. at detoxification stations. (More $KMnO_4$ may be needed if the stream has a high permanganate demand). Continue the application of $KMnO_4$ until all FINTROL-treated water has passed the station. The water may be considered detoxified when fingerling rainbow trout or fingerling bluegills survive for at least 48 hours in livecars placed 100 yards downstream from the site of potassium permanganate ($KMnO_4$) introduction.

RE-ENTRY STATEMENT

Do not allow swimming in, drinking, or irrigation with FINTROL (Antimycin) treated water until a livecar of sensitive species of fish (fingerling rainbow trout or bluegill) survive for 48 hours in the treated waters. (See statement of How To Determine When Treated Water May Be Restocked).

SPECIAL INSTRUCTIONS

Prior to the use of a fish toxicant in either public or private waters, the Director of the State Fish and Game Department or Conservation Department must be contacted to determine whether a permit is required. Such products must be used by or under the technical supervision of personnel of state and federal fish and game agencies, trained in fisheries management, who will provide any special instructions applicable to the particular geographical area.

Label for Rotenone Fish Toxicant Powder (7.4% active rotenone)

RESTRICTED USE PESTICIDE
DUE TO AQUATIC, ACUTE ORAL AND INHALATION TOXICITY
For retail sale to, and use by, Certified Applicators or persons under their direct supervision and only for those uses covered by the Certified Applicator's certification.

ROTENONE FISH TOXICANT POWDER

ACTIVE INGREDIENTS:

Rotenone- Minimum Guaranteed	7.4% w/w
Other Associated Resins	11.1%
OTHER INGREDIENTS:	81.5%
TOTAL:	100.0% w/w

ROTENONE ASSAY _____% ROTENONE

PRENTOX® - Registered Trademark of Prentiss Incorporated

SAMPLE

KEEP OUT OF REACH OF CHILDREN

DANGER
POISON

FIRST AID
Have the product container or label with you when calling a poison control center or physician, or going for treatment.

If swallowed	• Call a Poison Control Center, physician, or the National Pesticide Information Center at 1-800-858-7378 immediately for treatment advice. • Have person sip a glass of water if able to swallow. • Do not induce vomiting unless told to do so by the Poison Control Center or physician. • Do not give anything by mouth to an unconscious or convulsing person.
If on skin or clothing	• Take off contaminated clothing. • Rinse skin immediately with plenty of water for 15-20 minutes. • Call a Poison Control Center, physician, or the National Pesticide Information Center at 1-800-858-7378 for treatment advice.
If in eyes	• Hold eye open and rinse slowly and gently with water for 15-20 minutes. • Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. • Call a Poison Control Center, physician, or the National Pesticide Information Center at 1-800-858-7378 for treatment advice.
If inhaled	• Move person to fresh air. • If person is not breathing, call 911 or an ambulance, then give artificial respiration, preferably mouth-to-mouth, if possible. • Call a Poison Control Center, physician, or the National Pesticide Information Center at 1-800-858-7378 for treatment advice.

For information on this pesticide product (including health concerns, medical emergencies, or pesticide incidents), call the National Pesticide Information Center at 1-800-858-7378.

SEE INSIDE LEAFLET FOR ADDITIONAL PRECAUTIONARY STATEMENTS AND DIRECTIONS FOR USE

Manufactured by: 5/02 **E.P.A. REG. NO. 655-691**
E.P.A. EST. NO. 655-GA-1

PRENTISS INCORPORATED

Plant: Kaolin Road, Sandersville, GA 31082
Office: C.B. 2000, Floral Park, NY 11002-2000

PRECAUTIONARY STATEMENTS
HAZARDS TO HUMANS AND DOMESTIC ANIMALS
DANGER

Fatal if inhaled or swallowed. Harmful if absorbed through the skin. Causes moderate eye irritation. Prolonged or frequently repeated skin contact may cause allergic reactions in some individuals. Do not breathe dust. Use a dust/mist filtering respirator (MSHA/NIOSH approval number prefix TC-21C), or a NIOSH approved respirator with any N, R, P or HE filter. Avoid contact with skin, eyes or clothing. Wash thoroughly with soap and water after handling and before eating, drinking or using tobacco. Remove contaminated clothing and wash clothing before reuse.

ENVIRONMENTAL HAZARDS

This pesticide is extremely toxic to fish. Fish kills are expected at recommended rates. Consult your State Fish and Game Agency before applying this product to public waters to determine if a permit is needed for such an application. Do not contaminate untreated water when disposing of equipment washwaters.

STORAGE AND DISPOSAL

Do not contaminate water, food or feed by storage or disposal.
STORAGE: Store only in original container, in a dry place inaccessible to children and pets. If spilled, sweep up and dispose of as below.
PESTICIDE DISPOSAL: Wastes resulting from the use of this product may be disposed of on site or at an approved waste disposal facility.
CONTAINER DISPOSAL: Completely empty bag into application equipment. Then dispose of bag in a sanitary landfill or by incineration, or if allowed by State and local authorities by burning. If burned, stay out of smoke.

DIRECTIONS FOR USE
It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

USE RESTRICTIONS:
Use against fish in lakes, ponds, and streams (immediately above lakes and ponds).

Since such factors as pH, temperature, depth, and turbidity will change effectiveness, use this product only at locations, rates, and times authorized and approved by appropriate state and Federal fish and wildlife agencies. Rates must be within the range specified in the labeling.

Properly dispose of dead fish and unused product. Do not use dead fish as food or feed.

Do not use water treated with rotenone to irrigate crops or release within ½mile upstream of a potable water or irrigation water intake in a standing body of water such as a lake, pond or reservoir.

Note to User: Adjust pounds of Rotenone according to the actual Rotenone Assay as noted under the Ingredient Statement on this label. For example, if the required amount of 5% rotenone is 21 pounds, and the Rotenone Assay is 7%, use 5/7 of 21 pounds or 15 pounds of this product to yield the proper amount of active rotenone.

APPLICATION DIRECTIONS:

Treatment of Lakes and Ponds

1. **Application Rates and Concentrations of Rotenone**

The actual application rates and concentrations of rotenone needed to control fish will vary widely, depending on the type of use (e.g. selective treatment, normal pond treatment, etc.) and the factors listed above. The table below is a general guide for the proper rates and concentrations.

2. **Total Amount of Product Needed for Treatment**

To determine the total number of pounds needed for treatment, divide the number of acre-feet covered by one pound for a specific type of use (e.g., selective treatment, etc), as indicated in the table below, into the number of acre-feet in the body of water.

General Guide to the Application Rates and Concentrations of Rotenone Needed to Control Fish in Lakes and Ponds[1]

Type of Use	No. of Acre-Feet Covered by One Pound	Parts Per Million	
		Active Rotenone	5% Product
Selective Treatment	3.7 to 2.8	0.005 - 0.007	0.10 - 1.3
Normal Pond Use	0.74 to 0.37	0.025 - 0.050	0.5 - 1.0
Remove Bullheads or Carp	0.37 to 0.185	0.050 - 0.100	1.02 - 2.0
Remove Bullheads or Carp in Rich Organic Ponds	0.185 to 0.093	0.100 - 0.200	2.0 - 4.0
Pre-impoundment Treatment above Dam	0.123 to 0.074	0.150 - 0.250	3.0 - 5.0

5. **Restocking**

Waters treated with this product detoxify within 2 to 4 weeks after treatment, depending on pH, temperature, water hardness, and depth. To determine if detoxification has occurred, place live boxes containing samples of fish to be stocked in treated waters. More rapid detoxification can be accomplished by adding Potassium Permanganate or chlorine at a 1:1 ratio with the concentration of rotenone applied, plus sufficient additional compound to satisfy the chemical oxidation demand caused by organic matter that may be present in the treated water.

Treatment of Streams Immediately Above Lakes and Ponds

The purpose of treating streams immediately above lakes and ponds is to improve the effectiveness of lake and pond treatments and not to control fish in streams per se. The term "immediately" means the first available site above the lake or pond where treatment is practical.

In order to treat a stream immediately above a lake or pond, you must select a concentration of active rotenone, compute the flow rate of a stream, calculate the application rate, select an exposure time, estimate the amount of product needed, and follow the method of application.

1. **Concentration of Active Rotenone**

Select the "Concentration of Active Rotenone" based on the type of use from those on the table. For example, if you select "Normal Pond Use" you could select a concentration of "0.025 Parts per Million".

2. **Computation of Flow Rate for Stream**

Select a cross section of the stream where the banks and bottom are relatively smooth and free of obstacles. Divide the surface width into 3 equal sections and determine the water depth and surface velocity at the center of each section. In slowly moving streams, determine the velocity by dropping a float attached to 5 feet of loose, monofilament fishing line. Measure the time required for the float to move 5 feet. For fast-moving streams, use a longer distance. Take at least three readings at each point. To calculate the flow rate from the information obtained above, use the following formula:

$$F = \frac{Ws \times D \times L \times C}{T}$$

where F = flow rate (cu. ft./sec.), Ws = surface width (ft.), D = mean depth (ft.), L = mean distance traveled by float (ft.), C = constant (0.8 for rough bottoms and 0.9 for smooth bottoms), and T = mean time for float (sec.).

For example, after using the above formula, you might have computed the stream's flow rate to be "10 cu. ft. per sec."

3. **Calculation of Application Rate**

In order to calculate the application rate (expressed as "pound per sec"), you convert the rate in the table (expressed as "pound per acre-feet"), to "pound per cu. feet" and multiply by the flow rate (expressed as "cu. ft. per sec."). Depending on the size of the stream and the type of equipment, the rate could be expressed in other units, such as "ounces per hr."

The application rate for the stream above is calculated as follows:

$$R_s = R_p \times C \times F$$

where R_s = Application Rate for Stream (lb/sec), R_p = Application Rate for Pond (lb/acre feet), C = 1 acre foot/43560 cu. ft., and F = Flow Rate (cu. ft/sec).

In the example, the Application Rate for Stream would be:
R_s = 1 lb/0.74 acre-foot x 1 acre-foot/43560 cu. ft. x 10 cu. ft./sec.
R_s = .00031 lb/sec or 17.9 oz./hr.

4. **Exposure Time**

The "Exposure Time" would be the period of time (expressed in hours or seconds) during which target fish should **not** enter the lake or pond under treatment. In the example, this period of time could be 4 hours.

5. **Amount of Product**

Calculate the "Amount of Product" for a stream by multiplying the "Application Rate for Stream" by the "Exposure Time". In the example, the "Amount of Product" would be 71.6 oz. (17.9 oz./hr. x 4 hr.) or 4.5 lb.

RE-ENTRY STATEMENT
Do not allow swimming in rotenone-treated water until the application has been completed and all pesticide has been thoroughly mixed into the water according to labeling instructions.

[1]Adapted from Kinney, Edward, 1965 Rotenone in Fish Pond Management. USDI Washington, D.C. Leaflet FL-576.

Computation of acre-feet for lake or pond: An acre-foot is a unit of water volume having a surface area of one acre and a depth of one foot. Make a series of transects across the surface, taking depths with a measured pole or weighted line. Add the measurements and divide by the number made to determine the average depth. To compute **total acre-feet**, multiply this average depth by the number of surface acres, which can be determined from an aerial photograph or plat drawn to scale.

3. **Pre-Mixing Method of Application**

Pre-mix one pound of Rotenone with 3 to 10 gallons of water. Uniformly apply over water surface or bubble through underwater lines.

Alternately place undiluted powder in burlap sack and trail behind boat. When treating deep water (20 to 25 feet) weight bag and tow at desired depth.

4. **Removal of Taste and Odor**

Rotenone treated waters do not retain a detectable taste or odor for more than a few days to a maximum of one month. Taste and odor can be removed immediately by treatment with activated charcoal at a rate of 30 ppm. for each 1 ppm. Rotenone remaining (Note: As Rotenone detoxifies, less charcoal is required).

SPECIMEN

Label for Prentox® Prenfish™ Fish Toxicant Powder (5% active rotenone)

Product: 655-691 Prentox® Prenfish™ Fish Toxicant Powder

Material Safety Data Sheet
U.S. Department of Labor (OSHA 29 CFR 1910.1200)

Section 1: Product and Company Identification

Product: 655-691 Prentox® Prenfish™ Fish Toxicant Powder

Manufacturer's Name: **Prentiss Incorporated**
C. B. 2000
Floral Park, NY 11001
Telephone Number: **(516) 326-1919**

Section II: Composition/Information on Ingredients

Ingredient Name:	OSHA PEL	ACGIH TLV	%
Rotenone (CAS # 83-79-4)	(TWA) 5 mg/M³	(TWA) 5 mg/M³	7.4
Other Cube Resins	None	None	11.1
Other Ingredients	None	None	81.5

Section 3: Hazards Identification:

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Emergency Overview:

A tan powder with a wet chalk or dirt-like odor.

- Fatal if inhaled or swallowed
- Harmful if absorbed through skin
- Causes moderate eye irritation
- May cause allergic skin reactions in some individuals
- This pesticide is extremely toxic to fish

Potential Health Effects:

Primary Route(s) of Entry:

Ingestion, inhalation, and skin contact

Eyes:

Causes moderate eye irritation

Skin:

Harmful if absorbed through the skin. Prolonged or frequently repeated skin contact may cause allergic skin reactions in some individuals.

Ingestion:

Fatal if swallowed

Inhalation:

Fatal if inhaled

Signs and symptoms of acute overexposure:

May cause irritation of the eyes, nose and throat in addition to temporary numbness. Prolonged or repeated exposure can cause nausea, vomiting, abdominal cramps, muscle tremors, poor muscle coordination, seizures, shallow breathing, skin rashes and eye, nose and mouth lesions.

STORAGE AND DISPOSAL

Do not contaminate water, food or feed by storage or disposal.

Storage: Store only in original containers, in a dry place inaccessible to children and pets. Prentox Prenfish Toxicant will not solidify nor show any separation at temperatures down to 40°F and is stable for a minimum of one year when stored in sealed drums at 70°F.

Pesticide Disposal: Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide, spray mixture, or rinsate is a violation of federal law. If these wastes cannot be disposed of by use according to label instructions contact your state pesticide or Environmental Control Agency, or the Hazardous Waste representative at the nearest EPA Regional Office for guidance.

Container Disposal: Triple rinse (or equivalent). Then offer for recycling or reconditioning, or puncture and dispose of in a sanitary landfill, or by other procedures approved by state and local authorities.

DIRECTIONS FOR USE

It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

General Information

Prentox Prenfish Toxicant is a specially formulated product containing rotenone, to be used in fisheries management for the eradication of fish from lakes, ponds, reservoirs and streams.

Since such factors as pH, temperature, depth and turbidity will change effectiveness, use this product only at locations, rates, and times authorized and approved by appropriate state and federal fish and wildlife agencies. Rates must be within the range specified on the label.

Properly dispose of unused product. Do not use dead fish for food or feed. Do not use water treated with rotenone to irrigate crops or release within 1/2 mile upstream of a potable water or irrigation water intake in a standing body of water such as a lake, pond or reservoir.

Re-entry Statement: Do not allow swimming in rotenone-treated water until the application has been completed and all pesticide has been thoroughly mixed into the water according to labeling instructions.

For Use in Ponds, Lakes and Reservoirs

The actual application rates and concentrations of rotenone needed to control fish will vary widely, depending on the type of use (e.g., selective treatment, normal pond use, etc.) and the factors listed above. The table below is a general guide for the proper rates and concentrations.

Prentox Prenfish Toxicant disperses readily in water both laterally and vertically, and will penetrate below the thermocline in thermally stratified bodies of water.

Computation of Acre-Feet: An acre-foot is a unit of volume of a body of water having the area of one acre and the depth of one foot. To determine acre feet in a given body of water, make a series of transects across the body of water taking depths with a measured pole or weighted line. Add the soundings and divide by the number made to determine the average depth. Multiply this average depth by the total surface area in order to determine the acre feet to be treated. If number of surface acres is unknown, contact your local Soil Conservation Service, which can determine this from aerial photographs.

Amount of Prentox Prenfish Toxicant Needed for Specific Uses: To determine the approximate number of gallons of Prentox Prenfish Toxicant (5.0% Rotenone) needed, find your "Type of Use" in the first column of the table below and then divide the corresponding numbers in the forth column, "Number of Acre-Feet Covered by One Gallon" into the number of acre-feet in your body of water.

General Guide to the Application Rates and Concentrations of Rotenone Needed to Control Fish in Lakes, Ponds and Reservoirs[1]

Type of Use	Parts Per Million		Number of Acre-Feet Covered by One Gallon
	Prenfish Toxicant	Active Rotenone	
Selective Treatment	0.10 to 0.13	0.005 to 0.007	30 to 24
Normal Pond Use	0.5 to 1.0	0.025 to 0.050	6.0 to 3.0
Remove bullheads or carp	1.0 to 2.0	0.050 to 0.100	3.0 to 1.5
Remove bullheads or carp in rich organic ponds	2.0 to 4.0	0.100 to 0.200	1.5 to 0.75
Preimpoundment treatment above dam	3.0 to 5.0	0.150 to 0.250	1.0 to 0.60

[1] Adapted from Kinney, Edward. 1965. Rotenone in Fish Pond Management. USDI Washington, D.C. Leaflet FL-576.

Pre-Mixing and Method of Application: Pre-mix with water at a rate of one gallon Prentox Prenfish Toxicant to 10 gallons of water. Uniformly apply over water surface or bubble through underwater lines.

Detoxification: Prentox Prenfish Toxicant treated waters detoxify under natural conditions within one week to one month depending upon temperatures, alkalinity, etc. Rapid detoxification can be accomplished by adding chlorine or potassium permanganate to the water at the same rate as Prentox Prenfish Toxicant in parts per million, plus enough additional to meet the chlorine demand of the untreated water.

Removal of Taste and Odor: Prentox Prenfish Toxicant treated waters do not retain a detectable taste or odor for more than a few days to a maximum of one month. Taste and odor can be removed immediately by treatment with activated charcoal at a rate of 30 ppm for each 1 ppm Prentox Prenfish Toxicant remaining. (Note: As Prentox Prenfish Toxicant detoxifies, less charcoal is required.)

Restocking After Treatment: Wait 2 to 4 weeks after treatment. Place a sample of fish to be stocked in wire cages in the coolest part of the treated waters. If the fish are not killed within 24 hours, the water may be restocked.

Use in Streams Immediately Above Lakes, Ponds and Reservoirs

The purpose of treating streams immediately above lakes, ponds and reservoirs is to improve the effectiveness of lake, pond and reservoir treatments by preventing target fish from moving into the stream corridors, and not to control fish in streams per se. The term "immediately" means the first available site above the lake, pond or reservoir where treatment is practical, while still creating a sufficient barrier to prevent migration of target fish into the stream corridor.

In order to completely clear a fresh water aquatic habitat of target fish, the entire system above or between fish barriers must be treated. See the use directions for streams and rivers on this label for proper application instructions.

In order to treat a stream immediately above a lake, pond or reservoir you must: (a) select the concentration of active rotenone, (b) compute the flow rate of the stream, (c) calculate the application rate, (d) select an exposure time, (e) estimate the amount of product needed, (f) follow the method of application. To prevent movement of fish from the pond, lake or reservoir, stream treatment should begin before and continue throughout treatment of the pond, lake or reservoir until mixing has occurred.

1. Concentration of Active Rotenone

Select the concentration of active rotenone based on the type of use from those listed on the table. Example: If you select "normal pond use" you could select a concentration of 0.025 part per million.

2. Computation of Flow Rate for Stream

Select a cross section of the stream where the banks and bottom are relatively smooth and free of obstacles. Divide the surface width into 3 equal sections and determine the water depth and surface velocity at the center of each section. In slowly moving streams, determine the velocity by dropping a float attached to 5 feet of loose monofilament fishing line. Measure the time required for the float to move 5 feet. For fast-moving streams, use a longer distance. Take at least three readings at each point. To calculate the flow rate from the information obtained above, use the following formula:

$$F = \frac{Ws \times D \times L \times C}{T}$$

Where F = flow rate (cubic feet/second), Ws = surface width (feet), D = mean depth (feet), L = mean distance traveled by float (feet), C = constant (0.8 for rough bottoms and 0.9 for smooth bottoms), and T = mean time for float (sec.).3.

Calculation of Application Rate

In order to calculate the application rate (expressed as gallons/second), you convert the rate in the table (expressed as gallons/acre-feet), to gallons per cubic feet and multiply by the flow rate (expressed as cubic feet/second). Depending on the size of the stream and the type of equipment, the rate could be expressed in other units, such as ounces/hour, or cc/minute.

The application rate for the stream is calculated as follows:

$$R_s = R_p * C * F$$

where R_s = application rate for stream (gallons/second), R_p = application rate for pond (gallons/acre-feet), C = 1 acre foot/43560 cubic feet, and F = flow rate of the stream (cubic feet/second).

4. Exposure Time

The exposure time would be the period of time (expressed in hours or minutes) during which Prentox Prenfish Toxicant is applied to the stream in order to prevent target fish from escaping from the pond into the stream corridor.

5. Amount of Product

Calculate the amount of product for a stream by multiplying the application rate for streams by the exposure time.

$$A = R_s * H$$

where A = the amount of product for the stream application, R_s = application rate for stream (gallons/second), and H = the exposure time expressed in seconds.

For use in Streams and Rivers

Only state or federal Fish and Wildlife personnel or professional fisheries biologists under the authorization of state or federal Fish and Wildlife Agencies are permitted to make applications of Prentox Prenfish Toxicant for control of fish in streams and rivers. Informal consultation with Fish and Wildlife personnel regarding the potential occurrence of endangered species in areas to be treated should take place. Applicators must reference Prentiss Incorporated's Prentox Prenfish Toxicant Stream and River Use Monograph before making any application to streams or rivers.

Warranty Statement: Our recommendations for the use of this product are based upon tests believed to be reliable. The use of this product being beyond the control of the manufacturer, no guarantee, expressed or implied, is made as to the effects of such or the results to be obtained if not used in accordance with directions or established safe practice. The buyer must assume all responsibility, including injury or damage, resulting from its misuse as such, or in combination with other materials.

PRENTOX® PRENFISH TOXICANT STREAM AND RIVER USE MONOGRAPH

USE IN STREAMS AND RIVERS

The following use directions are to provide guidance on how to make applications of Prentox Prenfish Toxicant to streams and rivers. The unique nature of every application site could require minor adjustments to the method and rate of application. Should these unique conditions require major deviation from the use directions, a Special Local Need 24(c) registration should be obtained from the state.

Before applications of Prentox Prenfish Toxicant can be made to streams and rivers, authorization must be obtained from state or federal Fish and Wildlife agencies. Since local environmental conditions will vary, consult with the state Fish and Wildlife agency to ensure the method and rate of application are appropriate for that site.

Contact the local Water Department to determine if any water intakes are within one mile down flow of the section of stream, river or canal to be treated. If so, coordinate the application with the water department to make sure the intakes are closed during treatment and detoxification.

Application Rates and Concentration of Rotenone

Slow Moving Rivers: Apply rotenone as a drip for 4 to 8 hours to the flowing portion of the stream. Multiple application sites are used along the length of the treated stream, spaced approximately 1/2 to 2 miles apart depending on the water flow travel time between sites. Multiple sites are used because rotenone is diluted and detoxified with distance. Application sites are spaced at no more than 2 hours or at no less than 1 hour travel time intervals. This assures that the treated stream remains lethal to fish for a minimum of 2 hours. A non-toxic dye such as Rhodamine-WT® or fluorescein can be used to determine travel times. Cages containing live fish placed immediately upstream of the downstream application sites can be used as sentinels to assure that lethal conditions exist between sites.

Apply rotenone at each application site at a concentration of 0.25 to 1.0 part per million of Prentox Prenfish Toxicant. The amount of Prentox Prenfish Toxicant needed at each site is dependent on stream flow (see Computation of Flow Rate for Stream).

Application of Undiluted Material

Prentox Prenfish Toxicant can drain directly into the center of the stream at a rate of 0.85 to 2.4 cc per minute for each cubic foot per second of stream flow. Flow of undiluted Prentox Prenfish Toxicant into the stream should be checked at least hourly. This is equivalent to from 0.25 to 1.0 ppm Prentox Prenfish Toxicant, or from 0.012 to 0.050 ppm rotenone. Back-water, stagnant and spring areas of streams should be sprayed by hand with a 10% v/v solution of Prentox Prenfish Toxicant in water to assure a complete coverage.

Calculation of Application Rate:

$$X = F(1.69\ B)$$

X = cc per minute of Prentox Prenfish Toxicant applied to the stream, F = the flow rate (cu. ft./sec.) see Computation of Flow Rate for Stream section of the label, B = parts per million desired concentration of Prentox Prenfish Toxicant.

Total Amount of Product Needed for Treatment: Streams should be treated for 4 to 8 hours in order to clear the treated section of stream of fish. To determine the total amount of Prentox Prenfish Toxicant required use the following equation:

$$Y = X(0.0158\ C)$$

Y = gallons of Prentox Prenfish Toxicant required for the stream treatment, X = cc per minute of Prentox Prenfish Toxicant applied to the stream, C = time in hours of the stream treatment.

Application of Diluted Material

Alternatively, for stream flows up to 25 cubic feet per minute, continuous drip of diluted Prentox Prenfish Toxicant at 80 cc per minute can be used. Flow of diluted Prentox Prenfish Toxicant into the stream should be checked at least hourly. Use a 5 gallon reservoir over a 4 hour period, a 7.5 gallon reservoir over a 6 hour period, or a 10 gallon reservoir over an 8 hour period. The volume of the reservoir can be determined from the equation:

$$R = H * 1.25$$

where R = the volume of the reservoir in gallons, and H = the duration of the application in hours.

The volume of Prentox Prenfish Toxicant diluted with water in the reservoir is determined from the equation:

$$X = Y(102\ F)H$$

where X = the cc of Prentox Prenfish Toxicant diluted in the reservoir, Y = parts per million desired concentration of Prentox Prenfish Toxicant, F = the flow rate (cubic feet/second), H = the duration of the application (hours).

For flows over 25 cubic feet per minute, additional reservoirs can be used concurrently. Back-water, stagnant and spring areas of streams should be sprayed by hand with a 10% v/v solution of Prentox Prenfish Toxicant in water to assure a complete coverage.

Detoxification

To limit effects downstream, detoxification with potassium permanganate can be used at the downstream limit of the treated area. Within 1/2 to 2 miles of the furthest downstream Prentox Prenfish Toxicant application site, the rotenone can be detoxified with a potassium permanganate solution at a resultant stream concentration of 2 to 4 parts per million, depending on rotenone concentration and permanganate demand of the water. A 2.5% (10 pounds potassium permanganate to 50 gallons of water) permanganate solution is dripped in at a continuous rate using the equation:

$$X = Y(70\ F)$$

where X = cc of 2.5% permanganate solution per minute, Y = ppm of desired permanganate concentration, and F = cubic feet per second of stream flow.

Flow of permanganate should be checked at least hourly. Live fish in cages placed immediately above the permanganate application site will show signs of stress signaling the need for beginning detoxification. Detoxification can be terminated when replenished fish survive and show no signs of stress for at least four hours.

Detoxification of rotenone by permanganate requires between 15 to 30 minutes contact time (travel time). Cages containing live fish can be placed at these downstream intervals to judge the effectiveness of detoxification. At water temperature of less than 50° F detoxification may be retarded, requiring a longer contact time.

STOP

Adhesive Panel

RESTRICTED USE PESTICIDE
DUE TO AQUATIC AND ACUTE INHALATION TOXICITY
For retail sale to, and use only by, Certified Applicators or persons under their direct supervision and only for those uses covered by the Certified Applicator's certification.

PRENFISH TOXICANT

Liquid Emulsifiable

*For Control of Fish in Lakes, Ponds, Reservoirs and Streams

ACTIVE INGREDIENTS:	
Rotenone	5.0%
Other Associated Resins	5.0%
INERT INGREDIENTS*:	90.0%
TOTAL	100.0%

*This product contains aromatic hydrocarbons.
PRENTOX® - Registered Trademark of Prentiss Incorporated

KEEP OUT OF REACH OF CHILDREN

DANGER - POISONOUS

See inside booklet for additional precautionary statements.

FIRST AID
Have product container or label with you when obtaining treatment advice.

If swallowed	• Call a physician, Poison Control Center, or the National Pesticide Information Center at 1-800-858-7378 immediately for treatment advice. • Do not induce vomiting unless told to do so by the Poison Control Center or physician. • Do not give any liquid to the person. • Do not give anything by mouth to an unconscious or convulsing person.
If inhaled	• Remove victim to fresh air. • If not breathing, give artificial respiration, preferably mouth-to-mouth. • Call a physician, Poison Control Center, or the National Pesticide Information Center at 1-800-858-7378 immediately for treatment advice.
If in eyes	• Hold eyelids open and rinse slowly and gently with water for 15-20 minutes. • Remove contacts, if present, after the first 5 minutes, then continue rinsing eye. • Call a physician, Poison Control Center, or the National Pesticide Information Center at 1-800-858-7378 immediately for treatment advice.
If on skin or clothing	• Take off contaminated clothing. • Rinse skin immediately with plenty of water for 15-20 minutes. • Call a physician, Poison Control Center, or the National Pesticide Information Center at 1-800-858-7378 immediately for treatment advice.

For information on this pesticide product (including health concerns, medical emergencies, or pesticide incidents), call the National Pesticide Information Center at 1-800-858-7378.

EPA Reg. No. 655-422 9/02 EPA Est. No. 655-GA-1

Manufactured by:

PRENTISS INCORPORATED
Plant: Kaolin Road, Sandersville, GA 31082
Office: C.B. 2000, Floral Park, NY 11002-2000

SAMPLE

Synpren-fish® Toxicant (2.5% active rotenone)

RESTRICTED USE PESTICIDE
DUE TO AQUATIC AND ACUTE INHALATION TOXICITY
For retail sale to, and use only by, Certified applicators or persons under their direct supervision and only for those uses covered by the Certified Applicator's certification

SYNPREN-FISH TOXICANT

Liquid-Emulsifiable
***For Control of Fish in Lakes, Ponds, Reservoirs and Streams**

ACTIVE INGREDIENTS:	
Rotenone	2.5% w/w
Other Associated Resins	5.0%
Piperonyl Butoxide, Technical*	2.5%
INERT INGREDIENTS:**	90.0%
TOTAL:	100.0%

*Equivalent to 2.0% [Butylcarbityl] [6-propylpiperonyl] ether and 0.5% related compounds.
**This product contains aromatic petroleum solvents.

PRENTOX® - Registered Trademark of Prentiss Incorporated

KEEP OUT OF REACH OF CHILDREN

DANGER – POISONOUS

See Additional Precautionary Statements Below.

FIRST AID
Have product container or label with you when obtaining treatment advice.

If swallowed	• Call a poison control center, doctor, or the National Pesticide Information Center at 1-800-858-7378 immediately for treatment advice. • Have person sip a glass of water if able to swallow. • Do not induce vomiting unless told to do so by the poison control center or doctor.
If on skin or clothing	• Take off contaminated clothing. • Rinse skin immediately with plenty of water for 15-20 minutes. • Call a poison control center, doctor, or the National Pesticide Information Center at 1-800-858-7378 immediately for treatment advice.
If inhaled	• Move person to fresh air. • If person is not breathing, call an ambulance, then give artificial respiration, preferably mouth-to-mouth, if possible. • Call a poison control center, doctor, or the National Pesticide Information Center at 1-800-858-7378 immediately for treatment advice.
If in eyes	• Hold eye open and rinse slowly and gently with water for 15-20 minutes. • Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. • Call a poison control center, doctor, or the National Pesticide Information Center at 1-800-858-7378 immediately for treatment advice.

For information on this pesticide product (including health concerns, medical emergencies, or pesticide incidents), call the National Pesticide Information Center at 1-800-858-7378.

PRECAUTIONARY STATEMENTS
HAZARDS TO HUMANS AND DOMESTIC ANIMALS
DANGER

Fatal if inhaled. May be fatal if swallowed. Harmful if absorbed through skin. Causes substantial but temporary eye injury. Causes skin irritation. Do not breathe spray mist. Do not get in eyes, on skin or on clothing. Wear goggles or safety glasses. When working with undiluted product, wear either a respirator with an organic-vapor-removing cartridge with a prefilter approved for pesticides (MSHA/NIOSH approval number prefix TC-23C), or a canister approved for pesticides (MSHA/NIOSH approval number prefix TC-14G), or a NIOSH approved respirator with an organic vapor (OV) cartridge or canister with any R, P or HE prefilter. Wash thoroughly with soap and water after handling and before eating, drinking or using tobacco. Remove contaminated clothing and wash before reuse.

ENVIRONMENTAL HAZARDS

This pesticide is extremely toxic to fish. Fish kills are expected at recommended rates. Consult your State Fish and Game Agency before applying this product to public waters to determine if a permit is needed for such an application. Do not contaminate untreated water when disposing of equipment washwaters.

CHEMICAL AND PHYSICAL HAZARDS

Combustible mixture. Flash point of this formulation is 115° F. DO NOT USE OR STORE NEAR HEAT OR OPEN FLAME.

E.P.A. REG. NO. 655-421 **5/01** **E.P.A. EST. NO. 655-GA-1**

Manufactured by:

PRENTISS INCORPORATED

Plant: Kaolin Road, Sandersville, GA 31082
Office: C.B. 2000, Floral Park, NY 11002-2000

STORAGE AND DISPOSAL

Do not contaminate water, food or feed by storage or disposal.

Storage: Store only in original containers, in a dry place inaccessible to children and pets. Prentox Synpren-Fish Toxicant will not solidify nor show any separation at temperatures down to 40° F and is stable for a minimum of one year when stored in sealed drums at 70° F.

Pesticide Disposal: Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide, spray mixture, or rinsate is a violation of Federal law. If these wastes cannot be disposed of by use according to label instructions contact your state pesticide or Environmental Control Agency, or the Hazardous Waste representative at the nearest EPA Regional Office for guidance.

Container Disposal: Triple rinse (or equivalent). Then offer for recycling or reconditioning, or puncture and dispose of in a sanitary landfill, or by other procedures approved by state and local authorities.

SAMPLE

DIRECTIONS FOR USE

It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

General Information

Prentox Synpren-Fish Toxicant is a specially formulated product containing synergized rotenone, to be used in fisheries management for the eradication of fish from lakes, ponds, reservoirs and streams. Since such factors as pH, temperature, depth and turbidity will change effectiveness, use this product only at locations, rates, and times authorized and approved by appropriate state and federal fish and wildlife agencies. Rates must be within the range specified on the label.

Properly dispose of unused product. Do not use dead fish for food or feed.

Do not use water treated with rotenone to irrigate crops or release within 1/2 mile upstream of a potable water or irrigation water intake in a standing body of water such as a lake, pond or reservoir.

RE-ENTRY STATEMENT: Do not allow swimming in rotenone-treated water until the application has been completed and all pesticide has been thoroughly mixed into the water according to labeling instructions.

For Use in Ponds, Lakes and Reservoirs

The actual application rates and concentrations of rotenone needed to control fish will vary widely, depending on the type of use (e.g., selective treatment, normal pond use, etc.) and the factors listed above. The table below is a general guide for the proper rates and concentrations. Prentox Synpren-Fish Toxicant disperses readily in water both laterally and vertically, and will penetrate below the thermocline in thermally stratified bodies of water.

Computation of Acre-Feet: An acre-foot is a unit of volume of a body of water having the area of one acre and the depth of one foot. To determine acre feet in a given body of water, make a series of transects across the body of water taking depths with a measured pole or weighted line. Add the soundings and divide by the number made to determine the average depth. Multiply this average depth by the total surface area in order to determine the acre-feet to be treated. If number of surface acres is unknown, contact your local Soil Conservation Service, which can determine this from aerial photographs.

Amount of Prentox Synpren-Fish Toxicant Needed for Specific Uses: To determine the approximate number of gallons of Prentox Synpren-Fish Toxicant (2.5% Rotenone) needed, find your "Type of Use" in the first column of the table below, and then divide the corresponding numbers in the third column, "Number of Acre-Feet Covered by One Gallon" into the number of acre-feet in your body of water.

General Guide to the Application Rates and Concentrations of Rotenone Needed to Control Fish in Lakes, Ponds and Reservoirs[1]

Type of Use	Parts Per Million		Number of Acre-Feet Covered by One Gallon
	Synpren-Fish Toxicant	Active Rotenone	
Selective Treatment	0.20 to 0.25	0.005 to 0.007	15 to 12
Normal Pond Use	1.0 to 2.0	0.025 to 0.050	3.0 to 1.5
Remove bullheads or carp	2.0 to 4.0	0.050 to 0.100	1.5 to 0.75
Remove bullheads or carp in rich organic ponds	4.0 to 8.0	0.100 to 0.200	0.75 to 0.38
Preimpoundment treatment above dam	6.0 to 10.0	0.150 to 0.250	0.50 to 0.30

[1] Adapted from Kinney, Edward. 1965. Rotenone in Fish Pond Management. USDI Washington, D.C. Leaflet FL-576

Pre-Mix and Method of Application: Pre-mix with water at a rate of one gallon Prentox Synpren-Fish Toxicant to 10 gallons of water. Uniformly apply over water surface or bubble through underwater lines.

Detoxification: Prentox Synpren-Fish Toxicant treated waters detoxify under natural conditions within one week to one month depending upon temperatures, alkalinity, etc. Rapid detoxification can be accomplished by adding chlorine or potassium permanganate to the water at the same rate as Prentox Synpren-Fish Toxicant in parts per million, plus enough additional to meet the chlorine demand of the untreated water.

Removal of Taste and Odor: Prentox Synpren-Fish Toxicant treated waters do not retain a detectable taste or odor for more than a few days to a maximum of one month. Taste and odor can be removed immediately by treatment with activated charcoal at a rate of 30 ppm for each 1 ppm Prentox Synpren-Fish Toxicant remaining. (Note: As Prentox Synpren-Fish Toxicant detoxifies, less charcoal is required.)

Restocking After Treatment: Wait 2 to 4 weeks after treatment. Place a sample of fish to be stocked in wire cages in the coolest part of the treated waters. If the fish are not killed within 24 hours, the water may be restocked.

Use in Streams Immediately Above Lakes, Ponds, and Reservoirs

The purpose of treating streams immediately above lakes, ponds and reservoirs is to improve the effectiveness of lake, pond and reservoir treatments by preventing target fish from moving into the stream corridors, and not to control fish in streams per se. The term "immediately" means the first available site above the lake, pond or reservoir where treatment is practical, while still creating a sufficient barrier to prevent migration of target fish into the stream corridor.

In order to completely clear a fresh water aquatic habitat of target fish, the entire system above or between fish barriers must be treated. See the use directions for streams and rivers on this label for proper application instructions.

In order to treat a stream immediately above a lake, pond or reservoir, you must: (a) select the concentration of active rotenone, (b) compute the flow rate of the stream, (c) calculate the application rate, (d) select an exposure time, (e) estimate the amount of product needed, (f) follow the method of application. To prevent movement of fish from the pond, lake or reservoir, stream treatment should begin before and continue throughout treatment of pond, lake or reservoir until mixing has occurred.

1. Concentration of Active Rotenone:

Select the concentration of active rotenone based on the type of use from those listed on the table. Example: If you select "normal pond use" you could select a concentration of 0.025 part per million.

2. Computation of Flow Rate for Stream:

Select a cross section of the stream where the banks and bottom are relatively smooth and free of obstacles. Divide the surface width into 3 equal sections and determine the water depth and surface velocity at the center of each section. In slowly moving streams, determine the velocity by dropping a float attached to 5 feet of loose, monofilament fishing line. Measure the time required for the float to move 5 feet. For fast-moving streams, use a longer distance. Take at least three readings at each point. To calculate the flow rate from the information obtained above, use the following formula:

$$F = \frac{Ws \times D \times L \times C}{T}$$

where F = flow rate (cubic feet/second), Ws = surface width (feet), D = mean depth (feet), L = mean distance traveled by float (feet), C = constant (0.8 for rough bottoms and 0.9 for smooth bottoms), and T = mean time for float (sec.).

3. Calculation of Application Rate:

In order to calculate the application rate (expressed as gallons/second), you convert the rate in the table (expressed as gallons/acre-feet), to gallons per cubic feet and multiply by the flow rate (expressed as cubic feet/second). Depending on the size of the stream and the type of equipment, the rate could be expressed in other units, such as ounces/hour, or cc/minute. The application rate for the stream is calculated as follows:

$$R_s = R_p * C * F$$

where R_s = application rate for stream (gallons/second), R_p = application rate for pond (gallons/acre-feet), C = 1 acre foot/43560 cubic feet, and F = flow rate of the stream (cubic feet/second).

4. Exposure Time:

The exposure time would be the period of time (expressed in hours or minutes) during which Prentox Synpren-Fish Toxicant is applied to the stream in order to prevent target fish from escaping from the pond into the stream corridor.

5. Amount of Product:

Calculate the amount of product for a stream by multiplying the application rate for streams by the exposure time.

$$A = R_s * H$$

where A = the amount of product for the stream application, R_s = application rate for stream (gallons/second), and H = the exposure time expressed in seconds. require major deviation from these use directions a Special Local Need 24(c) registration should be obtained from the state.

Before applications of Prentox Synpren-Fish Toxicant can be made to streams and rivers, authorization must be obtained from state or federal Fish & Wildlife agencies. Since local environmental conditions will vary, consult with the state Fish & Wildlife agency to ensure the method and rate of application are appropriate for that site.

Contact the local water department to determine if any water intakes are (within one mile) down flow of the section of stream, river or canal to be treated. If so, coordinate the application with the

For Use in Streams and Rivers

Only state or federal Fish & Wildlife personnel or professional fisheries biologists under the authorization of state or federal Fish & Wildlife agencies are permitted to make applications of Prentox Synpren-Fish Toxicant for control of fish in streams and rivers. Informal consultation with Fish & Wildlife personnel regarding the potential occurrence of endangered species in areas to be treated should take place. Applicators must reference Prentiss Incorporated's Prentox Synpren-Fish Toxicant Stream and River Use Monograph before making any application to streams or rivers.

Warranty Statement: Our recommendations for the use of this product are based upon tests believed to be reliable. The use of this product being beyond the control of the manufacturer, no guarantee, expressed or implied, is made as to the effects of such or the results to be obtained if not used in accordance with directions or established safe practice. The buyer must assume all responsibility, including injury or damage, resulting from its misuse as such, or in combination with other materials. **PRENTOX® SYNPREN-FISH TOXICANT**

STREAM AND RIVER MONOGRAPH

USE IN STREAMS AND RIVERS

The following use directions are to provide guidance on how to make applications of Prentox Synpren-Fish Toxicant to streams and rivers. The unique nature of every application site could require minor adjustments to the method and rate of application. Should these unique conditions

water department to make sure the intakes are closed during treatment and detoxification.

Application Rates and Concentration of Rotenone

Slow Moving Rivers: In slow moving rivers and streams with little or no water exchange use instructions for ponds, lakes and reservoirs.

Flowing Streams and Rivers: Apply rotenone as a drip for 4 to 8 hours to the flowing portion of the stream. Multiple application sites are used along the length of the treated stream, spaced approximately 1/2 to 2 miles apart depending on the water flow travel time between sites. Multiple sites are used because rotenone is diluted and detoxified with distance. Application sites are spaced at no more than 2 hours or at no less than 1 hour travel time intervals; this assures that the treated stream remains lethal to fish for a minimum of 2 hours. A non-toxic dye such as Rhodamine-WT® or fluorescein can be used to determine travel times. Cages containing live fish placed immediately upstream of the downstream application sites can be used as sentinels to assure that lethal conditions exist between sites.

Apply rotenone at each application site at a concentration of 0.5 to 2.0 parts per million of Prentox Synpren-Fish Toxicant. The amount of Prentox Synpren-Fish Toxicant needed at each site is dependent on stream flow (see Computation of Flow Rate for Stream).

Application of Undiluted Material

Prentox Synpren-Fish Toxicant can drain directly into the center of the stream at a rate of 0.85 to 2.4 cc per minute for each cubic foot per second of stream flow. Flow of undiluted Prentox Synpren-Fish Toxicant into the stream should be checked at least hourly. This is equivalent to from 0.5 to 2.0 ppm Prentox Synpren-Fish Toxicant, or from 0.012 to 0.050 ppm rotenone.

Back-water, stagnant and spring areas of streams should be sprayed by hand with a 10% v/v solution of Prentox Synpren-Fish Toxicant in water to assure a complete coverage.

Calculation of Application Rate:

$$X = F (1.692 B)$$

where X = cc per minute of Prentox Synpren-Fish Toxicant to the stream F = the flow rate (cu. ft/sec) (see *Computation of Flow Rate for Stream* section of the label) and B = parts per million desired concentration of Prentox Synpren-Fish Toxicant.

Total Amount of Product Needed for Treatment: Streams should be treated for 4 to 8 hours in order to clear the treated section of stream of fish. To determine the total amount of Prentox Synpren-Fish Toxicant required, use the following equation:

$$Y = X(0.0158C)$$

Y = gallons of Prentox Synpren-Fish Toxicant required for the stream treatment, X = cc per minute of Prentox Synpren-Fish Toxicant applied to the stream, C = time in hours of the stream treatment.

Application of Diluted Material

Alternatively, for stream flows up to 25 cubic feet per minute, continuous drip of diluted Prentox Synpren-Fish Toxicant at 80 cc per minute can be used. Flow of diluted Prentox Synpren-Fish Toxicant into the stream should be checked at least hourly. Use a 5 gallon reservoir over a 4 hour period, a 7.5 gallon reservoir over a 6 hour period, or a 10 gallon reservoir over an 8 hour period. The volume of the reservoir can be determined from the equation:

$$R = H * 1.25$$

where R = the volume of the reservoir in gallons, and H = the duration of the application in hours.

The volume of Prentox Synpren-Fish Toxicant diluted with water in the reservoir is determined from the equation:

$$X = Y(102\ F)H$$

where X = the cc of Prentox Synpren-Fish Toxicant diluted to 5 gallons, Y = parts per million desired concentration of Prentox Synpren-Fish Toxicant, F = the flow rate (cubic feet/second), H = the duration of the application (hours).

For flows over 25 cubic feet per minute, additional reservoirs can be used concurrently. Back-water, stagnant and spring areas of streams should be sprayed by hand with a 10% v/v/ solution of Prentox Synpren-Fish Toxicant in water to assure a complete coverage.

Detoxification

To limit effects downstream, detoxification with potassium permanganate can be used at the downstream limit of the treated area. Within 1/2 to 2 miles of the furthest downstream Prentox Synpren-Fish Toxicant application site, the rotenone can be detoxified with a potassium permanganate solution at a resultant stream concentration of 2 to 4 parts per million, depending on rotenone concentration and permanganate demand of the water. A 2.5% (10 pounds potassium permanganate to 50 gallons of water) permanganate solution is dripped in at a continuous rate using the equation:

$$X = Y(70\ F)$$

where X = cc of 2.5% permanganate solution per minute, Y = ppm of desired permanganate concentration, and F = cubic feet per second of stream flow.

Flow of permanganate should be checked at least hourly. Live fish in cages placed immediately above the permanganate application site will show signs of stress signaling the need for beginning detoxification. Detoxification can be terminated when replenished fish survive and show no signs of stress for at least four hours.

Detoxification of rotenone by permanganate requires between 15 to 30 minutes contact time (travel time). Cages containing live fish can be placed at these downstream intervals to judge the effectiveness of detoxification . Water temperature of less than 50 $^{\circ}$ F detoxification may be retarded, requiring a longer contact time.

SPECIMEN

PRECAUTIONARY STATEMENTS

HAZARDS TO HUMANS AND DOMESTIC ANIMALS

DANGER

Acute Hazards: Corrosive. Causes irreversible eye damage and skin burns. May be fatal if swallowed. Harmful if absorbed through skin.

Hazard Avoidance: Do not get in eyes, on skin, or on clothing. Do not breath dust. Wear protective clothing and protective eyewear as listed under "Personal Protective Equipment." Wash thoroughly with soap and water after handling and before eating or smoking. Remove contaminated clothing and wash before reuse.

PERSONAL PROTECTIVE EQUIPMENT (PPE):

Handlers who mix LAMPRICID Sea Lamprey Larvicide must wear:

- Coveralls over long-sleeved shirt and long pants
- Chemical-resistant gloves (such as butyl rubber)
- Chemical-resistant footwear plus socks
- Protective eyewear (goggles or face shield)

Applicators who apply diluted product must wear:

- Chemical-resistant gloves (such as butyl rubber)

USER SAFETY REQUIREMENTS:

Follow manufacturer's instructions for cleaning/maintaining PPE. If no such instructions are provided for washables, use detergent and hot water. Keep and wash PPE separately from other laundry.

USER SAFETY RECOMMENDATIONS:

Users should wash hands before eating, drinking, chewing gum, using tobacco, or using the toilet.

Users should remove clothing immediately if pesticide gets inside. Then wash thoroughly and put on clean clothing.

Users should remove PPE after handling this product. As soon as possible, wash thoroughly and change into clean clothing.

ENVIRONMENTAL HAZARDS

This product is toxic to fish and aquatic invertebrates. Nontarget aquatic organisms may be killed at rates recommended on this label. Directions for Use must be strictly followed to minimize hazard to non-target organisms. Do not contaminate water by cleaning of equipment or disposal of wastes.

Not to be used by unauthorized personnel. Nr. 2039

RESTRICTED USE PESTICIDE

DUE TO ACUTE HAZARDS TO THE EYE AND SKIN AND TO NONTARGET AQUATIC ORGANISMS, NEED FOR HIGHLY SPECIALIZED APPLICATOR TRAINING, AND NEED FOR SPECIALIZED EQUIPMENT.

ONLY FOR SALE TO AND APPLICATION BY CERTIFIED APPLICATORS OF THE U.S. FISH AND WILDLIFE SERVICE, FISHERIES AND OCEANS CANADA, AND PROVINCIAL AND STATE FISH AND GAME EMPLOYEES OR PERSONS UNDER THEIR DIRECT SUPERVISION.

LAMPRICID

SEA LAMPREY LARVICIDE

ACTIVE INGREDIENT:	
a,a,a -Trifluoro-4-Nitro-m-Cresol, Sodium Salt*:	38.0%
INERT INGREDIENTS:	62.0%
TOTAL:	100.0%

*Equivalent to [34.4%] a,a,a -Trifluoro-4-Nitro-m-Cresol

THIS PRODUCT CONTAINS 3.8 LBS OF SODIUM TFM PER GALLON

EPA Reg. No. 6704-45
EPA Est. No. 002-384-NJ-001

KEEP OUT OF REACH OF CHILDREN
DANGER - POISON

FIRST AID

Have label with you when obtaining treatment advice.

IF SWALLOWED	• Call a poison control center or doctor immediately for treatment advice. • Have person sip a glass of water if able to swallow. • Do not induce vomiting unless told to do so by the poison control center or doctor.
IF ON SKIN OR CLOTHING	• Take off contaminated clothing. • Rinse skin immediately with plenty of water for 15-20 minutes. • Call a poison control center or doctor immediately for treatment advice.
IF INHALED	• Move person to fresh air. • If person is not breathing, call an ambulance, then give artificial respiration, preferably mouth-to-mouth, if possible. • Call a poison control center or doctor immediately for treatment advice.
IF IN EYES	• Hold eye open and rinse slowly and gently with water for 15-20 minutes. • Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. • Call a poison control center or doctor immediately for treatment advice.

Manufactured by:	for: Fish and Wildlife Service
Pfister Chemical Inc.	United States Department of Interior,
Linden Ave.	18th and C Streets, N.W.
Ridgefield, NJ 07657	Washington, D.C. 120240

DIRECTIONS FOR USE

It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

CATEGORY OF APPLICATOR:
Aquatic Pest Control.

USE RESTRICTIONS:
For control of Sea Lamprey Larvae (*Petromyzon marinus*) in the Great Lakes Basin, the Lake Champlain system and the Finger Lakes.

Aerial applications of this product are prohibited.

PROTECTION OF DRINKING WATER:
Local, State, and Provincial Fish and Game Agencies must be contacted before product is applied. Municipalities that use streams requiring treatment as potable water sources must be notified of the impending treatment at least 24 hours prior to application. Agricultural irrigators that use streams requiring treatment as a source of irrigation water must be notified of the impending treatment at least 24 hours prior to application. Agricultural irrigators must turn off their irrigation system for a 24-hour period during and after treatment. Prior to use of any water potentially having residues must be tested for the presence of TFM. Water must not be used if there are any detectable residues of TFM.

PRETREATMENT DIRECTIONS:
Pretreatment surveys are always made to determine abundance of sea lamprey larvae (*Petromyzon marinus*). All waters in the Great Lakes Basin, the Lake Champlain system, and the Finger Lakes selected for treatment must first be analyzed on site to determine both the minimum concentration of LAMPRICID required to kill sea lamprey larvae and the maximum concentration that can be applied without causing undue mortality of non-target organisms. "Analysis" constitutes live animal toxicity tests, or the use of a multiple regression relating toxicity test results to on-site determination of total alkalinity and pH of the body of water.

APPLICATION DIRECTIONS:
When applying this product, do not apply in a way that will cause the concentrated product to contact unprotected workers or other persons, either directly or through drift.

Persons applying LAMPRICID must follow the Standard Operating Procedure for Application of Lampricides in the Great Lakes Fishery Commission's Integrated Management of Sea Lamprey (*Petromyzon marinus*) Control Program, and ensure that the correct application rates are used. Prior to and during the application of this chemical, take appropriate actions to notify public water users including notification actions specified in this manual.

The concentration of LAMPRICID needed to kill sea lamprey larvae may vary depending upon water chemistry. Measure volume or flow-rate and add the amount of LAMPRICID necessary at rates based on the foregoing analysis. Dispense LAMPRICID by application devices sufficiently accurate to maintain predetermined concentration. Concentration in the body of water must be monitored either by colorimetric analysis, gas chromatography, or high-performance liquid chromatography. LAMPRICID may be used by itself in the treatment of waters in the Great Lakes Basin, the Lake Champlain system, and the Finger Lakes. At times, however, formulations of Bayluscide (EPA REG. NO. 6704-88) may be used in combination with LAMPRICID (EPA REG. NO. 6704-45) for control of sea lamprey larvae. Application of Bayluscide may be as a simultaneous addition with LAMPRICID to reduce the amount of LAMPRICID required or as a subsequent addition downstream to enhance LAMPRICID larvicidal activity. Prior to using Bayluscide-LAMPRICID, pretreatment surveys must be made to determine larvae populations. When using Bayluscide in combination with LAMPRICID, mix in proportions that result in a final concentration of Bayluscide of not more than 2% of LAMPRICID by weight (based on active ingredient). Bayluscide may be added to LAMPRICID in two ways:

1. One method of application is to apply both lampricides at the primary application site. LAMPRICID is metered into the stream while Bayluscide is applied with a separate pump system in amounts calculated to deliver the desired ratio of Bayluscide to LAMPRICID. Bayluscide is applied separately to provide a uniform application and to enhance control of concentration.

2. A second application method is to apply Bayluscide into an existing LAMPRICID bank. Because a LAMPRICID bank can be diluted by ground water, swamp seepage, untreated tributaries, occasional rain, or other conditions that cannot be included when the application rates are calculated, the toxicity of the bank in the stream must be raised by the addition of LAMPRICID or Bayluscide. The latter may be used in place of LAMPRICID. In these situations, LAMPRICID alone is pumped into the stream at the primary application site. Bayluscide is introduced into the LAMPRICID bank at a point or points downstream in amounts calculated to produce the desired Bayluscide to TFM ratio.

STORAGE AND DISPOSAL

Do not contaminate water, food or feed by storage or disposal. Open dumping is prohibited.

STORAGE: Store only in original container, in a dry place inaccessible to children, pets, and domestic animals.

SPILLS: Handle and open container in a manner that will prevent spillage. If the container is leaking or material is spilled for any reason or cause, contain spill with a barrier of absorbent material. Refer to Precautionary Statements on label for hazards associated with the handling of this material. Do not walk through spilled material. Dispose of pesticide as directed below. In spill or leak incidents, keep unauthorized people away. For decontamination procedures or any other assistance that may be necessary, contact Chemtrec at 1-800-424-9300.

PESTICIDE DISPOSAL: LAMPRICID spray mixture or rinsate that cannot be used or chemically reprocessed should be disposed of in a landfill approved for pesticides or buried in a safe place away from water supplies.

CONTAINER DISPOSAL: Triple rinse (or equivalent) container and then offer for recycling, reconditioning, or disposal in approved landfill or bury in a safe place. Consult federal, provincial, state, or local authorities for approved alternative procedures.

TFM Bar (23% Active TFM)

[Front Panel]

RESTRICTED USE PESTICIDE

Due to Acute Eye Irritation, Acute Oral Toxicity and Aquatic Organism Toxicity, Need for Specialized Equipment and Highly Specialized Applicator Training.

For retail sale to, and use only by, USDI, FWS, State Fish and Game, Fisheries and Oceans Canada, and Provincial Certified Applicators trained in sea lamprey control or persons under their direct supervision.

TFM BAR

Active Ingredient:	
TFM, α,α,α-Trifluoro-4-Nitro-m-Cresol, Free Cresol	23.0%
Inert Ingredients:	77.0%
TOTAL:	100.0%

KEEP OUT OF REACH OF CHILDREN

DANGER

FIRST AID

Have label with you when obtaining treatment advice.

If swallowed	• Call a poison control center or doctor immediately for treatment advice • Have person sip a glass of water, if able to swallow • Do not induce vomiting unless told to do so by poison control center or doctor
If on skin or clothing	• Take off contaminated clothing. • Rinse skin immediately, with plenty of water, for 15-20 minutes. • Call a poison control center or doctor immediately for treatment advice.

[Front Panel]

If inhaled	• Move person to fresh air. • If person is not breathing, call an ambulance, then give artificial respiration, preferably mouth-to-mouth, if possible. • Call a poison control center or doctor immediately for treatment advice.
If in eyes	• Hold eye open and rinse slowly and gently with water for 15-20 minutes. • Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. • Call a poison control center or doctor immediately for treatment advice.
Hot Line Number: You may also contact 1-800-858-7378 for health concerns, emergency medical treatment information of pesticide incidents	

See Left Panel for additional precautionary statements.

Manufactured by:

Bell Laboratories
Madison, WI 53704

Manufactured For:

Fish and Wildlife Service
United States Department of Interior
18th and C Streets, NW
Washington, DC 20240

EPA Reg. No. 6704-86
EPA Establishment No. 12455-WI-01

Batch No. _____

Net Contents _____ lbs.

[Left Panel]

PRECAUTIONARY STATEMENTS

HAZARDS TO HUMANS AND DOMESTIC ANIMALS

DANGER

Acute Hazards: Corrosive. Causes irreversible eye damage. May be fatal if swallowed. Harmful if absorbed through skin or inhaled.

Hazard Avoidance: Do not get in eyes, on skin, or on clothing. Avoid breathing vapors. Wear protective clothing as listed under "Personal Protective Equipment." Wash thoroughly with soap and water after handling and before eating or smoking. Remove contaminated clothing and wash before reuse.

PERSONAL PROTECTIVE EQUIPMENT:

Handlers must wear:

- Protective eyewear (goggles, face shield, or safety glasses)
- Long-sleeved shirt and long pants
- Chemical-resistant gloves (such as Natural Rubber, selection Category A)
- Socks and shoes

[Left Panel]

User Safety Requirements:

Follow manufacturer's instructions for cleaning/maintaining PPE. If no such instructions are provided for washables, use detergent and hot water. Keep and wash PPE separately from other laundry.

User Safety Recommendations:

Users should wash hands before eating, drinking, chewing gum, using tobacco, or using the toilet.

Users should remove clothing immediately if pesticide gets inside. Then wash thoroughly and put on clean clothing.

Users should remove PPE immediately after handling this product. As soon as possible, wash thoroughly and change into clean clothing.

ENVIRONMENTAL HAZARDS

This chemical is toxic to fish and aquatic invertebrates. Nontarget organisms (such as freshwater clams and mussels) may be killed at recommended rates. Directions for use must be strictly followed to minimize hazards to non-target organisms. **Do not** contaminate water by the cleaning of equipment or disposing of equipment washwaters.

[Right Panel]

DIRECTIONS FOR USE

It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

READ THIS LABEL:

Read the entire label and Sea Lamprey Control Document No. SLC-92-001.3 [Standard Operating Procedures for Application of Lampricides in the Great Lakes Fishery Commission Integrated Management of Sea Lamprey (*Petromyzon marinus*) Control Program] for correct rates of application. This product must be used strictly in accordance with both the label's precautionary statements and applicable use directions, as well as with all applicable State and Federal laws and regulations.

GENERAL INFORMATION:

This product contains a fast-acting fish toxicant which kills sea lamprey larvae in 1-2 hours. The mode of action is uncoupling of oxidative phosphorylation. As many types of nontarget species are potentially vulnerable to TFM, it is necessary to use care and to follow the requirements of this label to minimize impacts.

USE RESTRICTIONS:

Use Pattern:

TFM Bars may be used for control of sea lamprey (*Petromyzon marinus*) in waters in the Great Lakes Basin, the Lake Champlain system and the Finger Lakes. Only apply this product according to this label.

Permits:

Obtain any permits needed from local, State, Provincial and Federal wildlife authorities.

Potable Water:

At least 24 hours prior to application, notify municipalities and agricultural irrigators that potable and irrigation water will be treated. Agricultural irrigators must turn off their irrigation systems for a 24-hour period during and after treatment. Prior to and during the application of this chemical, take all appropriate actions to notify public water users and municipalities including notification actions specified in the application manual referred to above.

[Right Panel]

Unauthorized Personnel:

May not be used by unauthorized personnel.

PRE-APPLICATION DIRECTIONS:

Pretreatment Surveys:

Pretreatment surveys are always made to determine abundance of sea lamprey larvae (*Petromyzon marinus*). All waters in the Great Lakes basin, Lake Champlain system and Finger Lakes that are selected for treatment must first be analyzed on site to determine both the minimum concentration of TFM required to kill sea lamprey larvae and the maximum concentration that can be applied without causing undue mortality of non-target organisms. "Analysis" constitutes live animal bioassays, or the use of multiple regression curves relating toxicity test results to on-site determination of pH or total alkalinity and conductivity of the body of water.

Lethal Concentration:

The concentration of TFM needed to kill a sea lamprey larvae may vary depending upon water chemistry and temperature. Measure volume or flow rate and add the amount of chemical necessary at rates based on the foregoing analysis. Concentration in the body of water must be monitored by spectrophotometric analysis or high performance liquid chromatography.

APPLICATION DIRECTIONS

Bar Placement: Suspend each bar at least one inch above the bottom of the stream to permit movement of water on all sides.

TFM Delivery Rate: When submerged in water, TFM bars dissolve in approximately 8 to 10 hours at 17 °C and 10 to 12 hours at 12 °C in current velocities 0.09 to 0.12 meter/sec. More rapid velocities will cause the bars to dissolve faster. First, calculate the amount of TFM (grams/hr) needed to supply a lethal concentration to larval sea lampreys in the stream. Then calculate the amount of TFM (grams/hr) released from a TFM bar based on the length of time the bars are expected to last at the prevailing temperature. Divide the amount of TFM needed by the amount released per bar to find the number of bars needed.

[Right Panel]

STORAGE AND DISPOSAL

Do not contaminate water, food, or feed by storage or disposal.

STORAGE: Store only in original container, in a cool (85°F or less) dry place inaccessible to children, pets and domestic animals, and where spills and leakage can be contained. If product becomes soft or liquifies due to high temperatures, cooling to below 85°F will return it to a solid state.

PESTICIDE DISPOSAL: Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide, spilled bait, or rinsate is a violation of Federal law. If these wastes cannot be disposed of according to instructions in the application manual, contact your State Pesticide or Environmental Control Agency, or the Hazardous Waste representative at the nearest EPA Regional Office for guidance.

CONTAINER DISPOSAL: Dispose of empty plastic wrappers and packing cartons in a sanitary landfill, or if allowed by state and local authorities, by burning. If burned, stay out of smoke.

Bayluscide® Wettable Powder (70% Active Niclosamide, Aminoethanol Salt)
[Front Panel]

RESTRICTED USE PESTICIDE

Due to Aquatic Organism Toxicity, Need for Specialized Equipment and Highly Specialized Applicator Training.

For retail sale to, and use only by, USDI, FWS, State Fish and Game, Fisheries and Oceans Canada, and Provincial Certified Applicators trained in sea lamprey control or persons under their direct supervision.

BAYLUSCIDE 70% WETTABLE POWDER-SEA LAMPREY LARVICIDE

Active Ingredient:	
Niclosamide, Aminoethanol Salt[1]	70.0%
Inert Ingredients:	30.0%
TOTAL:	100.0%

[1]Niclosamide, Active Equivalent (a.e.) = 59.0%

KEEP OUT OF REACH OF CHILDREN

CAUTION

FIRST AID

Have label with you when obtaining treatment advice.

If on skin or clothing	•Take off contaminated clothing. •Rinse skin immediately with plenty of water for 15-20 minutes. •Call a poison control center, doctor or 1-800-858-7378 immediately for treatment advice.
If inhaled	•Move person to fresh air. •If person is not breathing, call an ambulance, then give artificial respiration, preferably mouth-to-mouth, if possible. •Call a poison control center or doctor immediately for treatment advice.

[Front Panel]

If in eyes	•Hold eye open and rinse slowly and gently with water for 15-20 minutes. •Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. •Call a poison control center or doctor immediately for treatment advice.

See Left Panel for additional precautionary statements.

Manufactured by:

Pro-Serve
400 E. Brooks Rd., P.O. Box 161059
Memphis, TN 38186-1059

Manufactured For:

Fish and Wildlife Service
United States Department of Interior
18th and C Streets, NW
Washington, DC 20240

EPA Reg. No. 6704-87
EPA Establishment No. 33560-TN-01

Batch No. _____

Net Contents _____ lbs.

[Left Panel]

PRECAUTIONARY STATEMENTS

HAZARDS TO HUMANS AND DOMESTIC ANIMALS

CAUTION

Acute Hazards: Harmful if absorbed through skin or inhaled. Causes moderate eye irritation.

Hazard Avoidance: Do not get in eyes, on skin, or on clothing. Avoid breathing dust. Wear protective clothing as listed under "Personal Protective Equipment". Wash thoroughly with soap and water after handling and before eating or smoking. Remove contaminated clothing and wash before reuse.

PERSONAL PROTECTIVE EQUIPMENT:

Handlers must wear:

- Long-sleeved shirt and long pants
- Chemical-resistant gloves (such as rubber or made out of any water-proof material)
- Socks and shoes

User Safety Requirements:

Follow manufacturer's instructions for cleaning/maintaining PPE. If no such instructions are provided for washables, use detergent and hot water. Keep and wash PPE separately from other laundry.

User Safety Recommendations:

Users should wash hands before eating, drinking, chewing gum, using tobacco, or using the toilet.

Users should remove clothing immediately if pesticide gets inside. Then wash thoroughly and put on clean clothing.

Users should remove PPE immediately after handling this product. As soon as possible, wash thoroughly and change into clean clothing.

ENVIRONMENTAL HAZARDS

This chemical is toxic to fish and aquatic invertebrates. Nontarget organisms (such as freshwater clams and mussels) may be killed at rates recommended on this label. Directions for use must be strictly followed to minimize hazards to non-target organisms. **Do not** contaminate water by the cleaning of equipment or disposing of equipment washwaters.

[Right Panel]

DIRECTIONS FOR USE

It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

READ THIS LABEL:

Read the entire label and Sea Lamprey Control Document No. SLC-92-001.3 [Standard Operating Procedures for Application of Lampricides in the Great Lakes Fishery Commission Integrated Management of Sea Lamprey (*Petromyzon marinus*) Control Program] for correct rates of application. This product must be used strictly in accordance with both label's precautionary statements and applicable use directions, as well as with all applicable State and Federal laws and regulations.

Before using this product, obtain all necessary permits.

GENERAL INFORMATION:

This product contains a fast-acting fish toxicant which kills sea lamprey larvae in 1-2 hours. The mode of action is uncoupling of oxidative phosphorylation. As many types of nontarget species are potentially vulnerable to Bayluscide, it is necessary to use care and to follow the requirements of this label to minimize impacts.

USE RESTRICTIONS:

Use Pattern:

Bayluscide 70% Wettable Powder-Sea Lamprey Larvicide may be used as an additive in combination with TFM (EPA Reg. No. 6704-45) for control of sea lamprey (*Petromyzon marinus*) in waters in the Great Lakes Basin, the Lake Champlain system, and the Finger Lakes. Application of Bayluscide 70% Wettable Powder-Sea Lamprey Larvicide may be made as a simultaneous addition with TFM to reduce the amount of TFM required or as a subsequent addition downstream to enhance TFM larvicidal activity.

Pre-Application Notification:

Prior to and during the application of this chemical, take all appropriate actions to notify public water users including notification actions specified in the application manual referred to above.

Aerial Application:

Aerial application of this product is prohibited.

Pretreatment Surveys:

Prior to using Bayluscide 70% Wettable Powder-Sea Lamprey Larvicide-TFM, pretreatment surveys must be made to determine populations of larvae. All waters selected for treatment must first be analyzed on site to determine both the minimum concentration of material required to kill lamprey larvae and the maximum concentration that can be applied without causing undue fish mortality. "Analysis" constitutes live animal toxicity tests or the use of a regression established by past toxicity tests and the total alkalinity and pH of the water.

Lethal Concentration:

Lethal concentration may vary depending upon water chemistry and temperature. Carefully calculate stream discharge and add the amount of lampricide necessary to kill lamprey larvae with minimal fish mortality. Use application devices that accurately deliver Bayluscide at calculated rates. Bayluscide concentrations will be monitored by high-performance liquid chromatography to insure that minimum lethal concentrations for sea lampreys are maintained and calculated maximum concentrations are not exceeded.

Application Directions:

Prior to and during the application of this chemical, take appropriate actions to notify public water users including notification actions specified in the Sea Lamprey Control Document No. SLC-92-001.3. When using Bayluscide 70% Wettable Powder-Sea Lamprey Larvicide as an additive in combination with TFM, mix in proportions that result in a final concentration of Bayluscide 70% Wettable Powder-Sea Lamprey Larvicide of not more than 2% of TFM by weight (based on active ingredient). Bayluscide 70% Wettable Powder-Sea Lamprey Larvicide may be added to TFM in two ways:

1. One method of application is to apply both lampricides at the primary application site. TFM is metered into the stream while Bayluscide 70% Wettable Powder-Sea Lamprey Larvicide is applied with a separate pump system in amounts calculated to deliver the desired ratio of Bayluscide to TFM.

2. A second application method is to apply Bayluscide 70% Wettable Powder-Sea Lamprey Larvicide into an existing TFM bank. Because a TFM bank can be diluted by ground water, swamp seepage, untreated tributaries, occasional rain, or other conditions that cannot be included when the application rates are calculated, the toxicity of the bank in the stream must be raised by the addition of TFM or Bayluscide. The latter may be used in place of TFM. In these situations, TFM alone is pumped into the stream at the primary application site. Bayluscide 70% Wettable Powder-Sea Lamprey Larvicide is introduced into the TFM bank at a point or points downstream in amounts calculated to produce the desired Bayluscide to TFM ratio.

STORAGE AND DISPOSAL

Do not contaminate water, food, or feed by storage or disposal.

STORAGE: Store only in original container, in a dry place inaccessible to children, pets, and domestic animals and where spills and leakage can be contained. Spills: Handle and open container in a manner that will prevent spillage. If the container is leaking or material is spilled for any reason or cause, contain spill with a barrier of absorbent material. Refer to Precautionary Statements on label for hazards associated with the handling of this material. Do not walk through spilled material. Dispose of pesticide as directed above. In spill or leak incidents, keep unauthorized people away. For decontamination procedures or any other assistance that may be necessary, contact Chemtrec at 1-800-424-9300.

PESTICIDE DISPOSAL: Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide, spilled bait, or rinsate is a violation of Federal law. If these wastes cannot be disposed of by use according to label instructions, contact your State Pesticide or Environmental Control Agency, or the Hazardous Waste representative at the nearest EPA Regional Office for guidance.

CONTAINER DISPOSAL: Triple rinse (or equivalent), and then offer for recycling or reconditioning, or puncture and dispose of in a sanitary landfill, or by incineration, or, if allowed by state and local authorities, by burning. If burned, stay out of smoke.

Bayluscide® Granular (3.2% Active Niclosamide, Aminoethanol Salt)

EPA Reg. No. 6704-91 - April 24, 2003
Bayluscide 3.2% Granular Sea Lamprey Larvicide

[Front Panel]

RESTRICTED USE PESTICIDE

Due to Aquatic Organism Toxicity, Need for Specialized Equipment and Highly Specialized Applicator Training.

For retail sale to, and use only by, USDI FWS, State Fish and Game, Fisheries and Oceans Canada, and Provincial Certified Applicators trained in sea lamprey control.

BAYLUSCIDE 3.2% Granular Sea Lamprey Larvicide

Active Ingredient: Niclosamide, Aminoethanol Salt[1] 3.2%
Inert Ingredients: 96.8%
TOTAL: 100.0%
[[1]Niclosamide, Active Equivalent (a.e.) = 2.7%]

KEEP OUT OF REACH OF CHILDREN

CAUTION

FIRST AID
Have label with you when obtaining treatment advice.

If swallowed	•Call a poison control center or doctor immediately for treatment advice. •Have person sip a glass of water if able to swallow. •Do not induce vomiting unless told to do so by the poison control center or doctor.
If on skin or clothing	•Take off contaminated clothing. •Rinse skin immediately with plenty of water for 15-20 minutes. •Call a poison control center or doctor immediately for treatment advice.

If in eyes	•Hold eye open and rinse slowly and gently with water for 15-20 minutes. •Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. •Call a poison control center or doctor or 1-800-858-7378 immediately for treatment advice.

See Left Panel for additional precautionary statements.

Manufactured by:

Coating Place, Inc.
P.O. Box 930310
Verona, WI 53593

Manufactured For:

Fish and Wildlife Service
United States Department of Interior
18th and C Streets, NW
Washington, DC 20240

EPA Reg. No. 6704-91
EPA Establishment No. 043108-WI-001

Batch No. _____

Net Contents _____ lbs.

[Left Panel]

PRECAUTIONARY STATEMENTS

HAZARDS TO HUMANS AND DOMESTIC ANIMALS

CAUTION

Acute Hazards: Harmful if swallowed. Harmful if absorbed through skin. Causes moderate eye irritation.

Hazard Avoidance: Do not get in eyes, on skin, or on clothing. Wear protective clothing as listed under "Personal Protective Equipment." Wash thoroughly with soap and water after handling and before eating, drinking, chewing gum, using tobacco, or using the toilet. Prolonged or frequently repeated skin contact may cause allergic reactions in some individuals. Remove contaminated clothing and wash before reuse.

PERSONAL PROTECTIVE EQUIPMENT:

Handlers must wear:

- Long-sleeved shirt and long pants
- Chemical-resistant gloves (such as rubber or made out of any water-proof material, Selection Category A)
- Socks and shoes

User Safety Requirements:

Follow manufacturer's instructions for cleaning/maintaining PPE. If no such instructions are provided for washables, use detergent and hot water. Keep and wash PPE separately from other laundry.

User Safety Recommendations:

Users should wash hands before eating, drinking, chewing gum, using tobacco, or using the toilet.

Users should remove clothing immediately if pesticide gets inside, then wash thoroughly and put on clean clothing.

Users should remove PPE immediately after handling this product. As soon as possible, wash thoroughly and change into clean clothing.

ENVIRONMENTAL HAZARDS

This chemical is toxic to fish and aquatic invertebrates. Nontarget aquatic organisms may be killed at rates recommended on this label. Directions for use must be strictly followed to minimize hazards to nontarget organisms. **Do not** contaminate water by the cleaning of equipment or disposing of equipment washwaters.

[Right Panel]

DIRECTIONS FOR USE

It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

READ THIS LABEL

Read the entire label and Technical Operating Procedures of the Sea Lamprey Control Document No. SLC-92-001.3 [Manual for Application of Lampricides in the U.S. Fish and Wildlife Service Sea Lamprey (*Petromyzon marinus*) Control Program] for correct rates of application. This product must be used strictly in accordance with the label's precautionary statements and applicable use directions, as well as with all applicable State and Federal laws and regulations.

GENERAL INFORMATION

This product contains a fast-acting fish toxicant which kills sea lamprey larvae in 1-2 hours. The mode of action is uncoupling of oxidative phosphorylation. As many types of nontarget aquatic species are potentially vulnerable to Bayluscide, it is necessary to use care and to follow the requirements of this label to minimize impacts.

USE RESTRICTIONS

Use Pattern:

Bayluscide 3.2% Granular Sea Lamprey Larvicide is used in waters of the Great Lakes basin, the Lake Champlain system, and the Finger Lakes. This formulation may be used alone or in conjunction with applications of TFM, or the combination of TFM and Bayluscide 70% Wettable Powder Sea Lamprey Larvicide. Bayluscide 3.2% Granular Sea Lamprey Larvicide may also be used as a assessment tool in deep or turbid water. When applied to a water's surface, the granules fall rapidly to the bottom where they are lethal to sea lamprey larvae.

Pre-application Notification:

Prior to and during the application of this chemical, take all appropriate actions to notify public water users, including notification actions specified in the application manual referred to above.

Permits:

Obtain any permits needed from Local, State, Provincial, and Federal wildlife agencies.

Potable Water:

Local, State, and Provincial Fish and Game agencies must be contacted before product is applied. Municipalities that use streams requiring treatment as potable water sources must be notified of the impending treatment at least 24 hours prior to application. Agricultural irrigators that use streams requiring treatment as a source of irrigation water must turn off their irrigation systems for a 24-hour period during and after treatment.

Unauthorized Personnel:

May not be used by unauthorized personnel.

PRE-APPLICATION DIRECTIONS

Aerial Application:

Aerial application of this product is prohibited.

Pretreatment Surveys:

Prior to using Bayluscide 3.2% Granular Sea Lamprey Larvicide, pretreatment surveys must be made to determine populations of larvae.

APPLICATION DIRECTIONS

Persons applying Bayluscide 3.2% Granular Sea Lamprey Larvicide must follow Sea Lamprey Control Document No. SLC-92-001, "Standard Operating Procedure for Application of Lampricides in the Great Lakes Fishery Commission's Integrated Management of Sea Lamprey (*Petromyzon marinus*) Control Program," and ensure that the correct application rates are used. Prior to and during the application of this chemical, take appropriate actions to notify public water users, including notification actions specified in this manual. Determine water temperatures and pH. For best results, apply granules at water temperatures greater than 10 °C and pH greater than 7. Measure the area to be treated (length x width, in feet). Place markers to delineate the plot perimeter. Compute the total surface area to be treated in square feet. Application rate for Bayluscide 3.2% Granular Sea Lamprey Larvicide is 5 lb. AI/Acre. Compute the weight of granules to apply: ***lbs. of formulation required = square feet to be treated x .00359 lbs. formulation/sq. foot***. Use equipment that can be accurately calibrated to distribute the required amount of Bayluscide 3.2% Granular Sea Lamprey Larvicide evenly over the area to be treated.

STORAGE AND DISPOSAL

Do not contaminate water, food, or feed by storage or disposal.

STORAGE: Store only in original container, in a dry place inaccessible to children, pets, and domestic animals and where spills and leakage can be contained.
Spills: Handle and open container in a manner that will prevent spillage. If the container is leaking or material is spilled for any reason or cause, contain spill with a barrier of absorbent material. Refer to Precautionary Statements on label for hazards associated with the handling of this material. Do not walk through spilled material. Dispose of pesticide as directed above.
In spill or leak incidents, keep unauthorized people away. For decontamination procedures or any other assistance that may be necessary, contact Chemtrec at 1-800-424-9300.

PESTICIDE DISPOSAL: Improper disposal of excess pesticide or rinsate is a violation of Federal law. If these wastes cannot be disposed of by use according to label instructions, contact your State Pesticide or Environmental Control Agency, or the Hazardous Waste representative at the nearest EPA Regional Office for guidance.

CONTAINER DISPOSAL: Triple rinse (or equivalent), and then offer for recycling or reconditioning, or puncture and dispose of in a sanitary landfill, or by incineration, or, if allowed by state and local authorities, by burning. If burned, stay out of smoke.

Bayluscide® Emulsifiable Concentrate (20.6% Active Niclosamide, Aminoethanol Salt)

[Front Panel]

RESTRICTED USE PESTICIDE

Due to Eye Corrosiveness to Humans; Aquatic Organism Toxicity, Need for Specialized Equipment and Highly Specialized Applicator Training.

For retail sale to, and use only by, USDI FWS, State Fish and Game, Fisheries and Oceans Canada, and Provincial Certified Applicators trained in sea lamprey control or persons under their direct supervision.

BAYLUSCIDE 20% EMULSIFIABLE CONCENTRATE

Active Ingredient:	
Niclosamide.	20.6%
Inert Ingredients:	79.4%
TOTAL:	100.0%

KEEP OUT OF REACH OF CHILDREN

DANGER

Corrosive to the eye and Skin Sensitizer

FIRST AID

Have label with you when obtaining treatment advice.

If swallowed	•Call a poison control center or doctor immediately for treatment advice. •Have person sip a glass of water if able to swallow. •Do not induce vomiting unless told to do so by the poison control center or doctor.
If on skin or clothing	•Take off contaminated clothing. •Rinse skin immediately with plenty of water for 15-20 minutes. •Call a poison control center or doctor immediately for treatment advice.

If inhaled	•Move person to fresh air. •If person is not breathing, call an ambulance, then give artificial respiration, preferably mouth-to-mouth, if possible. •Call a poison control center or doctor immediately for treatment advice.
If in eyes	•Hold eye open and rinse slowly and gently with water for 15-20 minutes. •Remove contact lenses, if present, after the first 5 minutes, then continue rinsing eye. •Call a poison control center or doctor immediately for treatment advice.

NOTE TO PHYSICIAN

Probable mucosal damage may contraindicate the use of gastric lavage. No specific antidote is available. Treat symptomatically. See additional PRECAUTIONARY STATEMENTS on Left/Right/Side Panel.

[Left Panel]

PRECAUTIONARY STATEMENTS

HAZARDS TO HUMANS AND DOMESTIC ANIMALS

DANGER

Acute Hazards: Corrosive. Causes irreversible eye damage. Harmful if absorbed through skin. Prolonged or frequently repeated skin contact may cause allergic reactions in some individuals.

Hazard Avoidance: Do not get in eyes, on skin, or on clothing. Wear protective clothing and protective eyewear as listed under "Personal Protective Equipment." Wash thoroughly with soap and water after handling and before eating or smoking. Remove contaminated clothing and wash before reuse.

PERSONAL PROTECTIVE EQUIPMENT:

Handlers must wear:

- Long-sleeved shirt and long pants
- Chemical-resistant gloves (such as nitrile or butyl))
- Socks and shoes
- Protective eyewear (goggles, face shield, or safety glasses)

[Right Panel]

User Safety Requirements:

Follow manufacturer's instructions for cleaning/maintaining Personal Protective Equipment (PPE). If no such instructions are provided for washables, use detergent and hot water. Keep and wash PPE separately from other laundry.

User Safety Recommendations:

Users should wash hands before eating, drinking, chewing gum, using tobacco, or using the toilet.

Users should remove clothing immediately if pesticide gets inside. Then wash thoroughly and put on clean clothing.

Users should remove PPE immediately after handling this product. As soon as possible, wash thoroughly and change into clean clothing.

ENVIRONMENTAL HAZARDS

This chemical is toxic to fish and aquatic invertebrates. Nontarget organisms (such as freshwater clams and mussels) may be killed at rates recommended on this label. Directions for use must be strictly followed to minimize hazards to non-target organisms. **Do not** contaminate water by the cleaning of equipment or disposing of equipment washwaters.

PERMITS

Obtain any permits needed from local, State, Provincial, and Federal wildlife authorities.

POTABLE WATER

At least 24 hours prior to application, notify municipalities and agricultural irrigators that potable and irrigation water will be treated . Agricultural irrigators must turn off their irrigation systems for a 24-hour period during and after treatment.

UNAUTHORIZED PERSONNEL

May not be used by unauthorized personnel.

UNITED STATES DEPARTMENT OF INTERIOR Fish and Wildlife Service 18th and C Streets, NW Washington, DC 20240 EPA Reg. No. 6704-OE	Manufacturing by Pro-Serve 400 E. Brooks Road P.O. Box 161059 Memphis, TN 38186-1059 EPA Est. No. 33560-TN-01

Net Contents: _____

DIRECTIONS FOR USE

It is a violation of Federal law to use this product in a manner inconsistent with its labeling.

READ THIS LABEL:

Read the entire label and Sea Lamprey Control Document No. SLC-92-001.3 [Manual for Application of Lampricides in the U.S. Fish and Wildlife Service Sea Lamprey (*Petromyzon marinus*) Control Program] for correct rates of application. This product must be used strictly in accordance with both label's precautionary statements and applicable use directions, as well as with all applicable State and Federal laws and regulations.

Before using this product, obtain all necessary permits.

GENERAL INFORMATION:

This product contains a fast-acting fish toxicant which kills sea lamprey larvae in 1-2 hours. The mode of action is uncoupling of oxidative phosphorylation. As many types of nontarget species are potentially vulnerable to Bayluscide, it is necessary to use care and to follow the requirements of this label to minimize impacts.

USE RESTRICTIONS:

<u>Use Pattern:</u>

Baylusicide 20% Emulsifiable Concentrate may be used as an additive in combination with TFM (EPA Reg. No. 6704-45) for control of sea lamprey (*Petromyzon marinus*) in waters in the Great Lakes Basin, the Lake Champlain system, and the Finger Lakes. Application of Bayluscide 20% Emulsifiable Concentrate may be made as a simultaneous addition with TFM to reduce the amount of TFM required or as a subsequent addition downstream to enhance TFM larvicidal activity.

Pre-Application Notification:

Prior to and during the application of this chemical, take all appropriate actions to notify public water users including notification actions specified in the application manual referred to above.

Aerial Application:

Aerial application of this product is prohibited.

Pretreatment Surveys:

Prior to using Bayluscide 20% Emulsifiable Concentrate-TFM, pretreatment surveys must be made to determine populations of larvae. All waters selected for treatment must first be analyzed on site to determine both the minimum concentration of material required to kill lamprey larvae and the maximum concentration that can be applied without causing undue fish mortality. "Analysis" constitutes live animal toxicity tests or the use of a regression established by past toxicity tests and the total alkalinity and pH of the water.

Lethal Concentration:

Lethal concentration may vary depending upon water chemistry and temperature. Carefully calculate stream discharge and add the amount of lampricide necessary to kill lamprey larvae with minimal fish mortality. Use application devices that accurately deliver Bayluscide at calculated rates. Bayluscide concentrations will be monitored by gas chromatography or by high-performance liquid chromatography to insure that minimum lethal concentrations for sea lampreys are maintained and calculated maximum concentrations are not exceeded.

Application Directions:

Prior to and during the application of this chemical, take appropriate actions to notify public water users including notification actions specified in the Sea Lamprey Control Document No. SLC-92-001.3. When using Bayluscide 20% Emulsifiable Concentrate as an additive in combination with TFM, mix in proportions that result in a final concentration of Bayluscide 20% Emulsifiable Concentrate of not more than 2% of TFM by weight (based on active ingredient). Bayluscide 20% Emulsifiable Concentrate may be added to TFM in two ways:

1. One method of application is to apply both lampricides at the primary application site. TFM is metered into the stream while Bayluscide 20% Emulsifiable Concentrate is applied with a separate pump system in amounts calculated to deliver the desired ratio of Bayluscide to TFM.

2. A second application method is to apply Bayluscide 20% Emulsifiable Concentrate into an existing TFM bank. Because a TFM bank can be diluted by ground water, swamp seepage, untreated tributaries, occasional rain, or other conditions that cannot be included when the application rates are calculated, the toxicity of the bank in the stream must be raised by the addition of TFM or Bayluscide. The latter may be used in place of TFM. In these situations,

TFM alone is pumped into the stream at the primary application site. Bayluscide 20% Emulsifiable Concentrate is introduced into the TFM bank at a point or points downstream in amounts calculated to produce the desired Bayluscide to TFM ratio.

STORAGE AND DISPOSAL

Do not contaminate water, food, or feed by storage or disposal

STORAGE: Store only in original container, in a dry place inaccessible to children, pets, and domestic animals.

PESTICIDE DISPOSAL: Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide, spilled bait, or rinsate is a violation of Federal law. If these wastes cannot be disposed of by use according to label instructions, contact your State Pesticide or Environmental Control Agency, or the Hazardous Waste representative at the nearest EPA Regional Office for guidance.

CONTAINER DISPOSAL: Triple rinse (or equivalent), and then offer for recycling or reconditioning, or puncture and dispose of in a sanitary landfill, or by incineration, or, if allowed by state and local authorities, by burning. If burned, stay out of smoke.

Material Safety Data Sheet for Antimycin A

MATERIAL SAFETY DATA SHEET

Antimycin A in Acetone Issued 04/17/97

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Material Name: Antimycin A in Acetone
MANUFACTURER: Aquabiotics Corporation
10750 Arrow Point Drive
Bainbridge Island, WA 98110
TELEPHONE NUMBER: 1-206-842-1708
FAX NUMBER: 1-206-842-7266

2. COMPOSITION/INFORMATION ON INGREDIENTS

INGREDIENT NAME: Acetone *
CONCENTRATION: 80.0000%
CAS/RTECS NUMBERS: 67-64-1 / AL3150000
OSHA-PEL 8HR TWA: 750 ppm
STEL: 1000ppm
CEILING: N/L
ACGIH-TLV 8HR TWA: 750 PPM
STEL: 1000 PPM
CEILING: N/L
OTHER LIMITS 8HR TWA: N/A
STEL: N/A
CEILING: N/A
* Hazardous per OSHA criteria

INGREDIENT NAME: Antimycin A *
CONCENTRATION: 20.0000 %
CAS/RTECS NUMBERS: 1397-94-0 / CD0350000
OSHA-PEL 8HR TWA: N/L
STEL: N/L
CEILING: N/L
ACGIH-TLV 8HR TWA: N/L
STEL: N/L
CEILING: N/L
OTHER LIMITS 8HR TWA: N/A
STEL: N/A
CEILING: N/A
* Hazardous per OSHA criteria

3. HAZARDS INFORMATION

EMERGENCY OVERVIEW: Flammable Liquid and a marine hazard. The active component is toxic by ingestion and may
also by skin absorption. It is an eye, skin and respiratory irritant.
ROUTE(S) OF ENTRY: Skin: Yes
Inhalation: Yes
Ingestion: Yes
INGESTION RATING: Highly Toxic
SKIN ABSORPTION RATING: Possibly highly toxic
INHALATION RATING: N/D
CORROSIVENESS RATING: N/D
SKIN CONTACT RATING: Irritant
SKIN SENSITIZATION RATING: N/D
EYE CONTACT RATING: Irritant
TARGET ORGANS: Eyes, skin, respiratory tract, cardiovascular system, nervous system, kidneys, possibly fetus
CARCINOGENICITY RATING: NTP: N/L IARC: N/L OSHA: N/L
ACGIH: N/L

None

SIGNS AND SYMPTOMS: N/D. Inhalation of vapors or aerosol could irritate the eyes, nose and respiratory tract. Direct contact with skin or eyes could produce severe irritation. Systemic intake could produce a decrease in blood pressure, nausea, light headedness, dizziness, excitement, incoordination, weakness, loss of coordinated speech and drowsiness.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE: N/D. Available information suggests pre-existing eye, skin, respiratory, kidney, nervous system or cardiovascular ailments.

4. FIRST AID MEASURES

EYES: Remove from source of exposure. Flush with copious amounts of water. If irritation persists or signs of toxicity occur, seek medical attention. No known antidote. Provide symptomatic/supportive care as necessary.

SKIN: Remove from source of exposure. Flush with copious amounts of water. If irritation persists or signs of toxicity occur, seek medical attention. No known antidote. Provide symptomatic/supportive care as necessary.

INGESTION: Remove from source of exposure. Seek immediate medical attention. No known antidote. Provide symptomatic/supportive care as necessary.

INHALATION: Remove from source of exposure. If signs of irritation or toxicity occur, seek medical attention. No known antidote. Provide symptomatic/supportive care as necessary.

5. FIRE FIGHTING PROCEDURES

FLASH POINT: O F (for acetone)
FLASH POINT METHOD: Closed Cup
LOWER EXPLOSIVE LIMIT(%): 2.6% (for acetone)
UPPER EXPLOSIVE LIMIT(%): 12.8% (for acetone)
AUTOIGNITION TEMPERATURE: 869 F (for acetone)

FIRE & EXPLOSION HAZARDS: Flammable Liquid. Keep away from heat, sparks and open flame.
EXTINGUISHING MEDIA: Use "alcohol" foam, dry chemical or carbon dioxide. Water may be ineffective.
FIRE FIGHTING INSTRUCTIONS: Wear protective clothing and self-contained breathing apparatus.

6. ACCIDENTAL RELEASE MEASURES

SPILL OR RELEASE PROCEDURES: Recover product and place in an appropriate container for disposal. Ventilate and wash the spill area.

7. HANDLING AND STORAGE

HANDLING: Ground and bond all containers during transfer operations.
STORAGE: Tight container.
SPECIAL PRECAUTIONS: Wash hands and face after handling this compound.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

ENGINEERING CONTROLS: Use local exhaust.
RESPIRATORY PROTECTION: Air purifying respirator with organic vapor cartridge.
SKIN PROTECTION: Butyl rubber.
EYE PROTECTION: Full-face respirator.
OTHER PROTECTION: Wear saranex tyvek coverings with hood and shoe covers if contact may occur.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE/PHYSICAL STATE: Brown to black liquid
ODOR: Acetone
BOILING POINT: 56.2 C (for acetone)
MELTING/FREEZING POINT: -94.6 C (for acetone)
VAPOR PRESSURE (mm Hg): N/D
VAPOR DENSITY (Air=1): N/D
EVAPORATION RATE: N/D

BULK DENSITY: N/D
SPECIFIC GRAVITY: 0.8 (for acetone)
SOLUBILITY: Miscible in water, alcohols, ethers and most organic solvents.
pH: N/D
VISCOSITY: N/D

10. STABILITY AND REACTIVITY

CHEMICAL STABILITY: Neutralize active component with bleach, potassium permanganate, or other strong oxidizer.
INCOMPATIBILITIES: Oxidizers.
HAZARDOUS DECOMPOSITION PRODUCTS: N/D
HAZARDOUS POLYMERIZATION: N/D

11. TOXICOLOGICAL INFORMATION

ORAL TOXICITY: N/D. LD50 = 30 mg/kg in rates for antimycin A. LD50 = 1738-10, 700 mg/kg in mice, rats and rabbits for acetone.
DERMAL TOXICITY: N/D. Cumulative lethal dosage for antimycin A in rabbits about 65-150 mg/kg in animals receiving one gram of a 5% suspension in carbowax twice daily for three applications. Death possibly the result of absorption through broken skin as marked inflammation present after second application. LD50 = 20,000 mg/kg in rabbits for acetone.
INHALATION TOXICITY: N/D. A 10% formulation of antimycin A in alcohol administered to rats and guinea pigs as an aerosol for 10 minutes a day for 5 days at a nominal concentration of 170 mg/m3 produced eye irritation with corneal lesions and respiratory irritation and damage. LCLo = 16,000 ppm/4H in rats and 467,300 ppm/1H in mice for acetone. Vapors can cause irritation of the respiratory tract.
CORROSIVENESS: N/D
DERMAL IRRITATION: N/D. No irritation found following dermal application of 0.5 gram of a 5% suspension of antimycin A in carbowax (25 mg antimycin A); however, exudation, edema and scab formation were found after the first two of six applications over three days. Acetone mildly irritating to rabbit skin. Repeated or prolonged contact can cause dermatitis.
OCULAR IRRITATION: N/D. Corneal opacity clearing in four weeks resulted following application of 0.1 gram of antimycin A to the eyes of guinea pigs. Application of 0.5 grams of 5% antimycin A in alcohol to the eyes of rabbits resulted in slight redness. Acetone severely6 irritating, with corneal injury in rabbits. Vapors can cause eye irritation and burning. Can cause stinging if splashed in the eyes.
DERMAL SENSITIZATION: N/D.
SPECIAL TARGET ORGAN EFFECTS: N/D. Dietary administration of antimycin A a dosage of 10 mg/kg/day for four weeks produced soft stools and reduced weight gain in rats. Dietary administration at a dosage of 0.5 mg/kg/day to rats prior to and during pregnancy resulted in reduced body weight of the offspring (about 10%). Infusion to dogs at a rate of 1mcg/kg/minute for 1 hour produced no adverse effects; however, infusion of 10 mcg/kg/minute produced decreased blood pressure, slowed heart rate and death. Acetone causes central nervous system depression at elevated vapor concentrations and irritation at lower concentrations. Produced kidney injury in rats at oral dosages of 500 mg/kg/day or more.
CARCINOGENICITY INFORMATION: N/D

12. ECOLOGICAL INFORMATION

ECOLOGICAL INFORMATION: Marine hazard. Used in conjunction with a surfactant to kill fish.

13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL METHODS: Dispose of product in accordance with federal, state and local regulations.

14. TRANSPORTATION INFORMATION

DOT STATUS: Regulated
PROPER SHIPPING NAME: Flammable Liquids, toxic, n.o.s. (Acetone, Antimycin A), 3, UN1992, II
HAZARD CLASS: 3
UN NUMBER: UN1992
PACKING GROUP: II
REPORTABLE QUANTITY: 5000/2270

IATA/ICAO STATUS: Regulated
PROPER SHIPPING NAME: Flammable liquid, toxic, n.o.s., (Acetone, Antimycin A)
HAZARD CLASS: 3
UN NUMBER: UN1992
PACKING GROUP: II
REPORTABLE QUANTITY: 5000/2270
IMO STATUS: Regulated
PROPER SHIPPING NAME: Not Authorized
HAZARD CLASS: N/D
UN HUMBER: N/D
PACKING GROUP: N/D
REPORTABLE QUANTITY: N/D
FLASH POINT: O F (for acetone)

15. REGULATORY INFORMATION

TSCA STATUS: Exempt
CERCLA STATUS: N/D
SARA STATUS: N/D
RCRA STATUS: N/D
PROP 65 (ca): N/D

16. OTHER INFORMATION

LEGEND: N/A =
N/D = Not Determined
N/L = Not Listed
L = Listed
C = Ceiling
S = Short-term
® = Registered Trademark of Aquabiotics Corporation
™ = Registered Trademark of Aquabiotics Corporation

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Material Safety Data Sheet for Prentox® Prenfish™ Fish Toxicant Powder (rotenone)

Product: 655-691 Prentox® Prenfish™ Fish Toxicant Powder

Material Safety Data Sheet
U.S. Department of Labor (OSHA 29 CFR 1910.1200)

Section 1: Product and Company Identification

Product: 655-691 Prentox® Prenfish™ Fish Toxicant Powder

Manufacturer's Name: **Prentiss Incorporated**
C. B. 2000
Floral Park, NY 11001
Telephone Number: **(516) 326-1919**

Section II: Composition/Information on Ingredients

Ingredient Name:	OSHA PEL	ACGIH TLV	%
Rotenone (CAS # 83-79-4)	(TWA) 5 mg/M³	(TWA) 5 mg/M³	7.4
Other Cube Resins	None	None	11.1
Other Ingredients	None	None	81.5

Section 3: Hazards Identification:

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Emergency Overview:

A tan powder with a wet chalk or dirt-like odor.

- Fatal if inhaled or swallowed
- Harmful if absorbed through skin
- Causes moderate eye irritation
- May cause allergic skin reactions in some individuals
- This pesticide is extremely toxic to fish

Potential Health Effects:

Primary Route(s) of Entry:
Ingestion, inhalation, and skin contact

Eyes:
Causes moderate eye irritation

Skin:
Harmful if absorbed through the skin. Prolonged or frequently repeated skin contact may cause allergic skin reactions in some individuals.

Ingestion:
Fatal if swallowed

Inhalation:
Fatal if inhaled

Signs and symptoms of acute overexposure:
May cause irritation of the eyes, nose and throat in addition to temporary numbness. Prolonged or repeated exposure can cause nausea, vomiting, abdominal cramps, muscle tremors, poor muscle coordination, seizures, shallow breathing, skin rashes and eye, nose and mouth lesions.

Section 4: First Aid Measures:

Eyes:
Flush eyes with plenty of water for 15 minutes. Get medical attention if irritation persists

Skin:
Wash with plenty of soap and water. Get medical attention if irritation persists

Ingestion:
Call a physician or Poison Control Center. Drink 1 or 2 glasses of water and induce vomiting by touching back of throat with finger. Do not induce vomiting or give anything by mouth to an unconscious person.

Inhalation:
Remove person to fresh air. If not breathing, give artificial respiration, preferably mouth to mouth. Get medical attention

Note to Physician:
If a small amount is ingested (or if treatment is delayed), oral administration of large amounts of activated charcoal and a cathartic is probably sufficient therapy.
Do not administer milk, cream or other substances containing vegetable or animal fats, which enhance the absorption of lipophilic substances.

Section 5: Fire Fighting Measures:

Extinguishing Media:
Carbon dioxide, dry chemical, foam or water

Fire Fighting Instructions:
As in any fire, wear self-contained breathing apparatus, pressure demand, MSHA/NIOSH approved (or equivalent), and full protective gear. Keep upwind. Isolate hazard area. Avoid inhalation of smoke and fumes. Use water or foam to reduce fumes. Do not touch spilled material. If possible, move containers from area. Extinguish only if flow can be stopped. Use flooding amounts of water as a fog. Cool containers with flooding amounts of water from as far a distance as possible. Avoid breathing vapors.

Flammability Classification/Rating:
NFPA/OSHA Class: IIIB
NFPA Rating (Fire): 1

Section 6: Accidental Release Measures:

General and Disposal: Use proper protective equipment to minimize personal exposure (see Section 8). Take all necessary action to prevent and to remedy the adverse effect of the spill. Ensure that the disposal is in compliance with all Federal, State/Provincial, and local regulations (see Section 13 for applicable RCRA number). Refer to Section 15 for applicable Reportable Quantity (RQ) and other regulatory requirements.

Land Spill: Sweep or shovel spilled material into a tightly sealed container. Dispose of with chemical waste.

Section 7: Handling and Storage:

Handling Precautions:
Do not breathe dust. Avoid contact with eyes, skin or clothing.

Storage Precautions:
Do not contaminate water, food or feed by storage. Store in a dry place, away from excessive temperature extremes.

Work/Hygienic Practices:
Wash thoroughly with soap and water after handling and before eating, drinking or using tobacco. Remove contaminated clothing and wash before reuse.

Section 8: Exposure Controls/Personal Protection:

Manufacturing, formulation and other Non-Agricultural uses.

Engineering controls:
Control airborne concentrations below the appropriate exposure guideline (see Section 2 for applicable OSHA/ACGIH Exposure Limits). Local exhaust ventilation may be necessary.

Eye/Face Protection:
Wear safety glasses, splash goggles or face shield.

Skin Protection:
Wear chemical resistant gloves (Neoprene, Nitrile rubber or PVC) and other protective clothing to avoid skin contact.

Respiratory Protection:
Ensure good ventilation. If not adequate, use a chemical cartridge type respirator approved by the National Institute of Occupational Health and Safety.

General Protection:
Eye wash facility and safety shower should be available. Wear a protective apron, long sleeves and pants to prevent skin contact.

Section 9: Physical and Chemical Properties:

Appearance:
Tan powder

Odor:
Wet chalk or dirt-like odor.

Basic Physical Properties:

Physical State: Solid

Solubility (H_2O): Insoluble

Bulk Density: Fluffed – 0.24 gm/cm^3 (14.7 lb./cu. Ft.). Packed – 0.45 gm/cm^3 (28.1 lb./cu. Ft.)

Section 10: Stability and Reactivity:

Stability: Stable.

Conditions to Avoid (Stability): High temperatures and constant exposure to sunlight

Incompatible Materials: Avoid strong oxidizers and reducing agents

Hazardous Polymerization: Will not occur

Section 11: Toxicological Information:

The following data were developed with rotenone dust containing 5% rotenone.

Eye Effects:

Irritation (Rabbit): Slightly irritating.

Skin Effects:

Irritation (Rabbit): Non-irritating.

Absorption (Rabbit): LD_{50} > 2,020 mg/kg (Slightly Toxic).

Sensitization (Guinea Pig): Sensitizing

Acute Oral Effects:

LD_{50} (Rat, male): 874 mg/kg (Slightly Toxic).

(Rat, female): 99.2 mg/kg (Moderately Toxic).

Acute Inhalation Effects:

4 hour LC_{50} (Rat, Male): 0.087 mg/L (Moderately Toxic).

4 hour LC_{50} (Rat, Female): 0.045 mg/L (Highly Toxic).

4 hour LC_{50} (Rat): 0.056 mg/L (Moderately Toxic).

Note: the severity classifications listed above are those of Prentiss Incorporated, and, particularly for eye irritation, may not always coincide with EPA-mandated Precautionary Statements.

The following data were developed with rotenone, the active ingredient in this product.

Chronic (Cancer) Information:

Rotenone was not carcinogenic when tested in rats and mice.

Carcinogenicity: **NTP:** No **IARC:** No **OSHA:** No

Teratogenicity (Birth Defects):

Rotenone was not teratogenic or fetotoxic when tested in rats and mice.

Reproductive Effects:

Rotenone had no adverse effects on reproduction when tested over two successive generations in rats.

Mutagenicity (Genetic Effects):

Rotenone was not mutagenic nor clastogenic when tested in the Ames test, Yeast test, Mouse Lymphoma test, Mouse Micronucleus test, Chromosome Aberration test and the Mitotic Recombination test in Yeast.

Section 12: Ecological Information:

Other Environmental Information:

This pesticide is extremely toxic to fish. Do not discharge effluent containing this product into lakes, streams, ponds, estuaries, oceans or other waters, unless in accordance with the requirements of a National Pollutant Discharge Elimination System (NPDES) permit and the permitting authority has been notified in writing prior to discharge. Do not discharge effluent containing this product to sewer systems without previously notifying the local sewage treatment plant authority. For guidance, contact your State Water Board or Regional Office of the EPA

Section 13: Disposal Considerations:

Do not contaminate water, food or feed by disposal.

Pesticide Disposal:

Pesticide wastes are acutely hazardous. Improper disposal of excess pesticide, spray mixture, or rinsate is a violation of Federal law. If these wastes cannot be disposed of by use according to label instructions, contact your State Pesticide or Environmental Control Agency or the Hazardous Waste Representative at the nearest EPA Regional Office for guidance.

Container Disposal:

Completely empty liner by shaking and tapping sides and bottom to loosen clinging particles. Empty residue into application equipment. Then dispose of liner in a sanitary landfill or by incineration if allowed by State and local authorities. If drum is contaminated and cannot be reused, dispose of in the same manner.

RCRA Information:

RCRA Hazardous Waste Ingredients: None.

Section 14: Transport Information:

Proper Shipping Name: Pesticide, Solid, Toxic, n.o.s. (Rotenone)
Hazard Class: 6.1, PG I
DOT Identification Number: UN2588
DOT Shipping Label: POISON

Additional Shipping Paper Description: Marine Pollutant

Note: For transport purposes (49 CFR Part 173.132), the calculated 1 hour LC_{50} (Rat) is: 0.224 mg/L (dust)

Section 15: Regulatory Information:

U.S. Federal Regulatory Information:

EPA Reg. No.: 655-691
TSCA Inventory: Registered pesticide, exempt from TSCA.
SARA Title III Notification and Information:

Section 302 (EHS) ingredients: None.
Section 304 (CERCLA & EHS) ingredients (RQ): None.
Section 313 ingredients: None.

SARA Title III Notifications and Information:

SARA Title III Hazard Classes:

Acute Health Hazard: Yes
Chronic Health Hazard: No
Fire Hazard: No
Sudden Release of Pressure Hazard: No
Reactivity Hazard: No

Material Safety Data Sheet for TFM

MATERIAL SAFETY DATA SHEET
(In accordance with OSHA CFR 1910.1200, ANSI Z 400.1-1998)

SECTION 1: Chemical Product & Company Identification

Product Name: TFM, Lampricide Sea Lamprey Larvicide, Sea Lamprey Larvicide LAMPRECID®
Chemical Name: α,α,α-trifluoro-4-nitro-m-cresol liquid formulation

Registrant Name & Address:
U.S. Fish and Wildlife Service
U.S. Department of the Interior
1849 C Street NW
Washington, DC 20240

Telephone Contact Number & Hours of Operation: (202) 483-7616 8:00 am-4:30 pm Monday-Friday

Emergency Telephone Contact Number: In the United States: Chemtrec:1-800-424-9300
In Canada: Canutec: 1-613-996-6666 (Collect)

SECTION 2: Composition/Information on Ingredients

Hazardous Ingredients(*):	% by weight	CAS No.	OSHA PEL TWA	OSHA PEL STEL	ACGIH TWA	TLV STEL
α,α,α-trifluoro-4-nitro-m-cresol	36-40	88-30-2	NE	NE	NE	NE
water	35-43	7732-18-6	NE	NE	NE	NE
isopropyl alcohol	11-13	67-63-0	980 mg/m^3	NE	983 mg/m^3	1230 mg/m^3
sodium hydroxide	6.4-7.8	1310-73-2	2 mg/m^3	NE	NE	2 mg/m^3 (1)
Other TFM related materials:						
3-hydroxy-4-nitrobenzoic acid	1.5-4.0	619-14-7	NE	NE	NE	NE
3-nitro-4-hydroxybenzoic acid	3.0-8.0	616-82-0	NE	NE	NE	NE
5-trifluoromethyl-2-nitrophenol	2.0-6.0	NA	NE	NE	NE	NE

*all ingredients in quantities > 1.0 % (0.1 % for carcinogens) that are **potentially** hazardous per OSHA definitions
(1) This is a ceiling value

Some States enforce the PEL's that OSHA promulgated in 1989, which were subsequently vacated by the U.S. Supreme Court. Check with your State OSHA agency to determine which PEL is enforced in your jurisdiction.

NDA = no data available NE = not established

SECTION 3: Hazards Identification EMERGENCY OVERVIEW

Physical description: Dark brownish red liquid

Odor: oily-nutty, phenolic

Potential Health Effects: WARNING! Causes eye and skin irritation. May be harmful or fatal if swallowed. May cause central nervous system depression with nausea, vomiting, dizziness and drowsiness. Personnel responding to a spill of this material should wear appropriate personal protective equipment.

Fire Fighting Measures: Keep away from heat, sparks or open flames.

NFPA RATING:	Health - 2	Flammability - 1	Reactivity -NDA	Special-NDA
HMIS RATING:	Health - 2	Flammability - 1	Reactivity - NDA	Protective Equipment - X

SECTION 4: First Aid Measures

Skin Contact: Remove contaminated clothing. Flush affected area with water for at least 15 minutes. Wash affected area with mild soap and water. Seek medical attention if symptoms develop and persist.
Ingestion: Immediately rinse mouth out with plenty of water. If within 30 minutes after ingestion, give victim a small glass of water or milk (NEVER give anything by mouth to an unconscious person). Do not induce vomiting unless instructed to do so by a physician or poison center. Seek medical attention immediately.
Eye Contact: Immediately flush with plenty of water. Remove contact lenses (if easy to do) and continue flushing for at least 15 minutes. Seek medical attention immediately.

Inhalation: Remove to fresh air. Seek medical attention immediately if breathing becomes difficult or other symptoms develop.

Antidotes/Notes to Physicians: There is no known specific antidote.

SECTION 5: Fire Fighting Measures

Flashpoint: 211.1°F (99.5°C)

Autoignition temperature: NDA

Flammable Limits: LEL: NDA UEL: NDA

Extinguishing media: Use water, foam, CO2

Hazardous products of combustion: Carbon monoxide, carbon dioxide, nitrogen containing chemicals (e.g. NO_2, NO_x, NH_3), and flourine containing compounds (e.g. HF).

Unusual fire and explosion hazards: Keep away from heat, sparks and flame.

Protective Equipment: Use NIOSH/MSHA approved SCBA and full protective gear.

SECTION 6: Accidental Release Measures

Extinguish all ignition sources immediately. Do not attempt to clean up chemical spills without appropriate personal protective equipment (see section 8). Do not touch or walk through spilled material. Absorb or cover with dry earth, sand or other non-combustible material and transfer to containers for disposal. For large spills, dike far ahead for later disposal. For large spills, water spray may reduce vapor, but may not prevent ignition in closed spaces. Keep waste out of sewers, watersheds, and waterways. Extinguish or remove all ignition sources. See Disposal Comments in Section 13.

SECTION 7: Handling & Storage

Handling: Avoid contact with eyes and skin. Use with proper personal protective equipment (see Section 8).

Storage: Store upright in a cool, dry, well ventilated area out of direct sunlight. Store away from incompatible materials (see Section 10). Use with proper personal protective equipment (see Section 8). Keep containers tightly closed at all times. Do not reuse container. Keep out of reach of children.

SECTION 8: Exposure Controls & Personal Protective Equipment

Engineering Controls: Use local exhaust in processing or storage areas. If any of the limits in section 2 are exceeded, local ventilation or respiratory protection may be necessary.
Skin: Protective gloves recommended to prevent skin contact. Contact glove manufacturer for more information.

Eye Protection Wear safety glasses with side shields.

Respiratory: If industrial hygiene surveys show that the exposure limits in Section 2 are exceeded, use of a NIOSH approved respirator is necessary. Seek professional advice prior to respirator selection or use. Follow OSHA respirator regulations (29 CFR 1910.134). Use a positive pressure air supplied respirator if there is a potential for an uncontrolled release, exposure levels are not known, or under any other circumstances where air purifying respirators may not provide adequate protection.

SECTION 9: Physical & Chemical Parameters

Physical State: Liquid
Odor: oily-nutty, phenolic
Vapor Density (air = 1): NDA
Boiling Point: NDA
Viscosity: NDA
Specific Gravity: NDA
pH: 9.0

Solubility in other solvents: NDA

Appearance: Dark brownish
Vapor Pressure: NDA
Percent Volatile by Volume: NDA
Freezing Point: NDA
Melting Point: NDA
Solubility in water: NDA
Density: 1.270 g/mL

Viscosity: 23.28 centipoise at 77°F (25°C)

SECTION 10: Stability & Reactivity

Stability: Stable

Incompatible Materials and conditions to avoid: NDA
Hazardous polymerization: Will not occur.

Hazardous decomposition products: Carbon monoxide, carbon dioxide, nitrogen containing chemicals (e.g NO_2, NO_x, NH_3), and flourine containing compounds (e.g HF).

SECTION 11: Toxicological Information

Product based:
There are no toxicological data available for this product. Exposure to this product can occur by eye and skin contact, ingestion and inhalation of vapors or mists. Overexposure by all routes may cause central nervous system depression with headache, nausea, dizziness and drowsiness. Eye and skin contact is expected to cause irritation. Ingestion is expected to cause irritation to the mouth, throat and esophagus and possibly nausea and vomiting. The rat-oral LD50 for technical grade TFM is 151 mg/kg. Based on this information, this product is expected to be harmful or fatal if swallowed. Inhalation of mists or vapors is expected to cause upper respiratory tract irritation with coughing and nasal discharge. There were no data located for this product regarding potential developmental, reproductive, mutagenic/genotoxic or carcinogenic effects following exposure.

Ingredient based:
This product contains technical grade α,α,α-trifluoro-4-nitro-m-cresol bars (TFM) (CAS# 88-30-2). Eye contact with technical grade TFM caused severe irritation in animal studies. Skin contact caused severe irritation in animal studies. The rabbit-dermal LD50 ranged from > 2.0 g/kg in females to 2.1 g/kg in males. Clinical signs of toxicity included decreased activity, lack of coordination, excessive salivation, prostration and death. TFM did not cause skin sensitization in animal studies using guinea pigs. Ingestion can cause severe irritation to the mouth, throat, esophagus, and stomach with nausea, vomiting, and diarrhea. Technical grade TFM may be harmful or fatal if swallowed based on a rat-oral LD50 (combined for males and females) of 151 mg/kg. Inhalation may cause upper respiratory tract irritation with coughing and nasal discharge. Tests for mutagencity have yielded mixed results. TFM was considered positive for inducing chromosome aberrations in Chinese hamster ovary cells under conditions of both nonactivation and activation. However, TFM did not induce significant changes in the *in vitro* rat primary hepatocyte unscheduled DNA synthesis assay or in the *in vivo* mouse micronucleus assay. TFM did not cause developmental effects at concentrations less than or equal to 125 mg/kg in animal studies. No significant reproductive effects were

observed in animal studies, particularly at low and middle dosing levels. There were no data located addressing potential carcinogenic effects following exposure to TFM.

This product also contains the TFM related materials 3-hydroxy-4-nitrobenzoic acid (CAS#619-14-7), 3-nitro-4-hydroxybenzoic acid (CAS# 616-82-0), and 5-trifluoromethyl-2-nitrophenol (no CAS#). No toxicological data were located for any of these ingredients.

Isopropyl alcohol (CAS#67-63-0) is a colorless liquid with an alcohol odor. Acute exposures by skin contact, inhalation, or ingestion can result in central nervous system depression, persistent nausea, vomiting, abdominal pain, hematemesis, areflexia, depressed respirations, and liguria followed by diuresis. The dermal toxicity of isopropyl alcohol is generally considered low. Skin contact with isopropyl alcohol can result in irritation, a burning sensation, rashes and an overall drying effect. Cases of hypersensitivity characterized by eczematous reactions have been observed. Absorption of harmful amounts can occur from prolonged skin contact. Symptoms of delayed skin absorption that have occurred in pediatric poisonings include respiratory distress, stupor, and coma with complete recovery in 36 hours. Humans exposed by inhalation to 400 ppm for 3-5 minutes experienced mild irritation of the eyes, nose, and throat; exposure to 800 ppm yielded increased (yet not severe) irritation and an uncomfortable atmosphere. Overexposure to the vapor can cause headaches, drowsiness, loss of coordination, collapse, and death. Ingestion of isopropyl alcohol can cause vomiting, depression, coma, shock, hypotension, facial flushing, bradycardia and dizziness. Complications following ingestion include renal insufficiency, including anuria followed by oliguria, nitrogen retention, and edema. The toxic dose is about 1 mL/kg of a 70% isopropyl alcohol solution but as little as 0.5 mL/kg may cause symptoms. Isopropyl alcohol has not been adequately evaluated in terms of carcinogenicity or potential reproductive or developmental toxicity.

This product contains sodium hydroxide (CAS#1310-73-2). Sodium hydroxide is corrosive to the skin, eyes and mucous membranes. Skin contact with 25-50% sodium hydroxide solutions have produced skin irritation in about 3 minutes. Prolonged skin contact can result in severe burns with deep ulcerations. Severe eye injury has been reported in workers exposed to high concentrations of dust or liquids. Eye contact can cause disintegration and sloughing of the conjunctival and corneal epithelium, corneal opacification, redness and ulceration. Inhalation of vapors can result in burning of the nose, throat, eyes and upper respiratory systems. Ingestion produces severe abdominal pain, corrosion of the lips, mouth, tongue, pharynx and vomiting of large pieces of mucosa. Corrosive injury to the mouth, throat, esophagus, and stomach may result in perforation, hemorrhage, and narrowing of the gastrointestinal tract. Death can result from shock, infection of corroded tissues, or asphixia. There were no data located classifying sodium hydroxide as a carcinogen or indicating reproductive or developmental toxicity.

Possible target organs: All tissues (irritation), central nervous system.
Medical conditions that may be aggravated by exposure: Existing skin (e.g. sensitive skin) disorders, central nervous system disorders.

Carcinogens: None of the components listed in Section 2 are considered carcinogens (or classified in regards to carcinogenicity) by OSHA, NTP, and IARC.

SECTION 12: Ecological Information

Ecotoxicity: NDA

Environmental Fate: NDA

SECTION 13: Disposal Considerations

This material (as packaged) may be considered a hazardous waste. Be aware that the waste owner has responsibility for final disposal. Regulations may also apply to empty containers, liners or rinsate. Laws may change or be reinterpreted; state and local regulations may be different from federal regulations. This information applies to materials as manufactured; contamination or processing may change waste characteristics and requirements.

SECTION 14: Transport Information

DOT Hazard Description: NDA

SECTION 15: Regulatory Information

Chemical Inventories: This product is exempt from TSCA regulation under FIFRA Section 3 (2) (B) (ii) when used as a pesticide.

Isopropyl alcohol (CAS#67-63-0) and sodium hydroxide (CAS# 1310-73-1) are listed on the TSCA Inventory, the DSL and the EINECS. α,α,α-trifluoro-4-nitro-m-cresol bars (TFM) (CAS# 88-30-2) is listed on the DSL and the EINECS. 3-hydroxy-4-nitrobenzoic acid (CAS#619-14-7), 3-nitro-4-hydroxybenzoic acid (CAS#616-82-0) are listed on the EINECS.

Reportable Quantities (RQ) (40 CFR table 302.4): Sodium hydroxide (CAS# 1310-73-1) 1000 lbs

SARA TITLE III (Superfund Amendments and Reauthorization Act):

Section 302 Extremely Hazardous Materials (40 CFR 355): None listed

Section 304 Notification Of Accidental Release (40 CFR 355): None listed

Sections 311/312 Hazard Categories (40 CFR 370):

Immediate (Acute) Health Effects:	YES
Delayed (Chronic) Health Effects:	YES
Fire Hazard:	NO
Sudden Release of Pressure Hazard:	NO
Reactivity Hazard:	NDA

Section 313 Toxic Chemical Release Reporting (40 CFR 372.65(a)): Isopropyl alcohol (CAS#67-63-0), only persons who manufacture by the strong acid process, no supplier notification required.

STATE REGULATORY INFORMATION: Since each state has the authority to promulgate standards more stringent than the federal government, this section cannot provide an inclusive list of all state regulations which apply to this product. Questions related to state regulations should be directed toward local officials.

SECTION 16: Other Information

For additional information, refer to the 2000 North American Emergency Response Guidebook and the ACGIH Documentation of the TLV's for individual components.

This information is provided in good faith, but without express or implied warranty.

This MSDS was prepared by Environmental Health & Safety, Inc., St. Paul, MN, 55116, USA

Material Safety Data Sheet for Bayluside Technical

MATERIAL SAFETY DATA SHEET
(In accordance with OSHA CFR 1910.1200, ANSI Z 400.1-1998)

SECTION 1: Chemical Product & Company Identification

Product Name: Bayluscide Technical
Chemical Name: Niclosamide ethanolamine salt, clonitralide
Synonyms: Bayer 73, Bayluside, Baylucit, 2-aminoethanol salt, Mollutox, Salicylanilide, 2'5-dichloro-4-nitro,-ethanolamine salt

Registrant Name & Address:
U.S. Fish and Wildlife Service
U.S. Department of the Interior
1849 C Street NW
Washington, DC 20240

Telephone Contact Number & Hours of Operation: (202) 483-7616 8:00 am-4:30 pm Monday-Friday

Emergency Telephone Contact Number: In the United States: Chemtrec:1-800-424-9300
In Canada: Canutec: 1-613-996-6666 (Collect)

SECTION 2: Composition/Information on Ingredients

Hazardous Ingredients(*):	% by weight	CAS No.	OSHA PEL TWA	OSHA PEL STEL	ACGIH TLV TWA	ACGIH TLV STEL
Niclosamide ethanolamine salt	>95.4	1420-04-8	15 mg/m^3 (1) 5 mg/m^3 (2)	NE NE	10 mg/m^3(1) 3 mg/m^3(2)	NE NE
**2-chloro-4-nitroaniline	0.4-1.5	121-87-9	NE	NE	NE	NE
**5-chloro-2-hydroxybenzoic acid	0.15-1.5	321-14-2	NE	NE	NE	NE

This product is capable of generating a nuisance dust.

1 - PNOC (Particulate not otherwise classified) as total dust
2 - PNOC as respirable fraction
*all ingredients in quantities > 1.0 % (0.1 % for carcinogens) that are **potentially** hazardous per OSHA definitions

**Present as impurities
Some States enforce the PEL's that OSHA promulgated in 1989, which were subsequently vacated by the U.S. Supreme Court. Check with your State OSHA agency to determine which PEL is enforced in your jurisdiction.

NDA = no data available NE = not established

SECTION 3: Hazards Identification EMERGENCY OVERVIEW

Physical description: Powdered bright yellow (with slight green tint) solid

Odor: metallic

Potential Health Effects: WARNING! TOXIC! Harmful if inhaled. Causes eye irritation. May cause skin irritation. Avoid breathing dusts. May cause upper respiratory irritation with coughing and nasal discharge. Personnel responding to a spill of this material should wear appropriate personal protective equipment.

Fire Fighting Measures: Keep away from heat, sparks or open flames.

NFPA RATING:	Health - 3	Flammability - 0	Reactivity -NDA	Special-NDA
HMIS RATING:	Health - 3	Flammability - 0	Reactivity - NDA	Protective Equipment - X

SECTION 4: First Aid Measures

Skin Contact: Remove contaminated clothing. Flush affected area with water for at least 15 minutes. Wash affected area with mild soap and water. Seek medical attention if symptoms develop and persist.
Ingestion: Immediately rinse mouth out with plenty of water. If within 30 minutes after ingestion, give victim a small glass of water or milk (NEVER give anything by mouth to an unconscious person). Do not induce vomiting unless instructed to do so by a physician or poison center. Seek medical attention immediately.
Eye Contact: Immediately flush with plenty of water. Remove contact lenses (if easy to do) and continue flushing for at least 15 minutes. Seek medical attention immediately.

Inhalation: Remove to fresh air. Seek medical attention immediately if breathing becomes difficult or other symptoms develop.

Antidotes/Notes to Physicians: There is no known specific antidote. Additional information about niclosamide may be found in the Physician's Generix.

SECTION 5: Fire Fighting Measures

Flashpoint: NDA

Autoignition temperature: NDA

Flammable Limits: LEL: NDA UEL: NDA

Extinguishing media: Use dry chemical or water

Hazardous products of combustion: Carbon monoxide, carbon dioxide, nitrogen containing chemicals (e.g. NO_2, NO_x, NH_3), and chlorine containing compounds (e.g. HCl).

Unusual fire and explosion hazards: Dusts may form an explosion hazard. Cool containers with water spray.

Protective Equipment: Use NIOSH/MSHA approved SCBA and full protective gear.

SECTION 6: Accidental Release Measures

Extinguish all ignition sources. Do not breathe dust. Harmful if inhaled. Cover with plastic sheet to prevent spreading. Absorb or cover with dry earth, sand or other non-combustible material and transfer to container. Remove containers from the spill area. Do not attempt to clean up chemical spills without appropriate personal protective equipment (see section 8). Ventilate area and wash spill site after material pickup is complete. See section 13 for information on the disposal of recovered material.

SECTION 7: Handling & Storage

Handling: Do not breathe dust. Harmful if inhaled. Minimize dust generation.

Storage: Store upright in a cool, dry, well ventilated area out of direct sunlight. Handling in both unloading and loading operations as well as fabrication may cause nuisance dust to be generated. Necessary precautions for personal protection should be taken. Store away from incompatible materials (see Section 10). Use with proper personal protective equipment (see Section 8). Keep containers tightly closed at all times. Do not reuse container. Keep out of reach of children.

SECTION 8: Exposure Controls & Personal Protective Equipment

Engineering Controls: Use local exhaust in processing or storage areas. If any of the limits in section 2 are

exceeded, local ventilation or respiratory protection may be necessary.
Skin: Protective gloves recommended to prevent skin contact. Contact glove manufacturer for more information.

Eye Protection Wear safety glasses with side shields.

Respiratory: If industrial hygiene surveys show that the exposure limits in Section 2 are exceeded, use of a NIOSH approved respirator is necessary. Seek professional advice prior to respirator selection or use. Follow OSHA respirator regulations (29 CFR 1910.134). Use a positive pressure air supplied respirator if there is a potential for an uncontrolled release, exposure levels are not known, or under any other circumstances where air purifying respirators may not provide adequate protection.

SECTION 9: Physical & Chemical Parameters

Physical State: Solid
Odor: metallic
Vapor Density (air = 1): NDA
Boiling Point: NDA
Viscosity: NDA
Specific Gravity: NDA
pH: 9.27 for a 1% suspension
Appearance: Bright yellow (with faint green tint) solid
Vapor Pressure: 2.0×10^{-14} Pa @ 77°F (25°C)
Percent Volatile by Volume: NDA
Freezing Point: NDA
Melting Point: 408°F-419°F (209°C-215°C)
Bulk Density: 0.45 g/mL
Solubility in water at pH 7: 2.83×10^{-5} g/mL @ 68°F (20°C)
Solubility in other solvents: slightly soluble in hexane, octanol, and methanol

Log K_{ow}: 5.33

SECTION 10: Stability & Reactivity

Stability: Stable

Incompatible Materials and conditions to avoid: Heat, strong oxidizing agents, strong acids.
Hazardous polymerization: Will not occur.

Hazardous decomposition products: Carbon monoxide, carbon dioxide, nitrogen containing chemicals (e.g. NO_2, NO_x, NH_3), and chlorine containing compounds (e.g. HCl).

SECTION 11: Toxicological Information

Product Based Information:
This product consists mostly of niclosamide ethanolamine salt (CAS# 1420-04-8). Exposure can occur by inhalation, eye or skin contact, and ingestion. This product may be harmful if inhaled based on a four hour LC50 of 1.95 mg/L. Inhalation may cause upper respiratory tract irritation with coughing and nasal discharge. Eye contact caused irritation based on animal studies. Skin contact caused mild irritation based on animal studies. The rabbit dermal LD50 is > 2000 mg/kg. This product did not cause skin allergic reactions in animal studies. Ingestion may cause irritation to the mouth, throat and esophagus and possibly nausea and vomiting. The rat-oral LD50 is > 5,000 mg/kg. Ingestion caused adverse effects to the gastrointestinal tract and dark or red lungs in random animals in animal studies. Additionally, ingestion resulted in red stained faces, non-formed feces, and/or hunched posture in some animals, which resolved by day 1 after treatment. Rats treated five days/week for three weeks in a subacute dermal toxicity study tolerated treatment without effects at the maximum dose of 200 mg/kg. Rats were fed dietary doses in a chronic feeding study. The no-observed effect level in this study was 2000 ppm. No pathological symptoms or demonstrated symptoms of poisoning were noted in dissected animals in chronic rat feeding studies (1-2.5% added to standard food five times weekly for 326 and 219 days, respectively. Niclosamide ethanolamine salt was found to be non-mutagenic in the Ames test. Additionally, niclosamide did not cause mutagenic effects using the *in vivo* test for chromosomal aberrations in mouse bone marrow cells or in the mouse lymphoma forward mutation assay. There were

no data located addressing potential developmental or reproductive effects. There were limited data located addressing the carcinogenicity of niclosamide ethanolamine salt. The National Cancer Institute conducted a study regarding the carcinogenicity of niclosamide amino ethanol salt in 1978 and found that niclosamide ethanolamine salt was not carcinogenic to male Osborne-Mendel rats or to female B6C3F1 mice. It was carcinogenic to female Osborne-Mendel rats and caused mammary adenocarcinomas and carcinomas of the glandular portion of the stomach. However, the occurrence of these cancers was not significantly higher than in control animals. It was concluded that there was no convincing evidence of carcinogencity following exposure to niclosamide ethanolamine salt to the species examined. Additional information about niclosamide may be found in the Physician's Generix.

Ingredient Based Information:
This product contains 2-chloro-4-nitroaniline (CAS#121-87-9). Limit data were located regarding this chemical. This chemical was shown to cause the transformation of hemoglobin to methemoglobin, nitrosulfhemoglobin, sulfhemoglobin and a decrease in oxyhemoglobin in animal studies.

There were no toxicological data located for 5-chloro-2-hydroxybenzoic acid (CAS#321-14-2).

Carcinogens: None per OSHA, NTP, or IARC
Target Organs: All tissues (irritation), and respiratory system (e.g. lungs).

Medical Conditions that May be Aggravated by Exposure: Existing skin (e.g. sensitive skin) conditions and respiratory or lung diseases/disorders (e.g. asthma, emphysema, bronchitis).

SECTION 12: Ecological Information

Ecotoxicity: Niclosamide ethanolamine salt (CAS# 1420-0408) is the active ingredient in formulations for molluscides and piscicides.

- In flow through tests, a 70% niclosamide ethanolamine salt mixture resulting in a water concentration of 0.38 mg/L caused a 50% decrease in reproduction in Daphnids.
- Niclosamide ethanolamine salt is not considered very toxic to birds. LD50's ranged from 500 mg/kg in gulls to > 2000 mg/kg in Mallards and Bobwhites for a 70% formulation of niclosamide ethanolamine salt.
- The LC50 for a 70% niclosamide ethanolamine salt mixture for Daphnids was 0.65 mg/L/21 days in a static bioassay without aeration at a pH of 7.2-7.5, water hardness of 40-50 mg/L as calcium carbonate and alkalinity of 30-35 mg/L.
- The LC50 for a 70% niclosamide ethanolamine salt mixture for Rainbow trout was 340 µg/L/96 hours (95% confidence limit of 289-399 µg/L) at 55.4°F (13°C) weight 1.4 grams, in a static bioassay without aeration at a pH of 7.2-7.5, water hardness of 40-50 mg/L as calcium carbonate and alkalinity of 30-35 mg/L.
- The LC50 for a 70% niclosamide ethanolamine salt mixture for *Gammarus pseudolimnaeus* was 2400 ug/L/96 hours (95% confidence limit of 1800-3100 µg/L) at 70°F (21°C) weight 1.4 grams, in a static bioassay without aeration at a pH of 7.2-7.5, water hardness of 40-50 mg/L as calcium carbonate and alkalinity of 30-35 mg/L.
- The LC50 for a 70% niclosamide ethanolamine salt mixture for *Orconectes* was 25,000 µg/L/96 hours (95% confidence limit of 19,000-33,000 µg/L) early instar, at 70°F (21°C) in a static bioassay without aeration at a pH of 7.2-7.5, water hardness of 40-50 mg/L as calcium carbonate and alkalinity of 30-35 mg/L.

Environmental Fate:

Terrestrial fate:	estimated K_{oc} of 350 (moderate soil mobility)
Aquatic fate:	estimated K_{oc} of 350 (expected to adsorb to suspended solids and sediment in water)
	Estimated Henry's Law Constant: < 3.8 x 10^{-8} atm-m^3/mole (mainly non-volatile from water surfaces
Estimated BCF:	46 (moderate, but not high potential for bioaccumulation)

Atmospheric fate: experimental vapor pressure < 7.5 x 10^{-8} mm Hg at 68°F (20°C) (will exist mainly in the particulate phase in the atmosphere).

Vapor phase niclosamide ethanolamine salt is degraded in the atmosphere by photochemically produced hydroxyl radicals with an estimated atmospheric half-life of 4.5 hours

SECTION 13: Disposal Considerations

This material (as packaged) may be considered a hazardous waste. Be aware that the waste owner has responsibility for final disposal. Regulations may also apply to empty containers, liners or rinsate. Laws may change or be reinterpreted; state and local regulations may be different from federal regulations. This information applies to materials as manufactured; contamination or processing may change waste characteristics and requirements.

SECTION 14: Transport Information

DOT Hazard Description: Pesticides, solid, toxic, n.o.s (niclosamide ethanolamine salt), 6.1, UN 2588, PGIII

SECTION 15: Regulatory Information

Chemical Inventories: This product is exempt from TSCA regulation under FIFRA Section 3 (2) (B) (ii) when used as a pesticide. In terms of inventories, niclosamide ethanolamine salt (CAS# 1420-04-8), 2-chloro-4-nitroaniline (CAS#121-87-9) and 5-chloro-2-hydroxybenzoic acid (CAS#321-14-2) are listed on the EINECS.

Reportable Quantities (RQ) (40 CFR table 302.4): None

SARA TITLE III (Superfund Amendments and Reauthorization Act):

Section 302 Extremely Hazardous Materials (40 CFR 355): None listed

Section 304 Notification Of Accidental Release (40 CFR 355): None listed

Sections 311/312 Hazard Categories (40 CFR 370):

Immediate (Acute) Health Effects:	YES
Delayed (Chronic) Health Effects:	NDA
Fire Hazard:	NO
Sudden Release of Pressure Hazard:	NO
Reactivity Hazard:	NDA

Section 313 Toxic Chemical Release Reporting (40 CFR 372.65(a)): Not listed

STATE REGULATORY INFORMATION: Since each state has the authority to promulgate standards more stringent than the federal government, this section cannot provide an inclusive list of all state regulations which apply to this product. Questions related to state regulations should be directed toward local officials.

SECTION 16: Other Information

For additional information, refer to the 2000 North Emergency Response Guidebook and the ACGIH Documentation of the Threshold Limit Values for individual components.

This information is provided in good faith, but without express or implied warranty.

This MSDS was prepared by Environmental Health & Safety, Inc., St. Paul, MN, 55116, USA