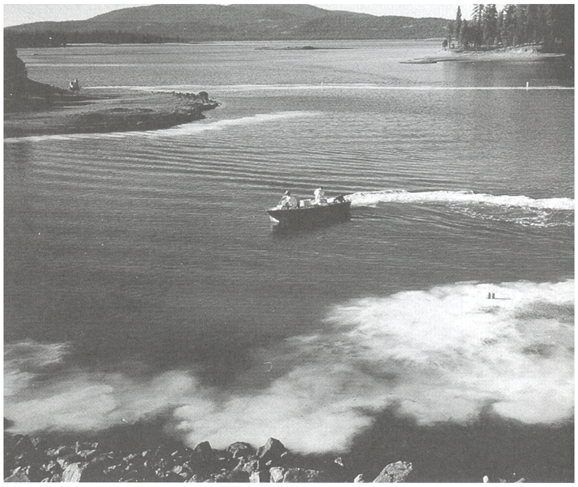

Chapter 4. Background Information on Use of Registered and Unregistered Piscicides

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.