Rotenone in Fisheries: Are the Rewards Worth the Risks?

Edited by

Richard L. Cailteux, Leo DeMong, Brian J. Finlayson, William Horton, William McClay, Rosalie A. Schnick, and Charlie Thompson

Trends in Fisheries Science and Management 1

Proceedings of the Symposium
Rotenone in Fisheries:
Are the Rewards Worth the Risks
Held in St. Louis, Missouri, USA
August 21, 2000

American Fisheries Society
Bethesda, Maryland
2001

Suggested citation formats:

Entire book

Cailteux, R. L., L. DeMong, B. J. Finlayson, W. Horton, W. McClay, R. A. Schnick, and C. Thompson, editors. 2001. Rotenone in fisheries: are the rewards worth the risks? American Fisheries Society, Trends in Fisheries Science and Management 1, Bethesda, Maryland.

Chapter within the book

Archer, D. L. 2001. Rotenone neutralization methods. Pages 5–8 *in* R. L. Cailteux, L. DeMong, B. J. Finlayson, W. Horton, W. McClay, R. A. Schnick, and C. Thompson, editors. Rotenone in fisheries: are the rewards worth the risks? American Fisheries Society, Trends in Fisheries Science and Management 1, Bethesda, Maryland.

Ebook available online at
http://www.fisheries.org/publications/rotenone

ISBN: 1-888569-33-6
Library of Congress Control Number: 2001093337

American Fisheries Society
5410 Grosvenor Lane, Suite 110
Bethesda, Maryland, 20814-2199 USA
http://www.fisheries.org

Contents

Introduction

B. J. Finlayson
California Department of Fish and Game
Pesticide Investigations Unit
1701 Nimbus Road, Suite F
Rancho Cordova, California 95670
bfinlayson@ospr.dfg.ca.gov

Fisheries managers rely on a wide variety of tools including piscicides for the management and assessment of fish populations to maintain diverse and productive aquatic ecosystems and high quality recreational fisheries. As many as 30 piscicides have been used for fisheries management in the United States and Canada. Only four are currently registered for use, two lampricidies, Lamprecide® and Bayluscide® and two general piscicides, antimycin and rotenone. Rotenone is by far the most commonly used piscicide in North America today with a current average annual use of 9,474 kg (as active ingredient) (McClay 2000).

Despite the ongoing need for rotenone, its continued use has become a concern for environmental and animal rights groups, and its use has been challenged, halted, and discouraged. In response to these increased concerns, the U.S. Fish and Wildlife Service in 1997 funded the American Fisheries Society's (AFS) sponsored Rotenone Stewardship Program. The Rotenone Stewardship Program has produced a number of products designed to promote its safe and effective use and ensure its continued availability as a fish management tool. These include the *Rotenone Use in Fisheries Management Administrative and Technical Guidelines Manual* (Finlayson et al. 2000) and the symposium *Rotenone Use in Fisheries: Are the Rewards Worth the Risk* that was held at the AFS 2000 National Meeting in St. Louis, Missouri.

Nine years previously, an AFS symposium focused on the use of fishery management chemicals. The *Chemical Rehabilitation Projects Symposium: Procedures and Issues* was presented at the Western Division Annual Meeting in Bozeman, Montana (July 15-19, 1991) and the National Annual Meeting in San Antonio, Texas (September 8-12, 1991). It was clear from these earlier presentations that there was a need for guidelines for the safe and effective use of rotenone. It was anticipated that the guidelines would minimize the occurrence of situations that have caused or have threatened the prohibition of its use as a fishery management tool. Thus, the concept of the Rotenone Stewardship Program was borne. This current symposium proceedings contains eleven papers covering a wide variety of topics including stewardship and use policies, environmental safety issues and several case histories from California to New York. Several of the papers included in these proceedings were originally given in 1991 but have been revised.

Three papers discuss stewardship and use policies. The paper *AFS Rotenone Stewardship Program* details how products of the program will assure the continued availability of rotenone for fisheries management. These products are grouped into four areas (1) technical and administrative guidelines, (2) public information program, (3) electronic information program, and (4) long-term strategies. The paper *A Programmatic Environmental Assessment for Funding Rotenone Projects through the Federal Aid in Sports Fish and Wildlife Restoration Programs* proposes to programmatically approve, under the National Environmental Policy Act, rotenone projects using Federal Aid in Sport Fish Restoration Program funds that meet specific criteria. The proposed criteria include use in standing (nonflowing) waters with application by surface methods, rates not to exceed 200 parts per billion, and excluding use when threatened or endangered species or domestic water sources are involved. It is anticipated that the impact of the Environmental Assessment will be a reduction in environmental compliance paperwork by the states for projects that are covered under this bureaucratic umbrella. The paper *The Use of Rotenone on National Forests* discusses United States Forest Service policy that sets strict environmental controls to assure minimal environmental impact. The policy includes elements of project planning, biological assessment, public review, and approval.

Two papers discuss environmental safety issues. The paper *Rotenone Detoxification Methods* describes why attempts to neutralize rotenone have been inconsistent and have occasionally resulted in becoming highly publicized failures. These incidents can be traced back to a lack of understanding of the factors influencing the efficacy of the potassium permanganate or inaccurate projections of rotenone concentrations being neutralized. The paper details application methods, rates, and equipment used to apply potassium permanganate to effectively and successfully neutralize rotenone. The paper *Chemical Residues in Surface and Ground Waters Following Rotenone Application to California Lakes and Streams* summarizes 15 years of environmental monitoring data. These data show that effects can be confined to the treatment and neutralization areas, the chemicals in surface waters generally persist for less than seven weeks, the synergist piperonyl butoxide may persist for up to nine months in cold water, little persistence of chemicals in sediments, and ground waters were not contaminated from the use of rotenone.

Three papers characterize different aspects of the Strawberry Reservoir treatment, one of the largest chemical rehabilitation projects undertaken. The paper *Overview of a Large-Scale Chemical Treatment: Strawberry Valley, Utah* provides the statistics of the treatment that involved the application to 875,000 pounds of powdered and 4,000 gallons of liquid rotenone to a basin over 170 square miles at a cost of $3,800,000. Several innovative procedures for handling and applying the rotenone were developed for this treatment. The paper *Utah's Procedure for Mixing Powdered Rotenone into a Slurry* describes the aspirator that revolutionized the use of powdered rotenone by allowing for the safe application of large quantities in short periods of time. The paper U*tah's Rotenone Sandmix: A Formulation to Maintain Fish Toxicity in Seeps and Springs* describes the gelatin-sand-rotenone mix that provided a cheap and effective way of maintaining lethal levels of rotenone in seeps and springs containing upwelling ground water thus, preventing the target fish from using these areas as refugia.

Finally, there are three papers describing very different case histories using rotenone in fisheries management. All three stress the importance of soliciting public input and gaining public support prior to beginning a project. The paper *The Use of Rotenone to Restore Native Trout in the Adirondack Mountains of New York – An Overview* details how the anthropogenic impacts including acid deposition in high elevation lakes and the introduction of competing nonnative fishes have caused drastic declines in brook trout abundance. New York began removing non-native and undesirable fish species to restore brook trout, and rotenone has been the only viable alternative that can restore degraded habitat. Rotenone has also been used extensively in the Western United States in restoration of cutthroat trout populations. The paper *Knife Lake and Knife River Rehabilitation Project* describes a Minnesota treatment to eliminate common carp and reintroduce walleye. Environmental review for the project fostered a close working relationship and sense of cooperation between governmental agencies and the public. This removal of carp resulted in improvements in water quality, reestablishment of aquatic macrophytes, and the successful reintroduction of game fish. In the paper *Northern Pike Control at Lake Davis, California,* the political and biological impacts of invasive species are discussed. A chronology of northern pike in California and their control efforts are given. Effective policies to provide consistent direction for management of detrimental and undesirable fish are being minimized as political forces attempt to alter decisions based on scientific facts.

Hopefully this symposium proceedings will increase the understanding of fish toxicants and further promote the safe and effective use of rotenone.

References

Finlayson, B.J., R.A. Schnick, R.. Cailteux, L. Demong, W.D. Horton, W. McClay, C.W. Thompson, and G.J. Tickacek. 2000. Rotenone use in fisheries management: administrative and technical guidelines. American Fisheries Society, Bethesda, Maryland.

McClay, W. 2000. Rotenone use in North America (1988-1997). *Fisheries* 25(5):15-21.

Rotenone Neutralization Methods

Donald L Archer
Utah Division of Wildlife Resources
1594 W. N. Temple
Salt Lake City, UT 84116
nrdwr.darcher@email.state.ut.us

Abstract.—Rotenone has been widely used to eradicate fish communities. Attempts to neutralize rotenone have been notoriously inconsistent and have occasionally resulted in tragic and highly publicized failures. Two major problems have been understanding the factors influencing the efficacy of the neutralizing agent and accurate projections of rotenone concentrations being neutralized. The chemical most commonly used to neutralize rotenone formulations is potassium permanganate ($KMnO_4$). Engstrom-Heg (1971, 1972) conducted some very definitive controlled experiments that demonstrate that dissolved electrolytes and organic matter have a major influence on the amount of $KMnO_4$ required to neutralize a given concentration of rotenone. This paper discusses application rates, field methods and equipment used to apply $KMnO_4$ effectively to neutralize field applications of rotenone.

Neutralization of rotenone at the terminus of the treatment area is an important but seldom reported element of chemical fish population renovation projects. The Utah Division of Wildlife Resources has successfully neutralized as much as 180 ft^3/s of water containing approximately 2 ppm of rotenone. Our technique has been successful under many different circumstances.

Failed attempts at effective neutralization have been attributable to unexpectedly high concentrations of rotenone and application of the often used, but erroneous rule of thumb that a 1:1 $KMnO_4$ to rotenone ratio is adequate for successful neutralization. Following a major mishap on a treatment project in the Virgin River in Southern Utah and Nevada that negatively impacted some 40 miles of river below the target area, the need for further study of the issue became apparent. Division personnel became familiar with research conducted in New York State by Engstrom-Heg (1971; 1972; 1976) on the use and efficacy of $KMnO_4$. The application of Engstrom-Heg's work has dramatically improved our effectiveness at neutralizing rotenone in field applications.

Four important points of that research have particular importance to the Division's field operations. First, the addition of $KMnO_4$ at a one to one ratio is insufficient except in very soft water (i.e., waters of less than 20 ppm total hardness) that does not contain significant organic matter. Waters of greater hardness or having significant organic matter require additional $KMnO_4$. Second, Engstrom-Heg (1972) demonstrated that there is a lag time for $KMnO_4$ to fully neutralize the rotenone and that lag time must be planned for when undertaking a neutralization operation. Engstrom-Heg (1972) developed curves showing the relationship between Noxfish concentration, $KMnO_4$ concentration and the contact time required for neutralization (Figure 1). The values taken from Figure 1 are then adjusted to compensate for water chemistry variables specific to the project. According to figure 1, it requires 6 times as much chemical to neutralize one ppm of rotenone in 10 minutes as it does to neutralize the same concentration of rotenone in 60 minutes. The amount of $KMnO_4$ required depends on how rapidly the rotenone is to be neutralized. Also note the curves rise steeply at concentrations greater than 3.4 ppm. Engstrom-

Heg (1972) theorized that, at concentrations above 3.4 ppm, rotenone goes into a colloidal state suggesting that it is wasteful to apply rotenone at any higher concentrations. The chart shows that the amount of potassium required depends on how rapidly the rotenone is to be neutralized.

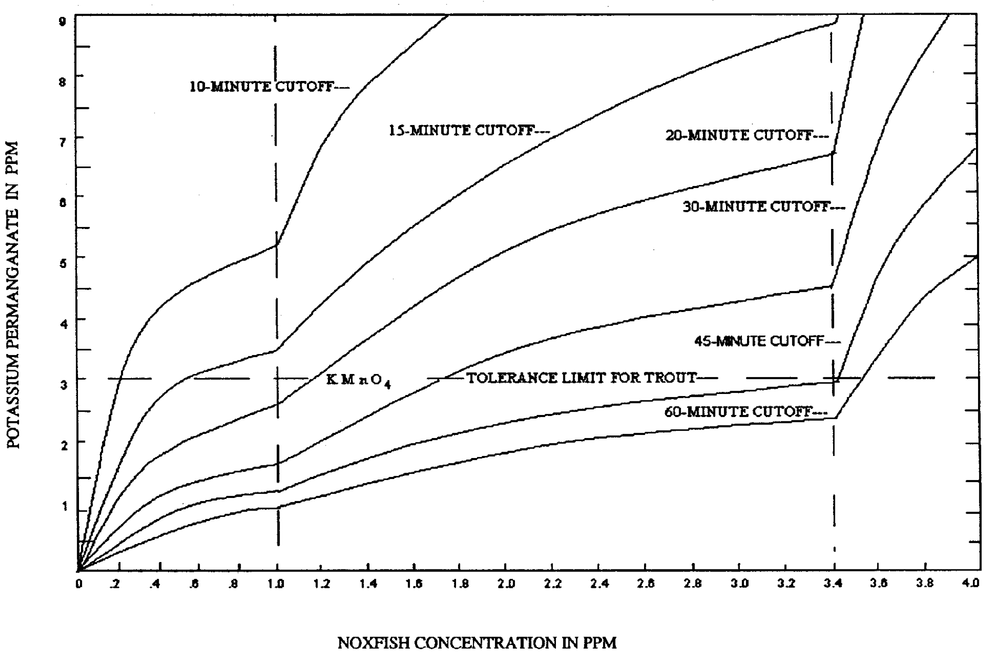


Figure 1. Relationship between Noxfish® concentration (5% rotenone), $KMNO_4$ concentration, and contact time required for neutralization (from Engstrom-Heg 1972).

Third, Engstrom-Heg (1972) also experimented with dissolved electrolytes and showed that they also influenced the efficacy of $KMnO_4$ to neutralize rotenone and that must be taken into account when calculating the proper concentration to use. He developed a formula to compensate for that factor which is as follows:

application rate = ($KMnO_4$ ppm from Fig. 1) × [1 + .002(total alkalinity ppm – 20)]

Fourth, Engstrom-Heg (1972) found that organic matter other than rotenone in the system neutralized $KMnO_4$ and that must be considered when calculating rates. He determined that adjusting for approximately 50% of the organic demand for $KMnO_4$ resulted in satisfactory application rates. To that end, the formula was modified as follows.

The formula is

Application rate = ($KMnO_4$ from Fig. 1) × [1 +.002(total alkalinity ppm – 20)]
+ ½ organic demand

Engstrom-Heg (1971) demonstrated that chlorine demand was essentially equivalent to $KMnO_4$ demand and therefore standard methods used to determine chlorine demand could also be used to determine the amount of $KMnO_4$ required to satisfy the organic demand. Fortunately the simple chemical kit used to test chlorine demand in swimming pools is very adequate for those computations.

Toxic Applications

The $KMnO_4$ concentrations required to neutralize rotenone and organic matter as determined by these computations can be toxic to fish. Marking and Bills (1975) found that the toxicity of $KMnO_4$ to rainbow trout increased with increased total hardness and that sustained exposure to concentrations in excess of 2 ppm was lethal.

The Division often applies $KMnO_4$ in excess of 4 ppm, however, in field applications the active $KMnO_4$ is very quickly reduced to naturally occurring compounds that are not toxic. Those broken down products represent much less of a downstream hazard than active rotenone passing downstream of the treatment zone. Without neutralization the rotenone may travel many miles over several hours before it becomes adequately diluted or neutralized.

Since there is a lag time for $KMnO_4$ to neutralize the rotenone there may be fish mortalities outside the target zone. It is imperative that the public and other agencies be informed of that possibility to avoid any alarm or negative publicity should such an event occur.

Field Applications

Initially the Division's procedure was to dilute the $KMnO_4$ in water and meter it into a stream through a constant headstand pipe in the form of a float valve in a 15-gallon barrel. That was a labor-intensive process and required constant attention, particularly on big projects. Late fall projects presented the prospect of freezing temperatures that could inactivate the apparatus. A search for alternatives discovered that there are bulk-dispensing machines designed for a variety of commercial uses that were capable of dispensing the dry chemical very effectively.

Several bulk-dispensing machines were purchased from Acrison, Inc. The type selected is a variable speed auger device that can be adjusted to dispense dry chemical at a constant rate. The model the Division procured can dispense $KMnO_4$ at a rate ranging from 2 to 45 pounds per hour, which has proven adequate for our purposes. A 150 kilowatt 120 volt AC gasoline powered generator has been used to provide power to those units. Those generators are very adequate to power the dispensers and simultaneously provide nighttime lighting.

The Division has used $KMnO_4$ in crystalline and free flowing forms but has found that problems of clumping and bridging in the hopper are avoided if the more expensive free flowing product used in potable water treatment plant applications is used. That material has some dust and since it is very caustic it can damage skin and mucous membranes of the nose and throat. Personnel are required to wear protective clothing and breathing apparatus for protection.

Field Setup

The Division has developed a monitoring and application system that has been very effective to date. A 30-sec neutralization rate is computed after determining the $KMnO_4$ demand as previously described. Two dispensing units are setup; the first unit is positioned at the terminus of the treatment zone and the second is situated downstream at least the distance that the rotenone would have traveled during the time lapse planned for total neutralization. Live cages of fish are established immediately above the first station to monitor the arrival of the rotenone. A second live cage is established immediately above the second station to monitor the efficacy of the first neutralization station. A third live cage is established below the planned effective range of the second station to assure that no rotenone has bypassed the second station. The neutralization process is started at the same time that rotenone is introduced into the stream to assure that none passes undetected downstream before the neutralization process has begun.

Three 3-person crews are employed for three 8-hour shifts. Two crew members attend the dispensers continuously. The third person roves between units assisting each attendant in recharging the dispensers, checking the live cages periodically and taking care of unexpected contingencies.

Each station maintains a log of activities, application rates, and observations relative to live cage fish behavior for later reference. Those logs are invaluable for later reference and to determine what may have happened should a failure occur.

Important Considerations

1. Safety—personnel are required to wear protective gear and have assistance lifting the 110-pound kegs. A Materials Safety Data Sheet should be present at both neutralization stations.
2. Accuracy—Application rates need to be computed at least twice by different people.
3. Backup—At least one set of backup generators and dispensers should be readily available.
4. Application—Rotenone applicators need to be briefed and cautioned against over dosing with rotenone. That is particularly important regarding unmetered hand applications.
5. Neutralization is not immediate so there is a zone downstream of the area targeted for treatment where fish mortalities may occur and it is imperative that the public and all interested entities are alerted of that possibility.

Most problems encountered when neutralizing rotenone are related to accurately calculating the concentration of rotenone that needs to be neutralized. Metered injections have not been a serious problem but the field crews that are involved in hand spraying seeps, dead water areas and off channel pools can create major uncertainties regarding the total amount of rotenone that has been applied to the stream. It is suggested that those crews receive training on the levels of application that are adequate to achieve the objective. Further, providing hand application crews with only enough rotenone to reasonably conduct the operation will safeguard against overdoses.

Example: Hand applicators commonly carry one backpack sprayer capable of holding approximately four gallons of spray mixture. One quart of 5% rotenone is sufficient to treat 27 ft^3 per second at 1 ppm for 20 minutes. It is obvious that hand applicators carrying four gallons of a highly concentrated spray mixture could seriously impact the treatment concentration. The author believes it is appropriate to use no more than one cup of 5% rotenone per 4-gallon sprayer, which would treat 8 cu ft per second for 15 minutes at 1.0 ppm.

References

Engstrom-Heg, R. 1971. Direct measurement of potassium permanganate demand and residual potassium permanganate. New York Fish & Game Journal 18 (2):117–122.

Engstrom-Heg, R. 1972. Kinetics of rotenone-potassium permanganate reactions as applied to the protection of trout streams. New York Fish & Game Journal 19(1):47–58.

Engstrom-Heg, R. 1976. Potassium permanganate demand of a stream bottom. New York Fish & Game Journal 23(2):155–159.

Marking, L. L., and T. D. Bills. 1975. Toxicity of potassium permanganate to fish and its effectiveness for detoxifying antimycin. Transactions of the American Fisheries Society 104 (3):579–583.

Knife Lake and Knife River Rehabilitation Project

Timothy J. Brastrup
Minnesota Department of Natural Resources
1601 Minnesota Drive, Brainerd, Minnesota 56401, USA
tim.brastrup@dnr.state.mn.us

Abstract.—In October 1989, the Minnesota Department of Natural Resources (MNDNR) treated 1,266-acre Knife Lake and 70 miles of the Knife River system above the lake with a synergized rotenone concentrate formulation to eliminate the carp *Cyprinus carpio* population. This was a controversial project from initial planning through treatment, and required a lengthy mitigation process. Issues, such as environmental contamination, damage to endangered species, reduced lake-based recreation and economic loss, project cost, chemical toxicity, effects on nontarget organisms, and damage to cultural resources, were raised initially by two people in opposition. It required 18 months and the preparation of an Environmental Assessment Worksheet to mitigate or address these concerns. The mitigation process involved several MNDNR disciplines, various other units of government, and a large sportsmen's organization. Because of the lengthy mitigation process, the cost increased from the planned $119,150 to $350,000. The results of the treatment were total removal of rough fish, improvements in water quality, reestablishment of aquatic macrophytes, and successful reintroduction of game fish. Walleye *Stizostedion vitreum* are again successfully spawning in the Knife River and numbers have greatly increased. Carp have not appeared in the watershed through 2000 and most of the pre-treatment fish assemblage has been reestablished. In a debriefing meeting following this project, MNDNR managers decided to take a pro-active approach to informing the public as a policy for future projects.

History of the Knife Lake System

Knife Lake and the Knife River are located in Kanabec and Mille Lacs Counties in east-central Minnesota (Figure 1). The Dakota nation once inhabited the area surrounding Knife Lake. At that time, the size of Knife Lake was smaller by comparison to its current size. As a result of historic resources and archeological surveys in the 1960s, most of the Knife Lake was listed on the National Register of Historic Places.

A log and earthen dam was constructed on the outlet of Knife Lake in 1927 to control water levels, and the elevation was set so that a larger, deeper basin was created. As a result, much of the shoreland inhabited by the Dakota Nation became inundated with water.

A permanent dam was reconstructed in 1929. The dam washed out during extremely high water conditions in 1972. To impede the rapid loss of water, a temporary dam made of large granite slabs was constructed. This served to somewhat maintain the water level until a permanent dam could be constructed in 1982.

During the interim period, carp *Cyprinus carp* from the lower Knife River and Snake River migrated into Knife Lake. The granite slabs served as a fish ladder, allowing carp to access the lake.

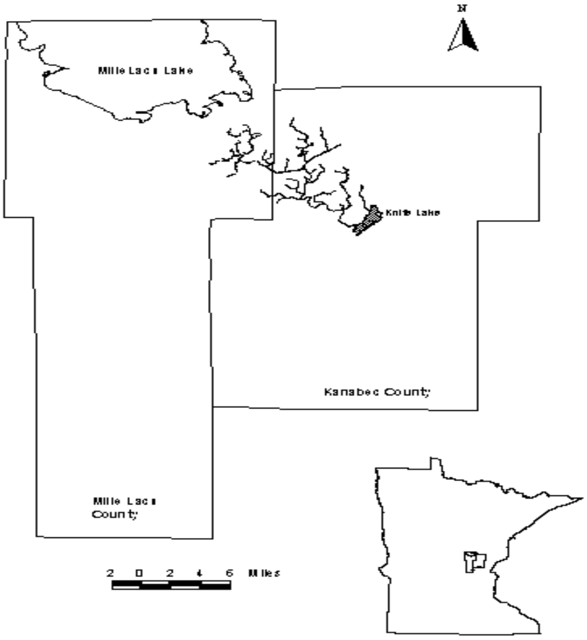


Figure 1. A map of the Knife Lake and Knife River rehabilitation project area. Knife Lake, Minnesota

According to MNDNR Lake Survey (1981), carp had achieved a dominant role in the fish community of Knife Lake. Several consecutive strong year classes had been recruited and the population rose to a very high and stable level (Figure 2). Over the next several years, fishing quality diminished as aquatic vegetation virtually disappeared and both prey and predator species populations collapsed. Water quality also worsened. Decades of unwise watershed agricultural practices loaded nutrients into the lake basin, and the lake experienced severe plankton algae blooms. With the carp's continuous internal recycling of nutrients, water quality and fish habitat degraded to the point where game fish populations diminished. Concerned sportsmen encouraged MNDNR fisheries managers to take remedial measures to improve fishing.

The objective of this project was to determine the best method for eliminating carp from the Knife Lake System for rehabilitation of the sport fishery, increasing water quality and restoration of aquatic macrophytes. Once the method was determined, carp could be eliminated.

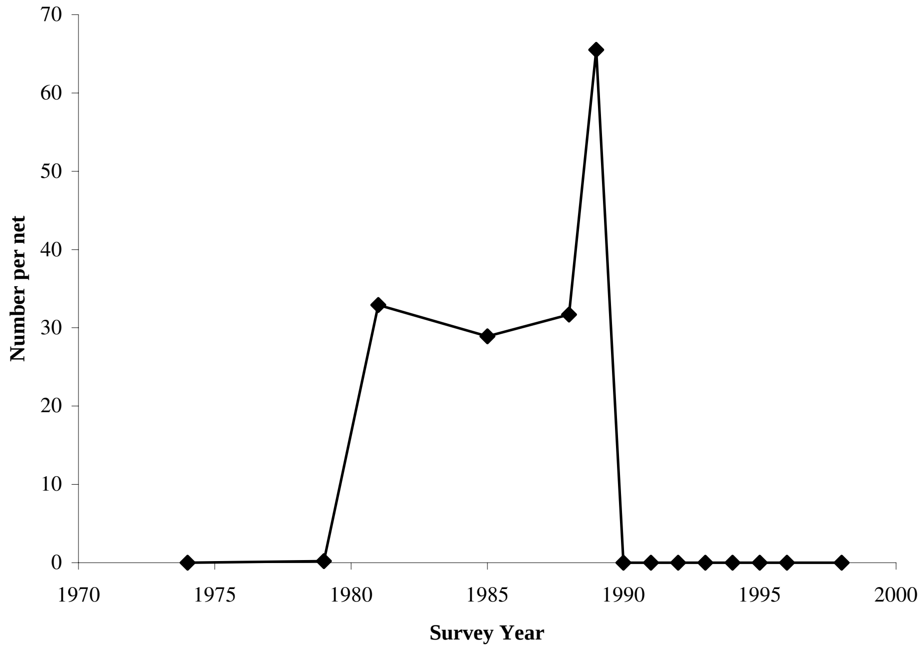


Figure 2. Catch per unit effort of carp in test nets in Knife Lake, Minnesota.

Social Pressure

In 1988, Knife Lake Sportsmen's Club Officers requested a public meeting to discuss ways to improve both the condition of Knife Lake and angling quality. Specifically, the club officers were interested in a rotenone application to eliminate the carp. On April 3, 1988, a public meeting was held in Mora, Minnesota. Approximately 300 members of the public attended. The MNDNR regional fisheries manager agreed that a feasibility study would be conducted, which would focus on alternatives that would address the poor angling and poor water quality. It was at this public meeting that the first indication of opposition to the rotenone alternative was voiced.

Feasibility Study

Standard lake (Scidmore 1970) and stream (Sternberg 1978b) surveys were conducted in 1988 to determine the current fish population status. The stream survey included tributaries to the main-stem Knife River. It was important that current information on the nongame fish species of the river be collected so that native fish assemblages could be reestablished following rotenone treatment.

A reconnaissance of the entire Knife River and its tributaries above the lake was conducted on the ground and by air. The number and location of all beaver dams were indexed and mapped for future reference. Riparian ownership was mapped, and names, addresses, and telephone numbers were provided by the Kanabec County Soil Conservation Service agent. A map of the watershed was drawn (Figure 3), and stream flows and volumes were calculated. The calculations resulted in 182 acre-feet of water in the river and its tributaries. Lake volumes were calculated by the horizontal plane method (Johnson 1978a; Table 1), so that estimates of the amount of rotenone needed for treatment could be planned. The lake volume referenced to the top of the dam was 10,922 acre-feet. In addition, the volumes of four river and tributary impoundments were calculated. The volume of the four impoundments was 366 acre-feet.

The MNDNR Division of Waters was requested to provide a lake drawdown analysis to facilitate a rotenone treatment. Since the Knife Lake Dam was constructed with 30• diameter drawdown conduits for dam repair emergencies, the lake could be drawn down approximately five vertical feet. The Division of Waters used the HEC-1 model to examine several scenarios for the drawdown (MNDNR 1989b).

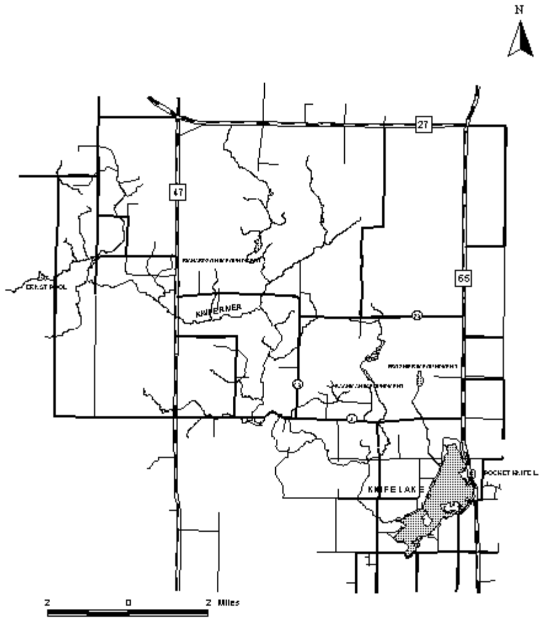


Figure 3. A map of the Knife Lake Watershed, Minnesota

Table 1. Lake volume calculations using the horizontal plan method for Knife Lake. These calculations pertain to the lake prior to the five-foot drawdown for the Knife Lake and Knife River Rehabilitation Project, October 1989.

1986 lake map B-0460
18' maximum depth

Note: There are 18 islands in Knife Lake with a combined area of 36.8 acres. By definition, the planimetered area of the lake is the open-water area and does not include the islands.

Planimetered area of:

Lake	=	1,266.3 acres
5' contour	=	1,080.6 acres
7' contour	=	884.4 acres
9' contour	=	640.8 acres
11'contour	=	362.4 acres
13' contour	=	122.4 acres
18' contour	=	0.1 acres

Volume (Horizontal Plane Method): $V = ({}^{A}1 + {}^{A}2)/2 \times d$

V0'	-	5'	=	5,867.25
V5'	-	7'	=	1965.0
V7'	-	9'	=	1525.2
V9'	-	11'	=	1003.2
V11'	-	13'	=	484.8
V13'	-	14'	=	76.2
V13'		18'	=	.25
Total volume			=	10,922.00 acre feet

Mean depth = Total volume / Planimetered area = 10,922 / 1,266 = 8.6 feet

Variables used in the model were exceedence probabilities, average monthly flows, watershed size, desired drawdown elevation goal, and use of various numbers of siphons in addition to the dam conduits, weather predictions, and starting date.

The number of crewmembers necessary was determined, as was the amount and kind of equipment needed in the event that a rotenone application was made. The projection of cost was made based on the total volume of water, stream flows, concentration of active ingredient, and 1988 cost per gallon of 2.5% synergized rotenone liquid concentrate. Also included in the cost estimate were salaries, equipment rental, travel, and subsistence costs. The cost was estimated at $119,150; however, by the time planning efforts were complete, the cost of rotenone had increased, and several costly mitigation measures were implemented. The total cost of the project thus became $350,000.

Other alternatives, such as netting and watershed projects to improve the water quality, were considered. One alternative was to install a downstream electric weir near the mouth of the Knife River. This would eliminate the need to treat the 70 miles of the river and tributaries. It was learned, however, that such as installation would require the purchase of easements of approximately two miles of land, and a ditch would have to be constructed as an outlet for stunned carp to enter and leave the electric field. These alternatives were found to not be viable. At this point, the rotenone application appeared to be the most viable alternative.

Environmental Assessment Worksheet

An Environmental Assessment Worksheet (EAW) was prepared so that all known alternatives were considered and potential environmental impacts were anticipated. Since the project was large, MNDNR decided to prepare a discretionary EAW to be sure of achieving as much environmental safety as possible.

The EAW included the identification of the responsible government agency, contact persons, a description of the proposed project, the reason for the EAW preparation, estimated cost, size of the project area, number of residential units, list of all known local, state and federal permits required, project's consistency with local comprehensive land use plan, description of current and recent past land use, a description of the soils on the site, a determination of any sinkholes, peat soils, and erodible slopes, approximate depth in feet, any government shoreland classifications, any physical alterations of the lake or stream, any surface water appropriation or groundwater effects, erosion or sedimentation control measures to be taken, the generation of surface runoff, generation of noise, dust or odors, generation of solid waste, affects on fish, wildlife or habitat as well as native species that are officially listed as state endangered, threatened, or of special concern, the location of any historical, archaeological or architectural resources, the potential of destruction of parks, unique farmland, or scenic views, average daily traffic, and if there were adequate utilities present. The preparation of the EAW allowed all conceivable issues to be addressed by members of the MNDNR and the public, leaving little for error (MNDNR 1989a).

Review of the EAW resulted in many useful additions and refinements to the issues. Concerns raised included harm to native species, chemical fate, damage to cultural resources, loss of recreation and local income, environmental damage, lack of effort to reduce watershed-contributed nutrient loading, contamination of local wells, nuisance dead fish, loss of invertebrate communities, inability to detoxify lake water prior to the return of full lake volume and flowout elevation, and inability to eliminate all of the carp. A Benefit and Cost Consideration Worksheet (MNDNR 1979), prepared to accompany the treatment application form and used as an attachment to the EAW, indicated a net benefit-cost ration of 30.3:1 (Table 2).

Public Input

A public meeting was held in March 1989, at Mora, Minnesota to explain the results of the feasibility study and the EAW. At this meeting the individuals opposing the potential chemical rehabilitation project brought up discussion on potential damage to cultural resources.

Members of the public in attendance at this meeting were told that the chemical rehabilitation project was feasible. They were informed that, depending on the results of the public review and the determination by the Environmental Quality Board, the project would likely proceed with a treatment of the lake, river and its tributaries in October 1989. Members of the public present at this meeting were informed of the use of rotenone formulations as a control for rough fish (Sousa et al. 1985).

A 30-day review and comment period ended on July 12, 1989. The findings of the Environmental Quality Board were that no significant environmental harm would occur as a result of this project. On August 15, the drawdown of the lake and preparation for environmental mitigation began.

Table 2. Benefit and cost consideration worksheet developed during the planning phase, October 1989.

Cost

Rehabilitation cost		
Force account labor and equipment	$ 3,200	
Chemical (5,024-gallon rotenone at $16 per gallon)	88,260	
Contracted aerial spraying and demurrage and shipping	27,490	
Fish stocking for 10-year project life	30,238	
	149,188	
Amortized cost (10 years)	14,918	per year
Administrative overhead cost		
10% of amortized cost for force account labor and equipment and contracted aerial spraying.	3,069	per year
Total amortized cost	17,987	per year

Benefit

1.	Anticipated project life	10 years
2.	Anticipated fishing pressure of 50 angler hours/acre/year (see page 2 of rehabilitation proposal worksheet)	16.7 angler trips/acre per year
3.	Monetary benefit assigned one angler trip	$26
4.	1,266-acre lake will provide 21,000 angler trips/year at $26/trip	$546,000 year benefit

Benefit/cost ratio

The benefit/cost ratio for this project is 30.3: 1 and is considered favorable.

Cultural Resources

Much of Knife Lake was on the National Register of Historic Places because a tremendous Native American cultural resource was present. As a result, the State Archaeologist, State Historic Preservation Office, Minnesota Indian Affairs Council, MNDNR Community Liaison Officer, United States Fish and Wildlife Service, Federal Aid Office, and the MNDNR Division of Parks &Recreation Archaeologist determined that several measures would need to be performed in order to approve the project.

Signs were posted around the shoreline stating the statutory protection of cultural artifacts and the penalty for unauthorized collecting. A cultural survey was funded by the MNDNR Section of Fisheries. A total of $50,000 was budgeted for the cost of the survey and artifact collection by the State Archaeologist. The MNDNR Section of Fisheries hired a security agency to patrol the shoreline and provide security for the artifacts, which would be in jeopardy of unauthorized collecting since the lakebed was now becoming exposed due to the drawdown. The cost of the security patrol contract was $26,000. The Knife Lake Sportsmen's Club hired an off-duty peace officer to patrol the shoreline during the intervals when the security agency was not on duty.

Additionally, Operation Neighborhood Watch was initiated by the Kanabec County Sheriff's Department to discourage artifact looting. At the request of the Minnesota Indian Affairs Council, Kanabec County closed one county-owned public access located in a park with a known Indian burial ground. A news release stating the statutory protection of cultural artifacts was printed in newspapers statewide.

As cooperators, the North American Native Fishes Association (NANFA) volunteered to conduct a qualitative survey of the fish species of the Knife River and its tributaries in August 1989, just prior to the application. The MNDNR allowed NANFA to conduct the survey because the results would be useful in determining what species were to be reestablished following the project.

Application Preparation

Permission to enter private property was gained for riparian landowners so that helicopter landing zones and drip barrel stations could be established. Six strategically located landing zones and four drip stations were established following riparian landowners' permission.

Action Plan

Following identification of the treatment area, the project was divided into four jobs or treatment portions. A West Tributary Area (Job 1) consisted of 40 miles of waterways (26 miles of which were dry and 14 miles in need of treatment), two artificial impoundments, and numerous beaver impoundments. These impoundments accounted for approximately 80 surface acres. An East Tributary Area (Job 2) consisted of 42 miles of waterways, 7 miles of which contained flowing water or pockets of water and 35 miles of dry streambed or with isolated pockets of water, one natural wetland and three artificial impoundments. These impoundments and the natural wetland accounted for 82 surface acres of water to be treated. Knife Lake North (Job 3) and Knife Lake South (Job 4) accounted for 601.7 and 493.3 surface acres, respectively. See Tables 3,4,5 and 6 for a detailed data summary and a map of jobs (Figure 4).

The four jobs were presented for bidding to interested helicopter companies. The previous information was provided to guide bidders based on loads and air miles.

Stream flows were calculated using pygmy meter velocity measurements and the standard formula for flow one week prior to treatment in order to calibrate the five drip station barrels properly. The 30-gallon barrels of rotenone formulation were ordered specifically for ease in handling at remote drip station sites.

Lake contours were marked with 2 foot high, brightly colored floats that would be easily seen from an application helicopter. Contours marked were the 0-4 feet, 4-8 feet, and 8+ feet. See Figure 5 for lake contours.

Dam Operation Plan

Preparation of a dam operation safety plan was required. This plan outlined the emergency procedures to follow in the event of a dam failure. Additionally, the MNDNR

Table 3. Headwater impoundments and river volumes and gallons of toxicant applied to the West Tributary Area, October 1989 (Job 1).

Streams- refer to map for indicated treatment lengths.

Length to be treated- 14miles
Stream width-14 feet or less
Estimated acreage- 23 acres
Average depth- 1.5 feet
River Volume- 34.5 acre-feet
Gallons rotenone- 53 gallons
Gallons water- 215 gallons

Length to be flown (additional to 14 miles to be treated) to search for isolated water pockets for spraying- 26 miles

Impoundments- refer to map for locations.

Major impoundments	Acres	Acre-feet	Gallons rotenone	Gallons water	Total gallons	Gallons per acre	Loads 75 gallons each
Ernst	40	60	70	210	280	7.0	4
Quarry	20	40	47	93	140	7.0	2
Beaver	20	100	117	83	200	10.0	3
	80	200	224	386	620		9

Seven estimated hours flying time for Job 1, including time needed between flights for loading.

Division of Waters Permit was needed because the drawdown was considered to be a water appropriation as well as a discharge station.

Base Station

The Knife Lake Sportsmen's Club offered their clubhouse, near the lake, for use as a base station during the treatment. A telephone was installed and volunteers cooked for both the MNDNR and volunteer crews. The MNDNR Division of Forestry committed two tactical communications specialists for the project. These individuals organized a base-station radio center as well as mobile truck units so that communication could be maintained at all times.

Shoreline Inspections

Kanabec County Planning and Zoning Officials, Knife Lake Improvement District Officers, and United States Soil Conservation Service Agents from Kanabec County conducted an inspection of the lake's shoreline for nonapproved septic system drain fields. This inspection was facilitated by the lake drawdown. All legal wells were mapped and checked for static level during the drawdown. As a contingency plan in the event that any local wells became impacted during the drawdown, a truck was contracted to provide potable water until the water level in the lake had returned.

Table 4. Impoundment and river volumes, and gallons of toxicant applied to the East Tributary Area, October 1989 (Job 2).

Streams- refer to map for indicated treatment lengths.

Length to be treated- 7 miles
Stream width- 14 feet or less
Estimated acres- 22.4 feet
Average depth – 1.5 feet
Gallons rotenone- 51 gallons
Gallons water-300 gallons

Length to be flown (additional to 7 miles to be treated) to search for isolated water pockets for spraying- 35 miles

Impoundments – refer to map for locations.

Major impoundments	Acres	Acre feet	Gallons rotenone	Gallons water	Total gallons	Loads Gallons per acre	75 gallons each
Richard Impoundment	10	10	15	45	70	7.0	1
Bachmans Impoundment	20	40	52	88	140	7.0	2
Foschier Impoundment	32	128	150	74	224	7.0	3
Pocket Knife Lake	20	120	140	0	140	7.0	2
		82	298	357	207	574	8

Nine estimated hours flying time for Job 2, including time needed between flights for loading.

Table 5. Lake contour volumes and gallons of toxicant applied to the North Lake Area, October 1989.

Contour	Acres	Acre-feet	Gallons rotenone	Gallons water	Total gallons	Gallons per acre	Loads 75 gallons each
0-4 feet	167.3	335	392	780	1,171	7.0	16
4-8 feet	308.0	1,848	2,162	0	2,161	7.0	29
8+ feet	126.4	1,074	1,257	0	1,074	9.9	14
	601.7	3,257	3,811	780	4,406		59

Table 6. Lake contour volumes and gallons of toxicant applied to the South Lake Area, October (Job 4).

Contour	Acres	Acres feet	Gallons rotenone	Gallons water	Total per gallons	Gallons gallons acre	Loads 75 each
0-4 feet	280.8	562	658	1,308	1,966	7.0	26
4-8 feet	208.1	1,249	1,461	0	1,461	7.0	20
8+ feet	4.4	38	45	0	45	10.0	1
	493.3	1,849	2,164	1,308	3,472		47

Safety

Fifteen volunteers and thirteen employees scheduled to take part in the rotenone application were given Employee Right to Know Training. This training consisted of an explanation of the nature of the formulation, it's actions and indications, mode of action, method of application, formulation contents, precautionary measures, and clean-up procedures. All attendees were given a material safety data sheet and formulation label to be kept on their person throughout the project.

A letter explaining the type of project with an attached material safety data sheet and product label were mailed to Mora Hospital in anticipation of any accidents requiring medical attention.

All workers were issued chemical gloves and masks were offered, if desired. All workers were also issued a map and the approximate times that the various sectors would be treated and by what method. All employees were given training for a noncommercial pesticide applicator's license prior to the project.

Security

Project planners felt because of local rumors, there was potential for demonstration against the project at the rotenone-staging site. To ensure that peace was maintained, several law enforcement agencies were requested to be present. The Minnesota State Highway Patrol, Kanabec County Sheriff's Staff, and a conservation officer were stationed at the rotenone staging site to provide security. A City of Mora police officer was stationed at the Mora Municipal Airport to provide security for one of the application helicopters. No demonstrations took place and the project proceeded peacefully.

Shoreline Stabilization

Project Planners anticipated that unstable areas of the many islands on Knife Lake might erode as a result of being exposed during the drawdown. As a measure of mitigation, the United States Soil Conservation Service, and Agriculture Stabilization and Conservation Service coordinated a plan to fund rip-rapping projects along erodible island and mainland shorelines. In addition, plans were made to reestablish hard stem bulrush *Scirpus acutus* and softstem bulrush *S. validus* along portions of the shoreline where bulrush beds were known to have been prior to shoreline development and the establishment of carp.

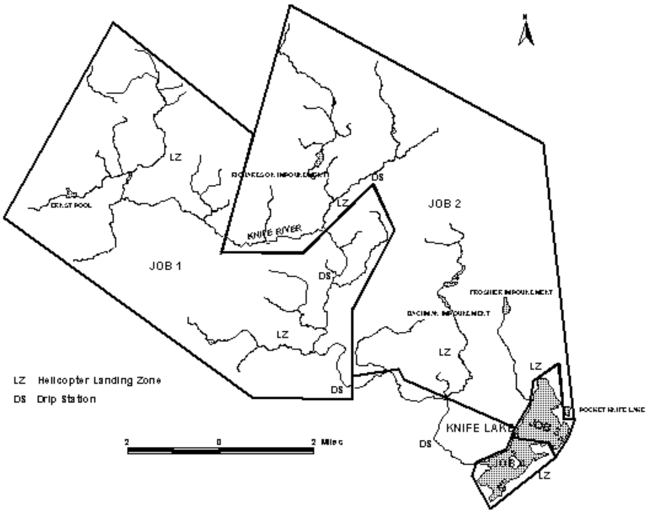


Figure 4. A map of the Knife Lake and Knife River rotenone applications jobs. Knife Lake, Minnesota

Formulation Quality Control

Arrangements were made to have samples of the rotenone formulation lots tested for active ingredient concentration. The testing was coordinated with the MNDNR Division of Fish and Wildlife Chemistry Laboratory. Arrangements were also made to monitor toxicity degradation following treatment. Samples were collected and tested every two days beginning on the day of treatment.

Debate

The two people initially opposed to this project remained vocal throughout the project planning process and well after completion of the project. One individual spoke on several radio programs, criticizing the chemical application option as well as the MNDNR.

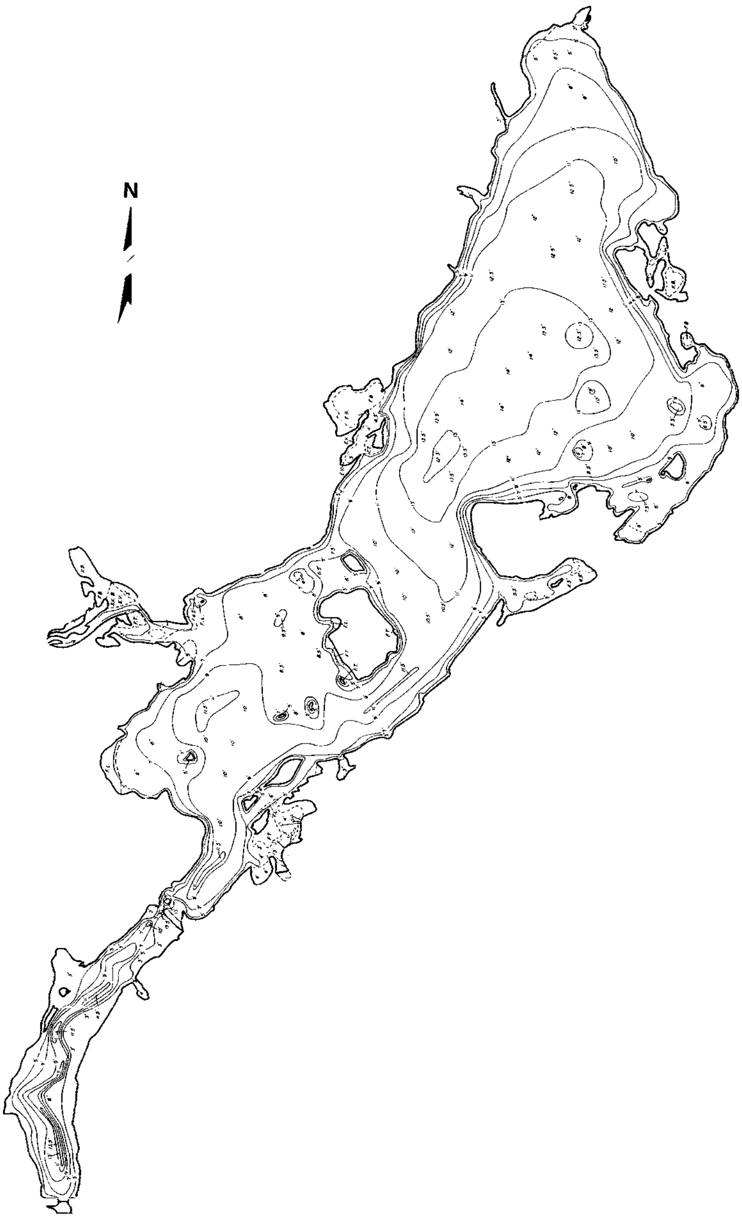


Figure 5. A map of the lake bathometric contours for Knife Lake, Minnesota

Additionally, they were quoted in numerous inflammatory newspaper articles, which gained statewide attention and drew criticism from some of the uniformed public. At least 20 requests for response to criticism through radio, television, newspapers, magazines, and over the telephone were given. One of the individuals mobilized a group of Native Americans to stage a demonstration at the MNDNR central office, requiring the Commissioner of Natural Resources to debate the issue in public with no time to prepare for the questions on specific details.

The opposition was unprepared to debate the issue based on knowledge or fact. At the field level, the primary mode of debate was to clarify the facts, dispel misconceptions, and debate the issues armed with the literature available. The most beneficial literature available was Schnick (1974).

A large majority of the public supported the project. The 350-member Knife Lake Sportsmen's Club was greatly supportive of the project. In fact, 65 of the members physically participated in the project in one form or another. The Mayor of Mora, the entire Kanabec County Board of Commissioners, and local residents wrote letters of support to the Commissioner of Natural Resources.

Final Preparation

The City of Mora granted permission to store a tanker with 5,460 gallons (52 30-gallon pails, 17 55-gallon barrels, and 2 5-gallon pails) of Nusyn-Noxfish® overnight in preparation for the following day's treatment. Chemical placards were affixed to each container and vehicle hauling the product for emergency handling procedures. Five days prior to the treatment, a news release informed the public statewide of the date of the treatment.

Three days prior to the treatments, all riparian zone landowner livestock owners were notified by telephone of the impending treatment. The advance warning was to inform livestock owners that cattle were not in danger of ill effects caused from ingesting any treated water, but the treatment would be aerial, and that the concentration of the formulation would be maintained for three days.

The day preceding the treatment, all of the beaver dams that impounded water in reaches planned for treatment were mapped in preparation for removal the following day. Also, four cages with black bullheads *Ameirus melas* were installed in the treatment area. Two cages were installed in the lake, and two were installed in the river. These fish served as indicators of toxicity in the bioassay.

Communication

A complete communiqué was delivered to the Commissioner's office daily, September 1 to the day of treatment, October 9. The communiqué informed the Commissioner's Office and the Fisheries Central Office of the project progress and warned of any impending opposition activities.

Treatment Procedures

Lake Aerial Application

Prior to the application of formulation, pesticide application warning signs were posted at river road crossings, along the shoreline of the lake, and at public access points on the lake. The signs stated the product being applied, by whom, and the date of safe entry.

The application of rotenone formulation began on Monday morning, October 9, 1989. A helicopter crew working out of the landing zone north of the lake applied the fish toxicant beginning at 0800 hours. The application consisted of 3,811 gallons of formulation and 780 gallons of water stationed at the north landing zone. Fifty-nine loads of spray, each 75 gallons, were applied. Job 3 was completed by 1200 hours, and the crew was transferred to the south landing zone, where 2,164 gallons of formulation and 1, 308 gallons of water were stationed for application. By 1500 hours, Job 4 had been completed.

Watershed Aerial Application

A medium-sized Bell Helicopter, working from two landing zones located on the western portion of the project area (Job 1), began spraying the river, the tributary system, and impoundments at 0800 hours on October 9, 1989. This helicopter crew received 277 gallons of formulation and 548 gallons of water for application to the river and tributaries from this landing zone. It required eleven 75-gallon loads to complete this job. The same helicopter moved to the East Tributary Area (Job 2) by approximately 1200 hours, and worked from two landings zones located in the north and east ends of the watershed. A total of 408 gallons of formulation and 507 gallons of water were then applied to the river, tributaries, and impoundments in the area. The job was completed by 1700 hours.

Drip Station Application

Drip stations were located on upper reaches of tributaries and strategic locations on the main stem of the Knife River. Drip stations consisted of reconditioned 55-gallon barrels, painted black, lying horizontally on a specially constructed cradle. Each barrel was fitted with a spigot and calibration cylinders to allow a metered delivery of formulation to the stream. Stream flows were calculated daily and the drip station calibration was monitored every two hours.

The drip stations were started at 0900 hours on October 9, 1989, and continued to operate continuously through 1200 hours on October 11, 1989, when the supply of formulation was exhausted. Three 30-gallon barrels of formulation were stationed at each drip station.

A night patrol of employees and volunteers provided security for the drip stations during the night and refilled the barrels to maintain proper flow. All empty formulation barrels, calibration vessels, and equipment were triple-rinsed on site and loaded on trucks for reconditioning. A barrel reconditioning facility near Ogilvie, Minnesota, contacted prior to the application, accepted the barrels for reconditioning, according to Minnesota Pesticide Use Law. The tanker, which contained 5,460 gallons of formulation, was triple-rinsed with water from a water tanker. The rinse was discharged into the Knife River at the application site, near the mouth of the river at Knife Lake.

Beaver Dam Removal

The beaver dams located during the previous day's surveys were systematically removed using Kinepac explosives. The local MNDNR Conservation Officer placed and detonated charges in dams to allow pooled treated water to move downstream. There were 11 beaver dams removed in this manner. This effort allowed continuous flow of treated water to kill fish for three days. All of the dam removal took place during the afternoon of the first day of treatment, October 9, 1989. The project was completed before the dams could be rebuilt by beavers.

Backpack Application

Backpack pump cans were used to apply formulation to two small wetland areas near a residential area and to two one-mile stretches of tributaries where the tree canopy was too dense for aerial application. Additionally, a one-half mile sector of stream was retreated on October 16, 1989 to ensure that some impounded water had been treated in an area of dense overhead tree canopy. In all, six pump cans were used on this portion of the application. The pump cans were thoroughly rinsed and the rinse was discharged into the treatment area.

Rinse Disposal

Water from a tank truck was used to rinse the empty rotenone tankers. The rinse was then discharged into the Knife River. Water from the tank truck was also used to triple-rinse the empty rotenone barrels. The rinse was discharged into Knife Lake. However, the rinse was poured onto the exposed lake bed and allowed to flow into the lake instead of directly into the lake. This is a violation of the Minnesota Pesticide Control Law Chapter 18B. The regulations state that triple-rinsed containers must be emptied directly into the project area.

The rinse disposal violation was reported to the Minnesota Department of Agriculture (MNDA), which leveled a fine of $1,650 against the MNDNR and ordered the excavation of the contaminated soil. The fine was paid and the excavated, contaminated soil was stored at the fisheries headquarters for detoxification.

Soil was tested for the active ingredient rotenone and synergist piperonyl butoxide periodically over a one-year period. The detoxification process was to allow photo degradation to occur. The detoxification process required two years to complete. The detoxified soil was then spread thinly on land at an MNDA-approved site.

Fish Removal

Local volunteers began collecting dead fish along the shore of the lake by 1600 hours on October 9, 1989. Prior to the project, the local landfill was contracted to accept the fish carcasses, and earth-moving equipment was on hand to cover the carcasses. Three five-yard dump trucks were in reserve to haul the fish to the landfill, and a backhoe operator was scheduled to load the fish in the event a decision was made to remove the fish.

The local lakeshore property owners, however, organized into an effective fish removal team by hauling small trailer loads of fish carcasses by all terrain vehicles to a common loading area and loading a manure spreader for field application and soil incorporation. A local farmer loaned a tractor and a manure spreader to volunteers, and allowed them to soil-incorporate the fish on his field. In all, 800,000 pounds of fish were killed in the application. Of this, 600,000 pounds of fish were physically removed from the lake by volunteers. Approximately 96% of the poundage of fish, or 768,000 pounds, was carp. This means that Knife Lake was supporting 606 pounds of carp per acre. It took volunteers two weeks to remove the dead fish. They were assisted by 10 inmates from the correctional facility in Lino Lakes, Minnesota.

Bioassay

By the end of the day on October 9, 1989, all of the bullheads used in the bioassay had died. Additionally, a reconnaissance of the entire lakeshore and much of the river and tributary system revealed only dead fish.

Water samples from both the surface and near bottom at several locations on the lake and river showed that the lake detoxified rapidly. Within 10 days no rotenone was detectable (see Table 7). Water temperatures remained near 50º F for most of that period.

An electrofishing survey two weeks following the application consisted of two hours of continuous sampling with a Coffelt boat-mounted boom electrofisher in Knife Lake.

This resulted in no fish being sampled. A Coffelt backpack electrofisher was used to sample two tributary stations, which resulted in sampling one fingerling black bullhead and one pearl dace. These fish were sampled in a tributary that was impounded by beaver and provided small refuge for small fish in an area that could not have been inhabited by carp. This site was inaccessible to carp because of beaver dams having been present preceding the carp’s entry into the system.

Table 7. Rotenone formulation residue in water samples taken from Knife Lake and Knife River following the Knife Lake and Knife River Rehabilitation Project, October 9–11, 1989. Samples were collected one foot above the bottom.

	Rotenone formulation (ppm)			
Site	Oct. 11	Oct. 13	Oct. 17	Oct. 24
Middle of bay south end of lake	1.78	0.65	0.69	<0.40
Middle of bay north end of lake	*	1.09	0.80	<0.40
Knife River 0.5 miles upstream from lake	0.69	0.63	2.03	<0.40

* Interference from contamination prevented determination. Assuming a similar degradation rate was observed at the south end of the lake, this value would be approximately 2.98 ppm.

Conclusions

Subsequent annual resurveys of the lake (1990 through 2000) and the entire river system have shown no evidence of carp being present. A ten-year fish reestablishment and assessment plan was established to accompany the fish toxicant application proposal. This fish reintroduction plan prescribed the stocking of walleye *Stizostedion vitreum*, largemouth bass *Micropterus salmoides*, yellow perch *Perca flavescens*, bluegill *Lepomis macrochirus*, channel catfish *Ictalurus punctatus*, and northern pike *Esox lucius* in the lake. The plan for the river and its tributaries was to reintroduce smallmouth bass *M. dolomieui* and the entire native fish assemblage documented prior to the application.

By 1990 the status of the project area is that gamefish populations were thriving and assuming high levels, as indexed by surveys; growth was excellent; 29 of the 33 species of native fish in the watershed have been successfully reestablished; and smallmouth bass were exploiting the entire river system above the lake. Water quality improved significantly, and aquatic macrophytes were becoming reestablished naturally. Additionally, angling success and satisfaction were high.

The status of the project by 2000 is that carp still are not present in Knife Lake nor the Knife River system, game and nongame fish species have continued to improve in density, water clarity improvement has stabilized, submerged aquatic plants have become quite dense and the relationships with local citizens remains excellent.

Carp have not been sampled during the frequent fish sampling surveys since 1990, a major goal of the 1989 rotenone treatment. Freshwater drum *Aplodinotus grunniens*, native to the watershed and abundant prior to the rotenone treatment, have also not been found. Freshwater drum are rough fish and therefore were not reintroduced.

The number of nongame fish species reestablished has increased from 29 to 32 of the original 33 species eliminated by the rotenone treatment. The reestablished nongame fish assemblage has exploited the entire Knife River system. Additionally, five species not sampled prior to the project that are found in nearby, nonproject waters, were introduced.

Walleye numbers have greatly increased. The 1998 gill-net survey indicated a catch rate of 20.7 fish per net, which is more than eight times higher than nettings prior to the rotenone treatment. Additionally, walleye have returned to spawning successfully in the Knife River, one of the original goals of the project. Stocking needs have decreased because of the contribution to the fishery from natural production.

Other species such as bluegill, northern pike, yellow perch, smallmouth bass and largemouth bass have increased to within lake class catch-per-unit-effort interquartile ranges and have quality components in the fishery. Although not introduced by area fisheries personnel, black crappie *Pomoxis nigromaculatus* have increased in numbers also. They were likely stocked by local individuals.

Water clarity has improved since the rotenone treatment; however, this is not as great as it was immediately following treatment. The secchi disc measurement was 0.2–2.0 feet prior to the project and by 1990 was between 3.0 feet and 5.0 feet. The secchi disc measurements since then have declined to 2.3–3.8 feet, a moderate improvement overall.

The improvements in water clarity and the elimination of carp have facilitated the return of submerged aquatic plants. According to MNDNR, Lake Survey Report (1979) nuisance stands of curly-leaf pondweed *Potamogeton crispus* have to become reestablished in Knife Lake. A similar condition existed prior to the appearance of carp in the early 1970s. Consequently, lakeshore property owners are harvesting plants in an effort to gain access to the lake for angling and recreation activities. Many beneficial submerged plants have become reestablished naturally as well as several hardstem bulrush stands as a result of aquatic plant restoration projects.

The relationships with local government, conservation groups, and individuals, established during the project planning process, remain strong in 2000. Fisheries staff continues to enjoy the assistance and support of local citizens and there is great cooperation on management programs and resource decision-making processes. The two individuals who opposed the project have not been in contact since project completion.

Summary

In October 1989, the Minnesota Department of Natural Resources (MNDNR) treated 1,266-acre Knife Lake and 70 miles of the Knife River System above the lake with rotenone to eliminate the carp population. Carp entered the system in the early 1970s, and their destructive habits radically altered the aquatic vegetation of Knife Lake. Game fish populations had also declined, providing little or no sport fishery. After considering all known alternatives for rehabilitating the fishery, it was evident that chemical rehabilitation was the only viable alternative. The reestablishment of aquatic vegetation and the game fish populations could only be accomplished by the removal of carp. Because of the carp, the degraded condition of the habitat and the continuous recycling of nutrients would have persisted despite continuing improvements to the watershed.

The rotenone treatment of Knife Lake and the Knife River system was the culmination of a yearlong planning effort that included technical and logistic preparation, several public meetings, and the preparation and public review of an Environmental Assessment Worksheet.

A large sportsmen's club contributed a great deal to the project by assisting in planning, mitigation efforts, and implementation. Local units of government also assisted in the planning, coordination, and implementation of this project. In all 25 local, state, and federal governmental agencies and citizens groups were involved in one aspect or another.

There was opposition to this project, however. Initially one local citizen and one other person identifying himself as an environmental activist opposed the project on the basis on environmental contamination, damage to endangered species or species of special concern, reduced lake-based recreation and economic loss, project cost, chemical toxicity, effects on nontarget organisms, and damage to cultural resources.

This project required a tremendous effort for environmental review. The preparation of the EAW allowed the MNDNR to realize several positive aspects of environmental review:

1. A thorough review of the treatment alternatives allowed for increased public awareness of important subtle details.

2. An awareness for environmental review by both the public and governmental agencies raises an environmental consciousness?

3. Environmental review fostered a close working relationship and sense of cooperation between governmental agencies and the public.

4. Environmental review allowed governmental agencies to coordinate with one another, minimizing duplication of effort.

5. The preparation of the EAW increased environmental safety by recognizing potential problems.

6. Environmental review played a large part in project success by requiring intensive planning.

7. MNDNR program policy was attacked; this required additional effort in gaining public confidence.

The project and environmental review process was not without negative aspects. Other difficult outcomes of the entire public review process included

1. The delaying of project implementation in an effort to stop the project.

2. It took great effort to work with a mobilized opposition.

3. The length of time required to respond to the public's requests for information and complete project mitigation greatly increased costs.

4. The diversion of effort from critical planning aspects for side issues was common.

The planning process was, nonetheless, a tremendous learning opportunity for project planners, providing experience both in environmental review and in working with people on a local level. The most valuable lessons learned from this project planning process were the benefits of

1. Taking pro-active approach to informing the public of project plans, and

2. Enlisting the public's input in planning stages and project implementation.

3. Informing the public and opposition of project details instead of reacting to the opposition's charges.

Acknowledgements

I thank Tim Rosinger, Minnesota DNR Division of Fisheries, for preparing the figures in this document, Linda McCabe and Ruth Ziegler, Minnesota DNR clerical, and Kathy Brastrup for word processing. I also thank Charles Anderson, Minnesota DNR Division of

Fisheries Coldwater Research Manager, Bill McClay, AFS, and Rich Cailteux, Florida Fish and Wildlife Conservation Commission for editing this manuscript.

Literature Cited

Johnson, M. W. 1978. The management of lakes for stream trout and salmon. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Special Publication No. 125.

MNDC (Minnesota Department of Conservation). 1979. Development procedural manual, revised April, 1979. Division of Game and Fish.

Minnesota Department of Natural Resources (MNDNR) 1970. Lake survey report. Division of Fisheries, Hinckley, Minnesota.

Minnesota, Department of Natural Resources (MNDNR) 1981. Population assessment report. Division of Fisheries, Hinckley, Minnesota.

Minnesota, Department of Natural Resources (MNDNR) 1989a. Environmental assessment worksheet, Knife Lake and Knife River rehabilitation project. Division of Fish and Wildlife, Hinckley, Minnesota.

Minnesota, Department of Natural Resources (MNDNR), 1989b. Hydrologic drawdown analysis for Knife Lake. Division of Waters, Cambridge, Minnesota.

Schnick, R. A., 1974. A review of the literature on use of rotenone in fisheries. United States Fish and Wildlife Service Literature Review 74-15, NTIS (National Technical Information Service) PB-235/AS, Springfield, Virginia.

Scidmore, W. J., 1970. Manual of instructions for lake survey. MNDNR, Section of Fisheries, Special Publication No. 1. St. Paul, Minnesota.

Sousa, R. J., F. P. Meyer, and R. A. Schnick, 1985. Better fishing through management. How rotenone is used to help manage our fishery resources more effectively. United States Department of Interior, Fish and Wildlife. St. Paul, Minnesota.

Sternberg, R. B. 1978b. Minnesota stream survey manual. Minnesota Department of Natural Resources, Section of Fisheries, Special Publication No. 120. St. Paul, Minnesota.

The Use of Rotenone to Restore Native Brook Trout in the Adirondack Mountains of New York—An Overview

Leo Demong
New York Department of Environmental Conservation
Post Office Box 248
Ray Brook, New York 12977, USA
lmdemong@gw.dec.state.ny.us

Abstract.—The brook trout *Salvelinus fontinalis* is endemic to the eastern United States, and historically was abundant in the lakes and ponds of the Adirondack Mountain region of New York State. Anthropogenic impacts have caused drastic declines in brook trout populations. A major cause of the decline has been introduction of competing fishes such as nonnative yellow perch *Perca flavescens*, bass *Micropterus spp*. and golden shiners *Notemigonus crysoleucas*. Range expansion of native fish species such as white suckers *Catostomus commersoni* and brown bullheads *Ameiurus nebulosus* has also been detrimental. Brook trout, a species that was commonly found alone or in simple communities with only one or two other fish species, is unable to compete successfully in these situations. Chemical reclamation using rotenone is the only viable tool that can restore these degraded systems. Follow-up studies by New York State biologists and Cornell University researchers have supported the findings of others; that the negative impacts of pond reclamation with rotenone are minor and short-term.

Introduction

The Adirondack Mountain Region of New York State is often said to be the largest remaining contiguous forest area east of the Mississippi River. With over 2,000 lakes and ponds, the Adirondacks are regionally and nationally important as a recreational and fishery resource. Significant development and colonization of the region did not occur until the mid-nineteenth century, but took place quickly thereafter. In response to the rapid exploitation of the area, especially extensive lumbering, the Adirondack Forest Preserve was established by law in 1885. This law, which prohibited lumbering of state forest lands, was the first such law in the United States which provided a mechanism to protect public land in perpetuity. The protection was incorporated into the New York State Constitution with Article XIV in 1896.

The Adirondack Park is a unique patchwork of interspersed public and private lands. Approximately 55% of the 6 million acres is in private ownership. Land use and development of these private lands is subject to the rules and regulations of the Adirondack Park Agency (APA), an Agency whose mission is to preserve the wild character of the region. The remaining 45 % is owned by the State of New York and is managed by the New York State Department of Environmental Conservation (DEC). These public lands are classified as intensive use, moderate intensity, wild forest or wilderness (including special primitive and canoe areas), with progressively strict allowable uses. Intensive Use areas may contain campgrounds and similar facilities while wilderness is to be managed so that the "hand of man is not apparent" (APA 1972). It is noteworthy that the State Land Masterplan anticipates fish management including pond reclamation with rotenone on all land classes. In addition to its role in regulating private land development, the APA also regulates all wetlands in the Adirondack Park. For this reason the DEC must obtain wetlands permits from the Adirondack Park Agency when applying pesticides to wetlands.

The Adirondack Brook Trout Restoration and Enhancement Program is based upon the premise that prior to colonization by Europeans, brook trout *Salvelinus fontinalis* were pervasive throughout the region, often existing alone or in simple fish communities with one or two other species. Support of this assertion includes early Adirondack Guidebooks and historic biological investigations. Wallace's *Guide to the Adirondacks* refers to the "general rule" that all ponds contain brook trout (Wallace 1894) and describes the quality trout fishing in many waters. Further evidence that brook trout were generally widespread in the region can be garnered from Mather (1882) who published information about the distribution of fishes which he obtained by making public inquiries. These inquiries were published in *Forest and Stream*, a popular publication of the times, and were also sent to various persons known to be familiar with Adirondack locales. Of 16 responses cited in Mather's report, only a handful of ponds were reported to not contain brook trout. George (1980) summed up the historical knowledge of brook trout distribution in the Adirondacks; "Under primeval conditions the brook trout was nearly ubiquitous in the Adirondacks. Its agility and facility in rapidly flowing water allowed it to spread widely, perhaps even concurrently with the demise of the glaciers, thus explaining its presence in unstocked waters above currently impassable waterfalls".

Unfortunately the rapid settlement of the Adirondacks by humans during the second half of the eighteenth and early nineteenth century was accompanied by an almost maniacal stocking of non-native fishes. Northern pike *Esox lucius*, yellow perch *Perca flavescens*, golden shiners *Notemigonus crysoleucas*, largemouth bass *Micropterus salmoides* and smallmouth bass *Micropterus dolomieui*, species now widely associated with the Adirondacks, are all introduced species. Brook trout are not well suited to live in association with these invaders, and their populations always suffered dramatic declines shortly following such introductions. By the time of the General Biological Surveys conducted in New York during the later 1920's and early 1930's, many waters were described as having been ruined by the introduction of these species. By 1960 greater than 90 per cent of the total water area in regions of the Adirondacks had been subject to warm water game fish and panfish introductions, causing a serious decline or elimination of the brook trout fishery (Zilliox and Pfeiffer 1960). Native fishes have also been widely stocked and species like brown bullheads *Ameiurus nebulosus*, white suckers *Catostomus commersoni* and sunfish *Lepomis spp*. are more widespread than historically. These native fishes may too depress brook trout stocks, but they are able to compete well in complex fish communities. For this reason, several native fish species including the above may be the target of a rotenone project.

The Early Program

Because most Adirondack lakes and ponds are natural water bodies and cannot be drained, there was no way to remove detrimental fish species once they had become established. Early attempts to reduce yellow perch populations included direct removal using fyke nets and artificially manipulating water levels to destroy eggs. Such attempts were unsuccessful in restoring trout fishing (Flick and Webster 1992). The advent of rotenone as a fish toxicant presented the first viable alternative to restore a native fish community to selected waters. New York was among the first states to use rotenone for this purpose. The New York Conservation Department, (New York's natural resource agency which is now part of the New York State Department of Environmental Conservation) undertook an ambitious project during the years 1952 to 1954 when yellow perch were eliminated from a chain of connected waters which formed the headwaters of the West Branch of the St. Regis River (Zilliox and Pfeiffer 1956). This project involved the treatment of 14 lakes and ponds and over 21 miles of streams. Four barrier dams were constructed to prevent the reintroduction of the eliminated fish. It is noteworthy that this area remains free of yellow perch, a species shown to be particularly detrimental to native brook trout, (Flick and Webster 1992) to the present day. The project has had enormous benefits that continue nearly a half-century later. Due to the exceptional angling opportunities afforded, the rotenone reclamation programs were popular with sportsmen and merchants. By 1975, approximately 125 Adirondack lakes and ponds had been treated. Unfortunately, the program never had a dedicated funding source and relatively few projects were undertaken during the period 1975-1988.

The Current Program

Analysis of survey data collected by the Adirondack Lake Survey Corporation from 1984-1987 revealed that of 1,123 lakes and ponds containing fish, 65% contained one or more non-native species of fish (Gallagher and Baker 1990). This statistic, coupled with reports of declining brook trout fishing, underscored the need for an active recovery program. In 1989, the DEC established a steady funding source and began implementing the Adirondack Brook Trout Restoration and Enhancement Program. This program provides for brook trout restoration via pond reclamation with rotenone and pond liming to mitigate acidification from acid rain. It seeks to preserve several Adirondack "heritage" strains of brook trout. Project goals include the management of 2,000 acres of Adirondack brook trout waters through an annual ongoing program.

Soon after initiation, the Adirondack Brook Trout Restoration and Enhancement Program came under fire from local and national environmental groups. Probably due to the lull in the program of the 1980's, the public was no longer familiar with the reclamation process. The Adirondack Park Agency, the agency responsible for pesticide regulation in Adirondack Park wetlands, was also uncomfortable with the process and permits were extremely difficult to obtain. In 1990 animal rights organizations sought injunctions preventing the treatment of several ponds. These injunctions were not sustained, but the program continued under a cloud. Further legal actions were brought forth in 1991 and 1992. Opposition to the program reached its zenith when demonstrators attempted to block the treatment of Little Green Pond in 1991 and several arrests were made. Not only was a large law enforcement presence necessary to complete the project, but the level of publicity led then DEC Commissioner Thomas Jorling to personally view the project. It became clear that DEC would need to answer its detractors if the brook trout restoration program were to proceed, in a normal fashion.

Although DEC biologists were comfortable with the reclamation process and were satisfied that the adverse impacts were minor and short-term, DEC concluded that it was important to better document the survival and recovery of non-target organisms. DEC agreed to APA permit conditions that called for making such observations and filing of reports. In this effort, DEC has documented that rotenone-caused mortality of crustaceans and invertebrates are generally modest. By comparing post-treatment invertebrate samples with pre-treatment collections, including those made by the Adirondack Lake Survey Corporation, biologists have shown that invertebrate diversity after reclamation is equal to or greater than it was prior to removal of non-native fish populations. Post-treatment mortality and survival observations led DEC to conclude that odonates (damselflies and dragonflies) are virtually not impacted in ponds treated with rotenone at concentrations commonly used in New York State (1.0 ppm). The documented lack of impacts to odonates was particularly important programmatically because some opponents of pond reclamation had raised the issue of project impacts on odonate species that were limited in distribution.

APA personnel were particularly concerned with the fate of amphibian populations. To answer these concerns, post-treatment sampling was conducted at several treated waters where amphibian mortality had been documented. At each pond, field personnel were able to collect all species that had experienced mortality. In most cases, other amphibian species that had not shown up in the mortality collections were also documented. In addition, the Bureau of Fisheries prepared an informational paper that detailed how nontarget organisms, including Adirondack species of amphibians, recovered following rotenone treatments. For amphibians, the mechanisms of recovery include the use of ephemeral spring pools for egg laying and the fact that Adirondack amphibians have life cycles that include terrestrial forms that would obviate any long-term impacts (Miller et al.1992).

The continued foraging and nesting success of loons, osprey and other waterfowl at treated waters was also documented. In short, DEC was able to document what the literature so clearly shows: that the impacts of rotenone at normal treatment concentrations are minor and short-term. The DEC will continue to make and document these pre- and post-treatment observations.

Other persons and groups objected to, what they viewed as, too frequent treatments of the same waters. The need for most re-treatments is probably due to unauthorized introductions of fish via illegal fishing with baitfish. However, in some cases undesirable species may survive the treatment. Considering these points, it was in DEC's best interest to do all it could to maximize the chance for complete removal of unwanted fish. A primary step toward this goal was to initiate steps to identify the very best candidate waters. Lakes that had large wetlands or tributary systems too extensive to be effectively treated were dropped from consideration. Candidates were screened more rigorously for effective barriers to the reintroduction of unwanted species. In some cases man-made barriers were rebuilt to make them more effective impediments to fish migration. High elevation candidates with outlet streams containing naturally occurring water falls and rock slides were identified and considered for treatment.

Because current New York State pesticide regulations limit rotenone treatment concentrations to 1.0 ppm. (a level considerably less than that allowed on the product label), DEC found it necessary to implement treatment strategies that ensured efficient and rapid dispersion of the chemical. A more precise protocol for deep pumping was incorporated. This consisted of three key parts: (1) an updated bathymetric map is constructed for all candidate waters, generally using three meter contours; (2) the total lake volume is calculated, and volume calculations are generated for each three meter lake stratum; and (3) deep pumping of stratified lakes is accomplished by applying rotenone through three meter vertical bars, treating each layer with the calculated amount of rotenone. The general procedure is to start at the deepest areas, working progressively to more shallow strata. This seems to drive many of the fish toward the surface where water temperatures are generally higher and rotenone toxicity is most acute. When the uppermost layer (surface to three meters) is treated, the fish mortality is rapid and impressive numbers of target fish sometimes surface. Although most liquid formulations of rotenone are designed to cross the thermocline, experience has shown that under summer conditions encountered in Adirondack ponds, the rotenone does not successfully penetrate the thermocline. This may be due to the very strong stratification that is often encountered, especially in highly colored waters. For example, a temperature profile in Big Hope Pond, Franklin County, at the time of reclamation in August 2000, had a temperature difference of 18°C between the surface and six meters. Some states generally treat during the late autumn when pond temperatures are more uniform to avoid such dispersal problems. However, several factors make summer treatments an important option in New York. These factors include more rapid breakdown of the rotenone, thus allowing summer treated ponds to be stocked with fall fingerling trout, and the need to free staff to conduct other fall field activities.

A protocol of toxicity testing was implemented which has helped to ensure that all areas of treated lakes receive the target concentration of rotenone. This methodology, based upon the toxicity work of Engstrom-Heg and Colesante (1979), calls for water samples to be collected from multiple stations and varying depths on the day following the initial rotenone application. Rotenone concentrations are estimated by observing the time to death of test fish. If the overall rotenone concentration is found to be less that the target concentration, additional rotenone is applied to lake areas or strata that have deficient concentrations. This testing procedure has resulted in “rotenone boosting” in several treatments and secondary fish mortalities have been observed after boosting. The protocol has resulted in several rotenone projects being successful that otherwise would likely have failed. Since 1989, only one lake has required a re-treatment due to the survival of a significant competitive species. In a few instances, banded killifish, *Fundulus diaphanus* a species not considered to be serious trout competitor, have survived rotenone applications, but re-treatments have not been warranted.

While DEC has been largely successful using a 1.0 ppm concentration, this level is uncomfortably close to the minimum level of toxicity to control some fish species. Occasionally brown bullheads (a species shown to be relatively tolerant of rotenone) are observed sluggishly swimming after rotenone treatments despite the fact that toxicity tests showed that the rotenone concentration reached 1.0 ppm. In these situations, DEC personnel have no recourse except to depart. Post-treatment netting indicates that DEC has been more successful at eliminating the more tolerant species when water temperatures are comparatively high. Hopefully, the Bureau of Pesticides' regulations will be modified to allow treatment at labeled recommendations.

Although DEC took measures to better document the modest impacts of rotenone treatments, staff concluded that it would be desirable to have independent investigators examine the issue. To test the hypothesis that non-native fish communities exert top-down effects, thus altering the biotic integrity of other food web components, Cornell University researchers studied three candidate waters, conducting pre- and post-treatment samples of the aquatic community (Harig and Bain 1995). They found that within a relatively short-time after removal of an abundant non-native fish community, the species composition of phytoplankton and zooplankton communities shifted to more closely resemble native communities. They concluded that "fish community composition influences lake ecosystem properties in small Adirondack Lakes and that fish community management can be used to promote different ecosystem qualities".

In summary, the DEC Bureau of Fisheries attempted to answer questions from persons, groups and agencies that were concerned about the reclamation process. It did so by documenting the mortality, survival and recovery of non-target organisms that may have been impacted by rotenone applications. DEC attempted to be responsive to various entities by preparing position papers on rotenone use and by providing detailed answers to those with concerns.

Heritage Strains

The genetic diversity of New York's heritage strains of brook trout is a substantial portion of the total diversity of the species complex (Perkins and Krueger, circa 1995) A key component of the Adirondack brook trout program is the fostering of the wild trout heritage by stocking these valuable fish in reclaimed ponds. Scientists think that there are at least seven remaining heritage strains of brook trout in the Adirondack Park. Currently, the Bureau of Fisheries is actively protecting four strains in the Adirondacks; the Windfall Pond strain and Little Tupper Lake Strain, both originating in Franklin County, the Horn Lake Strain which is native to Herkimer County, and Nate Pond Strain, native to Essex County. Several Department policies serve to minimize the possibility of hatchery influences on these special stocks. The Windfall Pond and Horn Lake Strain broodstocks are wild fish that are netted in natural ponds with trap nets in the fall and eggs are collected in the field. Little Tupper Lake Strain broodstock are captive and held at a rearing facility, but they are frequently replenished with wild fish caught in natural ponds. DEC is fostering the Nate Pond Strain by transferring captured wild fish to other natural ponds. When taking wild strain eggs, a minimum of 50 pairs of adults are stripped of gametes to ensure that each egg lot represents the full genetic variability of the strain. When rearing heritage strain brook trout in hatcheries, the normal procedure is to raise them only to the fall fingerling

stage before stocking, thus reducing the duration of hatchery selection. Wild strain fish are normally stocked only in lakes and ponds where natural reproduction is considered likely. In that way, the new population becomes naturalized which also preserves the wild attributes. Wild strain brook trout are always used for initial reintroductions in wilderness areas, in keeping with wilderness values.

Constraints to the Program

As previously stated, the historical record is clear that prior to the influence of Europeans, brook trout were abundant in virtually all Adirondack lakes and ponds, including the larger waterbodies. Many examples are well documented. The St. Regis Chain of Lakes (distinct from the chain of lakes mentioned above), comprise about 1,000 acres. In 1930 it was reported that yellow perch, northern pike and bass were still unknown in that system and brook trout were common (New York State Department of Environmental Conservation 1930). Today these non-native competitors dominate the fish fauna of the St. Regis Lakes, and brook trout have been extirpated. The same report describes how the former "famous" trout fishery in nearby Osgood Pond (600 acres) had already been destroyed by the introduction of yellow perch, black bass and pike. Other examples abound. Unfortunately, these relatively large resources cannot be restored. Not only would the cost of rotenone for such large projects be prohibitive, but the large wetlands, extensive tributaries, and low gradient outlets generally associated with these lower elevation lakes make effective treatments impossible. Of the literally thousands of acres of former brook trout habitat, only a very small percentage can ever be restored by reclamation with rotenone.

Persons and groups that do not support the application of rotenone might take reassurance from the fact only a small percentage of aquatic habitats can be treated. While Bureau of Fisheries' experience and the literature both support that impacts to wetlands and non-target species are minimal, the fact remains that for every acre that is subject to a rotenone treatment, literally thousands of acres of open water and wetlands will remain untouched.

Success of the Adirondack Brook Trout Restoration and Enhancement Program

Since the inception of the Adirondack Brook Trout Restoration and Enhancement Program in 1989, a total of forty-four lakes and ponds have been treated with rotenone. These forty-four waters represent 1,150 acres of quality brook trout resource restored. Twenty-one waters totaling 600 acres have been stocked one or multiple times with a heritage strain of brook trout and at least nine of these have established naturalized, self-sustaining populations. Likely, several other reclaimed ponds have also developed self-sustaining populations, but follow-up surveys have not yet been conducted to verify this supposition. In contrast, an analysis in April, 1976 found that only six state owned ponds, comprising fewer than 100 acres, were known to contain pure wild strains of brook trout (Keller 1979).

A significant number of Adirondack lakes and ponds that have not been reclaimed do support good quality brook trout fisheries. Some of these ponds still have native species associations, while others continue to support fair fishing in the face of moderate competition. In all, well over three hundred lakes and ponds comprising over 23,000 acres are managed for brook trout. The value of fishing for brook trout in Adirondack Lakes and Ponds exceeds $18,000,000 per year as based on the angling projections of Pfeiffer (1979) who estimated that anglers would expend in excess of ten angler trips per acre per year by 1992, and the economic estimates provided by the 1988 New York Statewide Angler Survey (Connelly et al. 1990). Costs associated with managing the brook trout resource include fish propagation, air stocking, supplies and materials for pond reclamation and liming, salaries and fringe benefits and indirect costs. In total, these are estimated to be $476,782 per year. A comparison of the costs of managing brook trout with the total value of the fishery reveals a highly advantageous benefit/cost ratio of 39:1 (Demong and Strait 1995). The intrinsic value of restoring and enhancing a piece of the Adirondack Heritage is inestimable.

References

APA (Adirondack Park Agency), Adirondack Park State Land Master Plan 1972. 1st Edition. Albany. 44 pp.

Connelly, N.A., T.L. Brown and B.A. Knuth. 1990. New York statewide angler survey. Division of Fish and Wildlife. New York State Department of Environmental Conservation. Albany. 158 pp.

Demong, L.M. and L.E.Strait. 1995. Economic implications of brook trout management. New York State Department of Environmental Conservation. Ray Brook. 3 pp.

Engstrom-Heg, R. and R.T. Colesante. 1979. Predicting rotenone degradation in lakes and ponds. New York Fish and Game Journal 26(1):22-36.

Flick, W.A. and D.A. Webster. 1992. Standing crops of brook trout in Adirondack waters before and after removal of non-trout species. North American Journal of Fisheries Management 12: 783-796.

Gallagher, J., and J. Baker. 1990. Current status of fish communities in Adirondack Lakes. Pages 3-11 to 3-44. In: Adirondack lakes survey: an interpretive analysis of fish communities and water chemistry, 1984-87. Adirondack Lakes Survey Corp., Ray Brook.

George, C.J. 1980. The Fishes of the Adirondack Park. New York State Department of Environmental Conservation. Albany. 92 pp.

Harig, A.L. and M.B. Bain. 1995. Restoring the indigenous fishes and biological integrity of Adirondack mountain lakes. Report of New York Cooperative Fish & Wildlife Unit, Department of Natural Resources, Cornell University. Ithaca.

Keller, W. T. 1979. Management of wild and hybrid strains brook trout in New York lakes, ponds and coastal streams. New York State Department of Environmental Conservation. Albany.

Mather, Fred. 1882. Memoranda relating to Adirondack fishes, with descriptions of new species, from researches made in 1882. Weed, Parsons and Co., Albany.

Miller, W.W. Jr., W.F. Schoch, and L.E. Strait. 1992. Restoration of aquatic Adirondack ecosystems and the recovery of nontarget species from rotenone treatments. New York State Department of Environmental Conservation. Ray Brook. 20 pp.

New York Conservation Department. 1930. A biological survey of the St. Lawrence watershed. Supplemental to Twentieth annual report. Albany.

Perkins, D.L., and C.C. Krueger. Circa 1995. Heritage brook trout project-summary report to the New York State Department of Environmental Conservation. Department of Natural Resources, Cornell University. Ithaca.

Pfeiffer, M.H. 1979. A comprehensive plan for fish resource management with the Adirondack zone. Bureau of Fisheries. New York State Department of Environmental Conservation. Ray Brook. 207 pp.

Wallace, E. R. 1894. Wallace's Guide to the Adirondacks. Watson Gill., Syracuse.

Zilliox, R.G. and M. Pfeiffer. 1956. Restoration of brook trout fishing in a chain of connected waters. New York Fish and Game Journal 3(2):167-190.

Zilliox, R.G. and M. Pfeiffer. 1960. The use of rotenone for Management of New York Trout Waters. Canadian Fish Culturist, 28: 3-12..

Chemical Residues in Surface and Ground Waters Following Rotenone Application to California Lakes and Streams

B. J. Finlayson, S. Siepmann, and J. Trumbo
California Department of Fish and Game
Pesticide Investigations Unit
1701 Nimbus Road, Suite F
Rancho Cordova, California 95670
bfinlayson@ospr.dfg.ca.gov, ssiepman@ospr.dfg.ca.gov, or jtrumbo@ospr.dfg.ca.gov

Abstract.—Over the past 15 years, the California Department of Fish and Game has monitored applications of the rotenone formulations Nusyn-Noxfish® (synergized liquid formulation) and Pro-Noxfish® (powdered formulation) to lakes and streams. The monitoring studies were designed to limit liability and address environmental and public health issues. Results indicated that (a) the half-life ($t_{½}$) of rotenone increased inversely with temperature from 0.6 to 7.7 days; (b) the degradation product rotenolone was generally not found in the absence of rotenone, except in waters of low alkalinity (<15 mg/L $CaCO_3$) and temperature (<11°C); (c) Nusyn-Noxfish® contaminant trichloroethylene (up to 4.9 µg/L) and additive xylene (up to 6.7 µg/L) were found typically only in lakes; (d) Nusyn-Noxfish® additives naphthalene (up to 332 µg/L) and methylnaphthalenes (up to 390 µg/L) were found in both lakes and streams; (e) potassium permanganate can neutralize rotenone within a contact time of 30 minutes; (f) Nusyn-Noxfish® synergist piperonyl butoxide can persist in cold (<10°C) and deep (>25 m) waters for up to nine months; and (g) ground water remained free of chemicals in both rotenone formulations. These studies demonstrated that (a) toxicity and other effects can be confined to the treatment and neutralization areas; (b) concentrations of chemicals in surface waters (with the exception of rotenolone and piperonyl butoxide in cold waters) persist for less than seven weeks; (c) rotenone, naphthalene, and methylnaphthalene persist in sediments for short periods; and (d) ground waters were not contaminated.

Introduction

The California Department of Fish and Game (CDFG) has used rotenone to (a) eradicate unwanted exotic fishes, (b) control fish diseases, (c) restore populations of threatened or endangered fishes, and (d) increase populations of desirable game fishes (CDFG 1994a). Rotenone use over the past 50 years has proceeded without serious incident, although not without public controversy. CDFG interacts with regulatory agencies that have jurisdiction over pesticide use, maintenance of water quality, and protection of public health. The amount of interaction has generally paralleled concern by the general public. Many of the issues expressed by the regulatory agencies and the public can be addressed through carefully designed monitoring studies. These include (a) identification and effects of chemicals in the rotenone formulation, (b) containment of chemicals and effects to the project area, and (c) possible contamination of adjacent ground water with chemicals.

Since 1987, CDFG has monitored nine projects (Figure 1) in California lakes and streams treated with the synergized liquid rotenone formulation Nusyn-Noxfish® (USEPA Reg. No. 432-550) and the powdered rotenone formulation Pro-Noxfish® (USEPA Reg. No. 432-829). All of the studies have focused on the application of Nusyn-Noxfish®; only one application (Lake Davis) involved Pro-Noxfish®. The objectives of the studies were to address environmental and human health concerns. These studies monitored the distribution and persistence of rotenone and the degradation product rotenolone (Pro-Noxfish® and Nusyn-

Noxfish® and other semivolatile and volatile organic compounds (Nusyn-Noxfish®) in surface and ground waters.

Figure 1. Location of monitoring sites in California.

Methods

Study sites

Kaweah River—The Kaweah River drainage in Tulare County was treated with Nusyn-Noxfish® at 2 mg/L in fall 1987 to eradicate the unauthorized introduction of white bass *Morone chrysops* (CDFG 1987; Harrington and Finlayson 1988; Figure 1). The treatments lasted approximately four weeks. Rotenone toxicity was allowed to naturally dissipate. Kaweah Reservoir, Bravo Reservoir, several ground water recharge (percolation) ponds, the Kaweah River, and nine wells were monitored (Tables 1 and 2). Water was collected from the surface, mid-depth, and bottom of Kaweah Reservoir at three locations. Approximately 12,000 gallons of Nusyn-Noxfish® were used in the treatments.

Mill Creek—The upper reaches (11 km) of Mill Creek (Walker River Drainage) in the Toiyabe National Forest above a fish barrier in Mono County were treated with Nusyn-Noxfish® at 1 mg/L in fall 1988 (CDFG 1988a) and fall 1989 (CDFG 1989a) to remove brook trout *Salvelinus fontinalis* and rainbow trout *Oncorhynchus mykiss* (Figure 1). The treatments were done in preparation for the reestablishment of Lahontan cutthroat trout *Oncorhynchus clarki henshawi*, a threatened species (Gerstung 1986). The target fish compete (brook trout) and hybridize (rainbow trout) with the Lahontan cutthroat trout. Rotenone was neutralized with potassium permanganate at the fish barrier to limit the effects downstream. Mill Creek and three wells located 2 km downstream of the fish barrier were monitored (Tables 1 and 2). Approximately 5 gallons of Nusyn-Noxfish® were used each year (10 gallons total).

Table 1. Characteristics of surface waters during monitoring studies.

Location (year)	Temperature (°C)	pH	Alkalinity (mg/L CaCO3)	Volume or flow (AF or cfs)
Kaweah Reservoir (1987)	12–21	7.8–9.1	50	25
Kaweah Reservoir	20–22	7.6–7.7	40–63	9,400
Bravo Reservoir	18–23	8.8	40	1,600
Lonestar Pond	13–16	-	-	845
Percolation Reservoir 5	14–27	9.4–9.5	18–20	8
Percolation Reservoir 12	14–26	9.3–9.5	90–96	7
U. Truckee River (1988–1990)	8–20	8.3	20	1
Meiss Lake	10–21	9.4	14	45
Mill Creek (1988–1989)	5–17	8.5	40	<1
Tule River (1988)	18–20	8.4	170	15
Success Reservoir	18–20	7.7	170	5,000
Frenchman Lake (1991)	10–22	8.3	70	22,000
Silver King Creek (1991–1993)	1–19	75	22	12
Wolf Creek (1991 & 1992)	8–12	7.4	30	3
Wolf Creek Lake	5–11	7.7	7	33
Silver Creek (1994–1996)	6–17	7.5	25	5
Lake Davis (1997)	1–12	7.5–9.2	31–42	48,000

Upper Truckee River—The upper reaches (9 km) of the Upper Truckee River in the Lake Tahoe Basin Management Unit above a fish barrier in Alpine County were treated with Nusyn-Noxfish® at 1 mg/L in fall 1988 (CDFG 1988b), fall 1989 (CDFG 1989b), and fall 1990 (CDFG 1990) to remove brook trout (Figure 1). The treatments were done in preparation for the reintroduction of Lahontan cutthroat trout (Gerstung 1986). Rotenone was neutralized with potassium permanganate at the fish barrier to limit effects. The Upper Truckee River, Meiss Lake, and three wells located 7 km downstream of the fish barrier were monitored (Tables 1 and 2). Approximately 50 gallons of Nusyn-Noxfish® were used each year (150 gallons total).

Tule River—Success Reservoir and 11 km of the Tule River upstream of the reservoir in Tulare County were treated with Nusyn-Noxfish® at 4 mg/L in fall 1988 to remove nongame fish species (CDFG 1989c; Figure 1). Rotenone toxicity was allowed to naturally dissipate. Success Reservoir, the Tule River and three wells adjacent to the Tule River were monitored (Tables 1 and 2). Water was collected from the surface and bottom of Success Reservoir at two locations. Approximately 4,300 gallons of Nusyn-Noxfish® were used in the treatment.

Frenchman Lake – Frenchman Lake and several miles of tributaries upstream (Feather River Drainage) in the Plumas National Forest in Plumas County were treated with Nusyn-Noxfish® at 2 mg/L in spring 1991 to eradicate the exotic predatory northern pike *Esox lucius* (CDFG 1991a, 1991b; Figure 1). Rotenone toxicity was allowed to naturally dissipate in the lake, but the discharge from the dam into Little Last Chance Creek was neutralized with potassium permanganate to limit effects. Frenchman Lake and three adjacent wells supplying water to Plumas National Forest campgrounds were monitored (Tables 1 and 2). Water was collected from the surface, mid-depth, and bottom of Frenchman Lake from four locations. Sediment was also collected. Approximately 15,000 gallons of Nusyn-Noxfish® were used in the treatment.

Silver King Creek—The upper reaches (10 km) of Silver King Creek (Carson River Drainage) in the Carson–Iceberg Wilderness Area of the Toiyabe National Forest above a fish barrier in Alpine County were treated with Nusyn-Noxfish® at 1 mg/L in summer 1991 (CDFG 1991c), summer 1992 (CDFG 1992a), and summer 1993 (CDFG 1994b) to remove rainbow trout and Lahontan cutthroat trout (Figure 1). The treatments were done in preparation for the reintroduction of Paiute cutthroat trout *Oncorhynchus clarki seleniris*, an endangered species (U.S. Fish and Wildlife Service 1985). The target fish hybridize with Paiute cutthroat trout. Rotenone was neutralized with potassium permanganate at the fish barrier to limit effects. Silver King Creek was monitored (Table 1). Sediment was also collected. Approximately 10 gallons of Nusyn-Noxfish® were used during each year of treatment (30 gallons total).

Wolf Creek—Wolf Creek Lake and the upper reaches (7 km) of Wolf Creek (Walker River Drainage) in the Toiyabe National Forest above a fish barrier in Mono County were treated with Nusyn-Noxfish® in fall 1991 (CDFG 1992b) and fall 1992 (CDFG 1992c) to remove brook trout and rainbow trout (Figure 1). The creek was treated at 1 mg/L and the lake received a 2 mg/L treatment. The treatments were done in preparation for the introduction of Lahontan cutthroat trout (Gerstung 1986). Rotenone was neutralized with potassium permanganate at the fish barrier to limit effects. Wolf Creek, Wolf Creek Lake, and the West Fork Walker River were monitored (Table 1). Sediment was also collected. Approximately 45 gallons of Nusyn-Noxfish® were used each year (90 gallons total).

Silver Creek—The upper reaches (13 km) of Silver Creek (Walker River Drainage) in the Toiyabe National Forest above a fish barrier in Mono County were treated with Nusyn-Noxfish® at 1 mg/L in summer 1994 (CDFG 1994c), summer 1995 (CDFG 1995), and summer 1996 (CDFG 1996) to remove brook trout (Figure 1). The treatments were done in preparation for the introduction of Lahontan cutthroat trout (Gerstung 1986). Rotenone was neutralized with potassium permanganate at the fish barrier to limit effects. Silver Creek and the West Fork Walker River were monitored (Table 1). Sediment was also collected. Approximately 5.5 to 8.5 gallons of Nusyn-Noxfish® were used each year (20 gallons total).

Lake Davis—Lake Davis (Feather River Drainage) and several miles of tributaries upstream of the lake in Plumas County were treated with Nusyn-Noxfish® at 1 mg/L and Pro-Noxfish® at 1 mg/L in fall 1997 (2 mg/L total) to eradicate exotic predatory northern pike (CDFG 1997; CDFG 1999; Siepmann and Finlayson 1999). Rotenone toxicity was allowed to naturally dissipate in the lake, but the discharge from the dam into Big Grizzly Creek was neutralized with potassium permanganate to limit effects. Lake Davis, Big Grizzly Creek, and several adjacent wells supplying water to private parties were monitored (Tables 1 and 2). Water was collected from the surface, mid-depth, and bottom of Lake Davis from ten locations (25 sites total). Sediment was also collected. Approximately 16,000 gallons of Nusyn-Noxfish® and 64,000 pounds of Pro-Noxfish® were used in the treatment.

Table 2. Characteristics of ground waters monitored.

Location (year)	Well type[a]	Well depth (m)	Horizontal distance[b] (m)
Kaweah River (l987)			
Corps of Engineers Well	D	61	0
Lemon Cove Well 1	D	46	183
Lemon Cove Well 2	D	11	400
Woodlake Well 1	M	66	400
Woodlake Well 2	D	24	45
Woodlake Well 3	D	21	18
Woodlake Well 4	I	-	183
Woodlake Well 5	M	49	30
Kaweah Percolation Resevoir 5 Well	D	43	45
U. Truckee River (1988–1990)			
Christmas Valley Well 1	D	8	20
Christmas Valley Well 2	D	1	3
Christmas Valley Well 3	D	17	10
Mill Creek (1988–1989)			
Walker Well 1	D	34	200
Walker Well 2	D	62	200
Walker Well 3	D	34	200
Tule River (1988)			
Springville Well	D	22	30
Country Club Well	I	10	200
Corps of Engineers Well	D	30	100
Frenchman Lake (1991)			
Big Cove Campground Well	D	17	30
Spring Creek Campground Well	D	35	400
Cottonwood Springs Well	D	12	1,000
Lake Davis (1997)			
South Davis Well 1	D	61	450
South Davis Well 2	D	73	640
South Davis Well 3	D	52	760
South Davis Well 4	D	26	670
Grasshopper Flat Campground Well	D	55	670

[a] D = Domestic use; I = Irrigation use; and M = Municipal use.
[b] Distance from surface water containing Nusyn-Noxfish®.

Sampling

Frequency—All of the surface and ground water monitoring sites were sampled prior to treatment to establish environmental levels of rotenone, rotenolone, and other organic chemicals found in the rotenone formulations. Surface water sites were sampled during (flowing waters) or immediately following (standing water) rotenone application at previously established sites and intervals until rotenone and the other chemicals had dissipated below the limits of detection. Ground water sites were sampled up to 456 days following treatment. Sediment samples were also taken from several study locations. Samples of undiluted Nusyn-Noxfish® were also analyzed to determine chemical levels.

Collection—Surface water was grab sampled at a depth of 0.5 m, and water from mid-depth and the bottom from Kaweah Reservoir, Frenchman Lake, Davis Lake, and Success Reservoir was collected using a Kemmerer bottle. Ground water was sampled as close to the wellhead as possible, sampling from an Schrader valve or faucet before the storage tank using standard procedures (Sava 1986). Well pumps were turned on for a minimum of 15 minutes to purge standing water in the well casing. Water samples for rotenone and rotenolone analysis were collected in 500-ml amber glass bottles with Teflon®-lined caps. Water samples for volatile organic chemicals (VOC) analyses were collected in 20-ml or 40-ml glass vials with Teflon®-lined silicone-septa screw caps. Water samples for semivolatile organic chemicals analyses were collected in 1-L amber glass bottles with Teflon®-lined or foil-lined caps. Water samples for analysis of the synergist piperonyl butoxide (PB) were collected in 500-ml or 1-L amber glass bottles with Teflon®-lined caps. Sediment samples were collected in chemically clean 500-ml polycarbonate jars (rotenone and rotenolone) and amber glass jars (VOC, PB, and semiVOC) with Teflon®-lined lids. Sediment was collected from shallow areas by placing a minimum of 100 ml of material from the bottom substrate into a jar. The remainder of the jar was filled with overlying water. All containers were filled to capacity and carefully capped as to avoid trapped air in the sample container. Generally, samples were collected in replicate; only one of the two replicates was analyzed. The other replicate served as insurance against analytical anomaly or breakage during transit.

Storage—All water samples were placed on ice immediately after collection and transported to a laboratory refrigerator and kept at a temperature of 4 °C until analyzed. Sediment samples for rotenone analysis were generally frozen for up to three months prior to analysis. The samples for VOC and semiVOC analyses were extracted and analyzed within time periods allowed by the method. Samples for rotenone and rotenolone analysis were extracted and analyzed within seven days. The water and sediment samples for VOC analyses were extracted within 14 days, and the sediment and water samples for semiVOC analyses were extracted within seven days.

Harrington and Finlayson (1988) conducted experiments to determine the effect of sample storage on rotenone residues in water. Surface water samples from several sites containing rotenone were split in the field among 10 duplicate samples. One set of five duplicate samples was analyzed before and the other set was analyzed after six days storage at a temperature of 4°C in the absence of light.

Chemical analyses

Nusyn-Noxfish®—Nusyn-Noxfish®, in addition to the active ingredient rotenone and the synergist PB, contains emulsifiers, carriers, and solvents (VOC and semiVOC) to disperse rotenone in water. Sixteen lots of Nusyn-Noxfish® were analyzed to determine the concentrations of each formulation constituent (Table 3). Rotenone was determined using the method of Dawson et al. (1983). VOC concentrations (Table 3) were determined using U.S. Environmental Protection Agency (USEPA) methods 624 (USEPA 1984a) or 8240 (USEPA 1994a), and semiVOC concentrations (Table 3) were determined using USEPA methods 625 (USEPA 1984b) or 8270 (USEPA 1994b). VOC and semiVOC analyses were completed to address public health issues (i.e., carcinogenicity) associated with some of these compounds (i.e., trichloroethylene) and to identify water quality monitoring needs. Quality assurance for the analyses was provided by systematic analysis of blanks, replicates, and spiked samples.

Water—Water samples from study sites were analyzed for Nusyn-Noxfish® constituents (Table 3). Concentrations of rotenone and the degradation product rotenolone were determined using the method described by Dawson et al. (1983). VOC concentrations were determined using USEPA methods 601 and 602, 502.2 or 8260 (USEPA 1984c, 1984d, 1989, 1994c, respectively), and semiVOC concentrations were determined using USEPA methods 610 or 8310 (USEPA 1984e; USEPA 1986). After 1991, USEPA methods 502.2 or 8260 were substituted for USEPA methods 601 and 602, and USEPA method 8310 was substituted for USEPA method 610. The PB was measured using USEPA method 8270 (USEPA 1994b). The detection limits for rotenone and rotenolone were 2.0 µg/L, for VOC typically varied from 0.2 µg/L (USEPA methods 8260 and 502.2) to 0.5 µg/L (USEPA methods 601 and 602), for semiVOC typically varied from 0.2 µg/L (USEPA method 8270) to 2.5 µg/L (USEPA method 610), and for PB typically varied from 2 to 8 µg/L. Quality assurance for the analyses was provided by systematic analysis of blanks, replicates, and spike samples. Recovery rates for samples spiked with rotenone and rotenolone were typically 78 to 80%. Recovery rates for samples spiked with VOC (USEPA methods 8260, 502.2, 601 and 602) were typically 86 to 116 % and for samples spiked with semiVOC (USEPA methods 8270 and 610) were typically 60 to 92%.

Sediment—Sediment samples from study sites were analyzed for Nusyn-Noxfish® constituents (Table 3). Sediment samples were analyzed for rotenone and rotenolone (Dawson 1986), VOC using USEPA method 8260 (USEPA 1994c), and semiVOC using USEPA method 8270 (USEPA 1994b). PB was measured using USEPA method 8270 (USEPA 1994b). The detection limits for rotenone and rotenolone were 30 µg/kg (dry weight), for semiVOC were 6 to 70 µg/kg (dry weight), for VOC were 5 to 6 µg/kg (dry weight), and for PB was 70 µg/kg PB (dry weight).

Table 3. Matrix for analytical methods used in analysis of Nusyn-Noxfish®, water, and sediment for rotenone, volatile organic compounds (VOC), semivolatile organic compounds (semiVOC), and piperonyl butoxide (PB).

Media	Rotenone	VOC	SemiVOC	PB
Nusyn-Noxfish®	Dawson et al. (1983)	624 (USEPA 1984a) 8240 (USEPA 1994a)	625 (USEPA 1984b) 8270 (USEPA 1994b)	
Water	Dawson et al. (1983)	601 & 602 (USEPA 1984c & USEPA 1984d) 502.2 (USEPA 1989) 8260 (USEPA 1994c)	610 (USEPA 1984e) 8310 (USEPA 1986)	8270 (USEPA 1994b)
Sediment	Dawson (1986)	8260 (USEPA 1994c)	8270 (USEPA 1994b)	8270 (USEPA 1994b)

Water Quality—Water temperature was recorded at the time of sample collection using a Yellow Springs Instruments® Model 57 oxygen meter. Water samples for pH and alkalinity determinations were collected in 500-ml high-density polyethylene bottles, stored on ice, and transported with the other samples to the laboratory. The pH was determined using a Hach® Model 1 pH meter, and total alkalinity was determined using the standard titration method (American Public Health Association 1985).

Results and Discussion

Constituents of Nusyn-Noxfish®

Nusyn-Noxfish® contains petroleum hydrocarbons as solvents and emulsifiers to disperse the rotenone in water (Penick Bio UCLAF 1987). The analyses of 16 different lots of Nusyn-Noxfish® (Table 4) for VOC and semiVOC during the past 15 years found mean concentrations of 73,502 mg/L for naphthalene, 95,055 mg/L for 2-methylnaphthalene, 1,925 mg/L for xylenes, and 565 mg/L for trichloroethylene. The Nusyn-Noxfish® manufactured in 1997 (Lots 32365, 32367, and 32369) contained significantly less (an order of magnitude) TCE and xylenes (means = 17.3 and 151µg/L, respectively) than the material manufactured prior (mean = 692 and 2,334 µg/L, respectively) to 1997 (Table 4). Other compounds that have been detected, but usually at less than the quantifiable limits, include acetone, benzene, ethylbenzene, methylene chloride, toluene, phenanthrene, anthracene, and bis (2-ethylhexyl) phthalate. None of these chemicals are known ingredients in the Nusyn-Noxfish® formulation (Roussel Bio Corporation 1991). No explanation is known for the presence of these "foreign" materials except that these are common ingredients in industrial fluids including gasoline and several are plasticizers. These may be contaminants in the industrial solvents used during product formulation or may have resulted from the use of plastics in the sampling process. Regardless, their occurrence was sporadic and at insignificant levels.

Table 4. Identified volatile organic compounds (VOC) and semivolatile organic compounds (semiVOC) in Nusyn-Noxfish® (in mg/L).

Lot number	TCE[a] (mg/L)	Xylenes (mg/L)	Naphthalene (mg/L)	Methyl Naphthalenes (mg/L)
10883	77	690	110,000	100,000
6425 HJA6-2	484	2,020	76,300	86,300
6425 HJA9-2	532	1,320	68,200	85,300
6425 HJA10-2	633	1,930	71,300	87,600
6425 HJA11-2	554	1,280	62,900	78,300
6425 HJA12-2	540	1,330	70,100	86,300
6425 HJA13-A	575	2,720	68,000	84,900
4974 ALM-02	710	3,234	74,240	74,180
4674 ALM-08	910	1,400	44,000	94,000
4674 AMM-06	910	5,400	81,000	100,000
4674 AMM-05	910	1,790	73,000	97,000
4674 AMM-08	1,200	1,830	80,000	97,000
32367	28	112	60,000	110,000
32365	16	193	58,000	110,000
32369	8	148	59,000	110,000
- -[b]	960	5,400	120,000	120,000
mean	565	1,925	73,502	95,055
SD	373	1,611	18,782	12,841
range	8-1,200	112-5,400	44,000-120,000	74,180-120,000

[a] TCE = Trichloroethylene
[b] No lot number given

Stability of rotenone

Typically a delay of one to seven days (three-day average) occurred between sample collection and analysis for rotenone and rotenolone while the samples were stored at a temperature of 4 °C in the absence of light. This delay could have a significant impact on the analytical results because rotenone is a short-lived compound. The degradation of rotenone in water from several locations was determined under normal storage conditions. Four of the six sites investigated showed significant ($p \leq 0.05$) differences in rotenone concentrations after six days of storage (Table 5). Water with higher alkalinity (>170 mg/L $CaCO_3$) and pH (>9.0) had higher degradation of rotenone (–24% and –25%) than did water with lower alkalinity (40 mg/L $CaCO_3$) and pH (7.7) that had lower degradation (no change to –16%). These results are in agreement with Clemens and Martin (1953) who found that rotenone degradation increased with increased alkalinity.

Table 5. Rotenone concentrations (in µg/L) before and after six days storage at a temperature of 4 ºC in the absence of light. Asterisks denote significant changes ($p > 0.05$) using the Kruskal-Wallis test; mean values with SD in parentheses.

Alkalinity (mg/L $CaC0_3$)	pH	Rotenone Before		After		Percent change
40	7.8	91.0	(7.1)	93.0	(6.1)	+2
180	9.2	68.0	(8.0)	52.0	(8.8)	–24*
40	7.7	31.6	(1.9)	28.2	(1.6)	–11*
40	7.7	47.8	(1.6)	40.0	(1.0)	–16*
40	9.3	238.0	(29.5)	238.0	(8.4)	0
172	9.6	14.0	(2.8)	10.5	(0.7)	-25*

Surface Waters

Rotenone—Nusyn-Noxfish® was applied in lakes and reservoirs at target concentrations from 2 to 4 mg/L. At this application rate, rotenone generally degraded to nondetectable levels within one to three weeks (Table 6). The estimated half-life ($t_{1/2}$) of rotenone averaged 2.3 days and varied from 0.58 days in Meiss Lake to 7.7 days in Lake Davis. Half-life values appeared to increase with increased water depth indicating photolysis may be an important route of rotenone decomposition. Kaweah Reservoir, Success Reservoir, Lake Davis, and Frenchman Lake had respective $t_{1/2}$ values of 1.7, 2.4, 7.7, and 3.5 days (average depths of 8 to 12 m) and Percolation Reservoir 12 and Meiss Lake had respective $t_{1/2}$ values of 0.94 and 0.83 days (average depths of 0.8 to 1.0 m). Rotenone appeared to have a longer half-life in colder water; Kaweah Reservoir (temperature of 20 to 22 °C), Frenchman Lake (temperature of 10 to 22 °C), and Lake Davis (temperature of 5 to 12 ºC) have similar average water depths but respective $t_{1/2}$ values of 1.7, 3.5, and 7.7 days. These values are in agreement with Gilderhaus et al. (1988) who found a $t_{1/2}$ value of 0.94 days for a warm (temperature of 23 to 27 °C), shallow (<1 m deep) pond and those of Dawson et al. (1991) who found $t_{1/2}$ values of 1.8 to 0.7 days for average water temperatures of 15 to 24 °C, respectively. Rotenone had a longer $t_{1/2}$ of 10.3 days in a colder (temperature of 0 to 5 °C), shallow pond (Gilderhaus et al. 1988).

Rotenolone—Rotenolone concentrations appeared to parallel rotenone concentrations and typically were not found in the absence of rotenone. Exceptions to this were Meiss Lake in 1988 and 1990 (CDFG 1988b; 1989b) and Wolf Creek Lake in 1991 (CDFG 1992b). A decrease in water temperature below 11°C in 1988 coincided with rotenolone residues persisting in Meiss Lake for three weeks, two weeks longer than rotenone residues (CDFG 1988b). Rotenolone persisted for at least six weeks past rotenone in Wolf Creek Lake (CDFG 1992b). The increased persistence of rotenolone in Meiss Lake and Wolf Creek Lake may be reflective of the low water alkalinity (<15 mg/L $CaCO_3$), cooler temperatures (≤11°C), high solar radiation at high elevations (>2,500 m), and the relatively sterile granitic soils of the Sierra Nevada Mountain Range. Rotenone may be more susceptible to photolysis than rotenolone. The persistence of rotenolone could delay stocking fish because rotenolone is reported to have toxicity comparable to that of rotenone in mammals (Yamamoto 1970). However, anecdotal observations indicate that rotenolone is approximately one-tenth as lethal as rotenone to salmonids.

Table 6. Rotenone and rotenolone concentrations (in µg/L) at various time intervals (days in parentheses) and corresponding half-life ($t_{½}$) values (in days) of rotenone decay assuming first-order kinetics.

Location (year)	Rotenone/rotenolone concentrations (µg/L)				$t_{½}$
Kaweah Reservoir (1987)	76/17 (1)	55/27 (3)	43/23 (5)	<2/<2 (12)	1.7
Bravo Reservoir (1987)	254/236 (1)	46/42 (2)	<2/<2 (6)	-	0.65
Lonestar Pond (1987)	310/46 (1)	49/10 (2)	24/13 (6)	<2/<2 (14)	1.8
Percolation Reservoir 5 (1987)	370/65 (1)	150/160 (3)	120/190 (8)	<2/<2 (15)	1.7
Percolation Reservoir 12 (1987)	200/70 (1)	27/61 (3)	<2/<2 (8)	-	0.94
Success Reservoir (1988)	122/64 (1)	39/20 (2)	22/34 (6)	<2/<2 (30)	4.6 [a]
Meiss Lake (1988)	64/220 (0.13)	30/70 (1)	8.2/52 (3)	<2/23 (6.2)	0.96
Meiss Lake (1989)	47/20 (0.08)	41/27 (0.17)	30/28 (0.5)	18/16 (1)	0.96
Meiss Lake (1990)	11/36 (0.04)	5.9/37 (2.9)	3.8/24 (0.92)	<2/13 (1.9)	0.58
Frenchman Lake (1991)	90/42 (1)	39/35 (2)	28/34 (3)	6/21 (14)	3.5
Wolf Creek Lake (1992)	16/70(8)	<2/90(21)	<2/70(28)	<2/55(51)	2.9[b]
Lake Davis (1997)	44/14(1)	32/18(3)	29/20(7)	11/20(21)	7.7

[a] A value of 2.4 days is computed without the 30-day value
[b] Assumes initial concentration of 100 µg/L rotenone

Neutralization - Rotenone was allowed to naturally degrade in the Tule River and Kaweah River drainages, Frenchman Lake, Meiss Lake, Wolf Creek Lake, and Lake Davis. Rotenone can be neutralized with potassium permanganate; however, potassium permanganate is toxic to fish at relatively low (2–4 mg/L) concentrations (Finlayson et al. 2000). Formulated rotenone applied at 2 mg/L (50 µg/L rotenone) was neutralized with potassium permanganate at 4 mg/L in the discharge from Frenchman Lake into Little Last Chance Creek and in the discharge from Lake Davis into Big Grizzly Creek. Rotenone applied at 1 mg/L formulation (25 µg/L) was neutralized with potassium permanganate at 3 mg/L at the fish barriers on Mill Creek, Upper Truckee River, Silver King Creek, Silver Creek, and Wolf Creek. A 30-minute contact (travel) time was utilized as the neutralization area. Flow rates of potassium permanganate were checked every 30 to 120 minutes. Stress of caged rainbow trout placed upstream and downstream was used to initiate the neutralization and judge the effectiveness of neutralization on-site, respectively. No direct on-site method for measuring rotenone concentrations exists. Results from water samples analyzed for rotenone in the laboratory indicated that potassium permanganate was very effective in oxidizing rotenone and rotenolone to concentrations below detection limits (2 µg/L). If potassium permanganate levels are in balance with rotenone levels, then toxic levels of potassium permanganate should be quickly reduced through the oxidation of organic components and rotenone in water. Typically, successful neutralization of rotenone with potassium permanganate occurs within the 30-minute neutralization zone. However, there have been several failures of the neutralization process in California. In 1992, fish were killed below the 30-minute neutralization zone in Silver King Creek probably due to lower than anticipated rotenone concentrations, in turn causing excessive (and probably toxic) potassium permanganate concentrations (CDFG 1992a). In 1997, fish were killed below the 30-minute neutralization zone in Big Grizzly Creek when the flow of potassium permanganate had been inadvertently decreased from 4 mg/L to 2 mg/L, in turn causing toxic concentrations of rotenone (Siepmann and Finlayson 1999). In both these instances, coldwater temperatures (<10ºC) may have contributed to the ineffective neutralization. The CDFG has experimented successfully with maintaining a nontoxic 1 mg/L potassium permanganate concentration at the end of the 30-minute neutralization zone with the aid of a calibrated field spectrophotometer. The results of the spectrophotometer were used to adjust the potassium permanganate flows accordingly (Parmenter and Fujimura 1994).

VOC and semiVOC—The four known nonrotenoid organic compounds found in undiluted Nusyn-Noxfish® (xylene, trichloroethylene, naphthalene, and 2-methylnaphthalene) have been found in surface water (Table 7). The concentrations of these in standing waters were generally close to expected values based on dilution. Maximum residues detected have been 4.9 µg/L for trichloroethylene, 6.7 µg/L for xylene, 332 µg/L for naphthalene, and 390 µg/L for 2-methylnaphthalene. Standing waters have contained higher concentrations of these components than flowing waters because of higher treatment rates of Nusyn-Noxfish® (2 to 4 mg/L versus 1 mg/L) and lack of conditions conducive to volatility. Flowing waters allow for chemicals to more easily volatilize through agitation in riffles, rapids, and waterfalls.

Neither trichloroethylene (<0.5 µg/L) nor xylene (<0.5 µg/L) have been found in flowing waters (Table 7), except for one sample collected immediately below a drip station (CDFG 1994a). Concentrations of trichloroethylene have never exceeded the USEPA drinking water standard (Maximum Contaminant Level) of 5 µg/L (USEPA 1985). Similarly, the concentrations of xylene have never exceeded the drinking water standard (Health Advisory) of 620 µg/L (USEPA 1981). Drinking water standards have not been developed for naphthalene and methylnaphthalenes, but acute toxicity values to mammals are greater than 1,500 mg/kg (Verschueren 1983). These short-lived VOC and semiVOC occur at levels that do not appear to be threats to public health. All four chemicals dissipated within two to three weeks.

PB—The synergist PB has been found to be a persistent chemical in deep and cool waters. It persisted for almost nine months in Lake Davis (Siepmann and Finlayson 1999). PB was present at about 32 µg/L one week after application in mid-October 1997. PB remained at 20 to 30 µg/L until the lake iced-over in late December 1997, and degraded to about 5 µg/L by the time the ice melted the following spring 1998. PB remained detectable (> 2 µg/L) in the cold (<10 ºC), deep water (>25 m) until early July 1998 (Siepmann and Finlayson 1999).

Ground Waters

Twenty-six wells have been monitored since 1987 for the presence of Nusyn-Noxfish® constituents. Samples for analysis of rotenone, rotenolone, VOC, and semiVOC were collected between 1 and 456 days following treatment (Table 8). All samples were negative for all compounds with the exception of a 1.5 µg/L xylene detection that was found in a single sample collected from the Corps of Engineers Well at Kaweah Reservoir, 59 days after the treatment. This finding was believed to be an anomaly. A subsequent sample collected at 185 days after treatment was negative for xylene.

Residues of rotenone or rotenolone were never found in any of the wells monitored. This was expected because the wells were a minimum of 1 m deep and at least 3 m horizontally from the rotenone-treated water bodies. Rotenone leaches vertically less than 2 cm in most soil types, less than 8 cm in sandy soil, and binds readily to sediment (K_{oc} of 1,060 to 1,810; Dawson 1986). Additionally, none of the other VOC or semiVOC constituents of the Nusyn-Noxfish® formulation have been detected in any of the wells monitored. This is probably due to the chemicals' volatility and lack of persistence in surface water.

Table 7. Maximum concentrations (in µg/L) of volatile organic compounds (VOC) and semivolatile organic compounds (semiVOC) detected (maximum duration of detection for standing waters in days in parentheses) following application of Nusyn-Noxfish® at 1 mg/L to flowing waters and 2 to 4 mg/L in standing waters. Expected concentrations based on dilution are in brackets. Samples were collected during application to flowing waters and within one day following application to standing waters.

Location (year)	Trichloroethylene (µg/L)	Xylene (µg/L)	Naphthalene (µg/L)	2-Methylnaphthalene (µg/L)
Standing waters (2-4 mg/L)				
Kaweah Reservoir (1987)	2.1 (<21)	<1.0	78 (<21)	NA[a]
Bravo Reservoir (1987)	4.9 (<14)	2.2 (<14)	<2.0	NA
Success Reservoir (1988)	<0.5	<0.5	<2.5	NA
Meiss Lake (1989)[c]	1.0	6.7	332	NA
Meiss Lake (1990)[c]	<0.5	0.9	24	21
Frenchman Lake (1991)	1.6 (<14)	4.5 (<7)	16 (<14)	57 (<7)
Lake Davis (1997)	0.8 (<7)	2.0 (<7)	210 (<14)	390[b] (<14)
	[1.1–2.2]	[3.8–7.6]	[147–294]	[190–380]
Flowing waters (1 mg/L)				
U. Truckee River (1989)	<0.5	<0.5	14	NA
U. Truckee River (1990)	<0.5	<0.5	4.2	<2.5
Mill Creek (1989)	<0.5	<0.5	19	NA
Silver King Creek (1991)	<0.2	<0.2	57	35
Silver King Creek (1992)	<0.5	<0.5	<0.5	<2
Silver King Creek (1993)	0.76	0.56	52	50
Wolf Creek (1991)	<0.2	<0.2	<0.2	0.7
Wolf Creek (1992)	<0.5	<0.5	<0.5	<2
Silver Creek (1994)	<0.2	<0.2	1.7	<2
Silver Creek (1995)	<0.2	<0.2	9.1	5.1
Silver Creek (1996)	<0.2	<0.2	5.2	<2
	[0.55]	[1.9]	[74]	[95]

[a] NA = not analyzed
[b] 1-methylnaphthalene was also detected at maximum concentration of 210 µg/L and degraded with 2-methylnaphthalene concentrations.
[c] Measurements in Meiss Lake taken only once.

Sediment

The presence of rotenone formulation constituents in sediment has been monitored at five locations since 1991 (Table 9). The majority of samples from sediments in flowing waters did not contain detectable residues (> 30 µg/kg, dry weight) of either rotenone or rotenolone. Only one sample contained a detectable rotenone concentration (37 µg/kg, dry weight). In one case, rotenolone was detected at an unusually high concentration (440 µg/kg, dry weight). This detection, however, is believed to be an analytical anomaly due to the magnitude of the detection, its presence in the absence of the parent compound, and its brief persistence (<24h). The other rotenolone residue detection in sediment from flowing water (60 µg/kg, dry weight) may also be anomalous. In no case did rotenone or rotenolone residues persist in flowing water sediments longer than seven days. Detections of rotenone and rotenolone in sediments in standing waters were more common than in flowing waters. The maximum concentrations detected were 522 and 890 µg/kg (dry weight) for rotenone and rotenolone, respectively. In no case did these residues persist in sediments from standing waters for longer than 60 days.

Table 8. Days after Nusyn-Noxfish® application that samples were collected from wells. All samples contained less than detectable concentrations of rotenone, rotenolone, volatile organic compounds (VOC) and semivolatile organic compounds (semiVOC).

Basin (year)	Rotenone/rotenolone (days)	VOC and semiVOC (days)
Kaweah River (1987)		
Corps of Engineers Well	24, 39, and 59	24, 39, 59[a], and 185
Lemon Cover Well 1	7, 28, and 49	49
Lemon Cover Well 2	7, 28, and 49	50
Woodlake Well 1	8, 28, and 50	50
Woodlake Well 2	7, 28, and 50	50
Woodlake Well 3	15, 37, and 58	58
Woodlake Well 4	7, 28, and 49	49
Woodlake Well 5	7, 28, and 49	7, 28, and 49
Kaweah Percolation Reservoir 5 Well	8, 30, and 51	51
Upper Truckee River (1988 & 1989)		
Christmas Valley Wells 1,2 & 3	2 and 30	NS[b]
Upper Truckee River (1990)		
Christmas Valley Wells 1 & 3	7 and 49	NS
Christmas Valley Well 2	7 and 49	7 and 49
Mill Creek (1988)		
Walker Wells 1, 2, & 3	2 and 30	NS
Mill Creek (1989)		
Walker Wells 1, 2, & 3	2 and 30	2 and 30
Tule River (1988)		
Springville Well	1 and 30	30 and 456
Country Club Well	1 and 30	30 and 456
Corps of Engineers Well	6 and 30	30 and 456
Frenchman Lake (1991)		
Big Cove Campground Well	1 and 30	1 and 30
Spring Creek Campground Well	1 and 30	1 and 30
Cottonwood Campground Well	1 and 30	1 and 30
Lake Davis (1997)[c]		
South Davis Wells 1,2,3 & 4	5,14,90,194, and 324	5,14,90,194, and 324
Grasshopper Campground Well	5,14,90,194, and 324	5,14,90,194, and 324

[a]Xylene was detected at 1.5 µg/L at day 59 and believed to be an anomaly; sample taken on day 185 was free of xylene.
[b]NS = not sampled.
[c]All of the Lake Davis wells were also analyzed for PB.

Table 9. Maximum concentrations (in µg/kg, dry weight) of rotenone, rotenolone, and semivolatile (semiVOC) organic compounds detected in sediment from formulated rotenone use sites. No volatile organic compounds (VOC) were detected. The durations of detectable residues (in days) are indicated in parentheses.

Location (year)	Rotenone (µg/kg)	Rotenolone (µg/kg)	Naphthalene (µg/kg)	Methyl Naphthalene (µg/kg)
Silver King Creek (1991)	<30	<30	<30	<30
Silver King Creek (1992)	<30	440[b] (<1)	<30	<30
Silver King Creek (1993)	<30	<30	<30	<30
Silver Creek (1994)	<30	<30	<70	<70
Silver Creek (1995)	37 (<7)	<30	<30	<30
Silver Creek (1996)	<30	<30	<30	<30
Wolf Creek (1991)	<30	60[b] (<7)	<30	<30
Wolf Creek (1992)	310[a] (<14)	890[a] (<14)	<30	<30
Frenchman Lake (1991)	180 (<14)	560 (<21)	24 (<180)	218 (<180)
Lake Davis (1997)	522 (<60)	134 (<60)	91 (<60)	231 (<60)

[a] Results are from Wolf Creek Lake. No residues above the reporting limit (30 µg/kg, dry weight) were found for Wolf Creek.
[b] Probable analytical anomaly.

All sediment samples were negative (<30 µg/kg, dry weight) for VOC constituents of formulated rotenone (xylene and trichloroethylene) in both flowing and standing waters. Likewise, the semiVOC naphthalene and methylnaphthalene were not detected in sediments in flowing waters. In standing waters, the maximum concentrations of naphthalene and methylnaphthalene in sediments were 91 and 231 µg/kg (dry weight), respectively. In no case did detectable residues of semiVOC persist in standing water sediments for longer than 180 days.

Conclusions

Fifteen years of monitoring Nusyn-Noxfish® applications and one Pro-Noxfish® application indicate that rotenone and the other organic compounds in surface and ground waters behave as expected based on dilution and known physicochemical properties. All chemicals with the exception of PB and rotenolone can be expected to dissipate from surface water within six weeks. The persistence of PB and rotenolone increases inversely with temperature, but neither has persisted for greater than nine months. None of the constituents in Nusyn-Noxfish® or Pro-Noxfish® have contaminated ground water. Only rotenone, rotenolone, and semiVOC were found in sediment, and none persisted longer than 180 days.

References

American Public Health Association (APHA). 1985. Standard methods for the examination of water and wastewater, 16th edition. APHA, Washington, D.C.

California Department of Fish and Game (CDFG). 1987. Final environmental impact report. White Bass Management Program. CDFG, Sacramento, California.

CDFG. 1988a. Pesticide Investigations Unit, pesticide laboratory report – California Regional Water Quality Control Board monitoring on rotenone treatment (1988) of Mill Creek. CDFG, Rancho Cordova, California (October 10, 1988).

CDFG. 1988b. Pesticide Investigations Unit, pesticide laboratory report – California Regional Water Quality Control Board monitoring on rotenone treatment (1988) of Upper Truckee River. CDFG, Rancho Cordova, California (October 24, 1988).

CDFG. 1989a. Pesticide Investigations Unit, pesticide laboratory report – California Regional Water Quality Control Board monitoring on rotenone treatment (1989) of Mill Creek. CDFG, Rancho Cordova, California (November 20, 1989).

CDFG. 1989b. Pesticide Investigations Unit, pesticide laboratory report – California Regional Water Quality Control Board monitoring on rotenone treatment (1989) of Upper Truckee River. CDFG, Rancho Cordova, California (November 5, 1989).

CDFG. 1989c. Pesticide Investigations Unit, pesticide laboratory report – California Regional Water Quality Control Board monitoring on rotenone treatment (1988) of Success Reservoir. CDFG, Rancho Cordova, California (January 27, 1989).

CDFG. 1990. Pesticide Investigations Unit, pesticide laboratory report – California Regional Water Quality Control Board monitoring on rotenone treatment (1990) of Upper Truckee River. CDFG, Rancho Cordova, California (September 27, 1990).

CDFG. 1991a. Subsequent environmental impact report – Northern Pike Eradication Project. CDFG, Sacramento, California.

CDFG. 1991b. Pesticide Investigations Unit, pesticide laboratory report (P1423) - monitoring on rotenone treatment (1991) of Frenchman Reservoir. CDFG, Rancho Cordova, California (November 1, 1991).

CDFG. 1991c. Pesticide Investigations Unit, pesticide laboratory report (P1427) – California Regional Water Quality Control Board monitoring on rotenone treatment (1991) of Silver King Creek. CDFG, Rancho Cordova, California (November 22, 1991).

CDFG. 1992a. Pesticide Investigations Unit, pesticide laboratory report (P1505) – California Regional Water Quality Control Board monitoring on rotenone treatment (1992) of Silver King Creek. CDFG, Rancho Cordova, California (October 15, 1992).

CDFG. 1992b. Pesticide Investigations Unit, pesticide laboratory report (P1437) – California Regional Water Quality Control Board monitoring on rotenone treatment (1991) of Wolf Creek. CDFG, Rancho Cordova, California (January 31, 1992).

CDFG. 1992c. Pesticide Investigations Unit, pesticide laboratory report (P1504) – California Regional Water Quality Control Board monitoring on rotenone treatment (1992) of Wolf Creek. CDFG, Rancho Cordova, California (September 29, 1992).

CDFG. 1994a. Rotenone Use for Fisheries Management – July 1994 – Final environmental impact report (subsequent impact report). CDFG, Sacramento, California.

CDFG. 1994b. Pesticide Investigations Unit, pesticide laboratory report (P1638) – California Regional Water Quality Control Board monitoring on rotenone treatment (1993) of Silver King Creek. CDFG, Rancho Cordova, California (February 1, 1994).

CDFG. 1994c. Pesticide Investigations Unit, pesticide laboratory report (P1690) – California Regional Water Quality Control Board monitoring on rotenone treatment (1994) of Silver Creek. CDFG, Rancho Cordova, California (October 6, 1994).

CDFG. 1995. Pesticide Investigations Unit, pesticide laboratory report (P1760) – California RegionalWater Quality Control Board monitoring on rotenone treatment (1995) of Silver Creek. CDFG, Rancho Cordova, California (November 1, 1995).

CDFG. 1996. Pesticide Investigations Unit, pesticide laboratory report (P1839) – California Regional Water Quality Control Board monitoring on rotenone treatment (1996) of Silver Creek. CDFG, Rancho Cordova, California (November 12, 1996).

CDFG. 1997. Lake Davis Northern Pike Eradication Project – January 1997 – Final environmental impact report. CDFG, Sacramento, California (January 9, 1997).

CDFG. 1999. Pesticide Investigations Unit, pesticide laboratory report (P-1870, 1891, 1896, 1911, 1913, 1916, 1931, 1961, 1967, 1971, and 2023). Results of well sampling as part of the Lake Davis Environmental Monitoring Plan. CDFG, Rancho Cordova, California (April 27, 1999).

Clemens, H., and M. Martin. 1953. Effectiveness of rotenone in pond reclamation. Transactions of the American Fisheries Society 89:166–177.

Dawson, V. 1986. Absorption/desorption of rotenone by bottom sediments. U.S. Fish and Wildlife Service, National Fisheries Research Laboratory, La Crosse, Wisconsin.

Dawson, V., P. Harmon, D. Schultz, and J. Allen. 1983. Rapid method for measuring rotenone in water at piscicidal concentrations. Transactions of American Fisheries Society 112:725–728.

Dawson, V., W. Gingerich, R. Davis, and P. Gilderhaus. 1991. Rotenone persistence in freshwater ponds: effects of temperature and sediment adsorption. North American Journal of Fish Management 11: 226–231.

Finlayson, B. J., R. A. Schnick, R. L. Cailteux, L. DeMong, W. D. Horton, W. McClay, C. W. Thompson, and G. J. Tickacek. 2000. Rotenone use in fisheries management: administrative and technical guidelines manual. American Fisheries Society, Bethesda, Maryland.

Gerstung, E. 1986. Fishery management plan for Lahontan cutthroat trout (Salmo clarki henshawi) in California and Western Nevada waters. CDFG, Inland Fish Division, Sacramento, California (December 1986).

Gilderhaus, P., V. Dawson, and J. Allen. 1988. Deposition and persistence of rotenone in shallow ponds during cold and warm seasons. U.S. Fish and Wildlife Service, Investigations in Fish Control 95.

Harrington, J. M., and B. J. Finlayson. 1988. Rotenone residues in water following application to Kaweah River and Tulare Lake Basin, California. CDFG, Environmental Services Division Administrative Report 88-1. Sacramento, California.

Parmenter, S. C., and R. W. Fujimura. 1994. Application and regulation of potassium permanganate to detoxify rotenone in streams. Proceedings of Desert Fishes Council XXVI:62-67.

Penick – Bio UCLAF. 1987. Letter to B. Finlayson, Environmental Services Supervisor, California Department of Fish and Game, from P. Callahan, Pesticide Registration Specialist. Lyndhurst, New Jersey (dated August 18, 1987).

Roussel Bio Corporation. 1991. Letter to B. Finlayson, Environmental Services Supervisor, California Department of Fish and Game, from R. Puchalski, Manager, Quality Control and Analytical Chemistry, Lincoln Park, New Jersey (dated June 10, 1991).

Sava, R. 1986. Guide to sampling air, water, soil, and vegetation for chemical analysis. California Department of Food and Agriculture, Sacramento, California.

Siepmann, S., and B. Finlayson. 1999. Chemical residues in water and sediment following rotenone application to Lake Davis, California. CDFG, Office of Spill Prevention and Response, Administrative Report 99-2. Sacramento, California.

U. S. Environmental Protection Agency (USEPA). 1981. Advisory option for xylenes (dimthylbenzene). USEPA, Office of Drinking Water, Washington, D.C.

USEPA. 1984a. Method 624 Purgable organic compounds by gas chromatography/mass spectrophotometry.

USEPA. 1984b. Method 625 Base/neutral and acid extractables by gas chromatography/mass spectrophotometry.

USEPA. 1984c. Method 601 Halogenated volatile organics.

USEPA. 1984d. Method 602 Aromatic volatile organics.

USEPA. 1984e. Method 610 Polyneuclear aromatic hydrocarbons.

USEPA. 1985. The drinking water criteria document on trichloroethylene, USEPA Office of Drinking Water, Washington, D.C.

USEPA. 1986. Method 8310 Polyneuclear aromatic hydrocarbons.

USEPA. 1989. Method 502.2 Volatile organic compounds in water by purge and trap capillary column gas chromatography with photo ionization and electrolytic conductivity detectors in series.

USEPA. 1994a. Method 8240 Volatile organic compounds by gas chromatography/mass spectrophotometry.

USEPA. 1994b. Method 8270 Semivolatile organic compounds by gas chromatography/mass spectrophotometry.

USEPA. 1994c. Method 8260 Volatile organic compounds by gas chromatography/mass spectrophotometry.

U.S. Fish and Wildlife Service (USFWS). 1985. Paiute cutthroat trout recovery plan. USFWS, Portland, Oregon (January 25, 1985).

Verschueren, K. 1983. Handbook of environmental data on organic chemicals. Van Nostrand Reinhold, New York.

Yamamoto, I. 1970. Mode of action of pyrethroids, nictinoids, and rotenoids. Annual Review Entomology 15: 257–272.

Northern Pike Control at Lake Davis, California

Dennis P. Lee
California Department of Fish and Game
Fisheries Programs Branch,1416 Ninth Street
Sacramento, California 95814, USA
dlee@dfg.ca.gov

Abstract.—Northern pike are listed in the California Code of Regulations Title 14 Section 671 as a “detrimental animal” and it is unlawful to import, transport or possess northern pike alive except under permit. In 1989 the Department of Fish and Game (DFG) confirmed the presence of northern pike in Frenchman’s Reservoir. Prior to this, northern pike were not known to occur in California. In 1991, Frenchman’s Reservoir and tributaries were treated with Nusyn-noxfish to eliminate northern pike and the treatment was considered successful. In 1994, the DFG confirmed the angler capture of a northern pike from Lake Davis. In early October 1997, the DFG cleared legal challenges and in mid-October treated the lake with a combination of powdered Pro-noxfish and Nusyn-noxfish, and tributary streams with Nusyn-noxfish. By July 1998, no chemicals from the treatment were detected and the DFG initiated rainbow trout stocking. Subsequently in May 1999, a northern pike was caught in Lake Davis, and the DFG again verified the presence of northern pike. The DFG developed 40 alternatives for controlling northern pike at Lake Davis from input at public meeting and workshops, and literature reviews. In February 2000, the DFG released *Managing Northern Pike at Lake Davis: A Plan for Y2000* that described 12 recommended containment and control actions to be implemented during 2000. Chemical treatment of the lake was not included as a control action. The plan also described a monitoring program to measure the plan's success and provide opportunities to make informed course corrections should they be needed.

Introduction

Northern pike *Esox lucius* are listed in the California Code of Regulations Title 14 Section 671 as a “detrimental animal,” and it is unlawful to import, transport, or possess northern pike alive except under permit. However, in 1988, an angler reported catching a 7-pound northern pike from Frenchman Lake, Plumas County. Subsequent sampling by the Department of Fish and Game (DFG) confirmed the presence of northern pike in Frenchman Reservoir. Prior to this, northern pike were not known to occur in any California waters. Sampling at other waters including nearby Lake Davis (Plumas County) produced no northern pike. In 1991, Frenchman Lake and tributaries were treated with 15,000 gallons of Nusyn-noxfish (20,000 acre feet of water treated) to eradicate northern pike. Following treatment, sampling failed to capture any northern pike from Frenchman Reservoir, and the treatment was considered successful.

In August 1994, the DFG confirmed the angler capture of a northern pike from Lake Davis. This report reviews information on Lake Davis and chronicles events dealing with the DFG efforts to control northern pike at Lake Davis through early 2000.

Northern Pike Distribution

Northern pike distribution is holartic, ranging from northwestern Europe across northern Asia to northern North America. In North America, they range from Alaska to Labrador, south through New England and much of New York, the northern part of the Ohio Valley, the Great Lakes region, and southward to Missouri and Nebraska. Dill and Cordone (1997) reported that the United States Fish Commission supposedly brought northern pike to California in December

1891. However, there is confusion regarding the identification and the fish may not have been northern pike, but rather grass pickerel *Esox americanus vermiculatus*. Neither species became established in California as a result of that introduction. During the period 1988 through 2000, northern pike have been collected from Frenchman Reservoir (extirpated by chemical treatment), the Feather River (extirpated by chemical treatment), and Lake Davis, and reported from Lake Oroville (unsubstantiated occurrence based on photo of an angler captured fish) and the Sacramento-San Joaquin Delta (unsubstantiated occurrence of a single northern pike salvaged at a pumping facility from a report by a DFG employee). Although other reports of northern pike in California waters have been received by the DFG, none have been substantiated (Patrick O'Brien, Senior Fishery Biologist, DFG, Rancho Cordova, personal communication).

Area of Interest

Lake Davis is located in the Feather River drainage of the Sacramento-San Joaquin Rivers watershed at an elevation of 5,775 feet m.s.l. within the Plumas National Forest. The reservoir was formed by construction of a dam by the California Department of Water Resources in 1967 as part of the State Water Plan to provide water mainly to agricultural water users in the Central Valley. The reservoir is located just north of the town of Portola on Big Grizzly Creek, a tributary to the Middle Fork Feather River. The reservoir surface area is 4,026 surface acres (1,619 ha), storage capacity 84,371 acre feet, mean depth 20.5 feet (6.3 m), maximum depth 108 feet (33 m), and with a shoreline length of 32 miles (52 km).

Three main tributaries, Big Grizzly, Freeman, and Cow Creeks feed the reservoir. The total drainage area is approximately 44 square miles. The reservoir basin morphology is a flooded river valley with a deep narrow channel and broad littoral zone. Extensive aquatic macrophyte growth occurs in near shore areas and may comprise up to 40% of lake area (DWR 1971). De Lain (1983) classified the lake as a meso-euthophic class reservoir based on growing season inorganic nitrogen concentration.

Coldwater (salmonid) habitat is restricted in the hypolimnion and metalimnion in summer due to oxygen deletion. Stratification occurs between mid-April and mid-May, destratification occurs between late September and early October (De Lain 1983).

Lake Davis pH ranges from 6.8 to 9; total dissolved solids 49 to 68 mg/l, total hardness 24 to 44 mg/l (soft) (DWR 1971; 1973). Annual ice cover occurs from March through April in most years with water temperatures ranging from a low of 5–7° C, and maximum surface water temperatures in July and August of about 17–18° C, with a maximum 23.5° C in August.

The lake provides habitat for both coldwater and warm water fish species but most angling effort is directed toward trout (Table 1). Estimates of total angling effort are not available.

Table 1. List of fish known to occur in Lake Davis, September 1999.

Common Name	Scientific Name
Largemouth bass	*Micropterus salmoides*
Pumpkinseed	*Lepomis gibbous*
Brown bullhead	*Ameiurus nebulosus*
Golden shiner	*Notemigonus crysoleucas*
Rainbow trout	*Oncorhynchus mykiss*
Northern pike	*Esox lucius*

Northern Pike in Lake Davis—Round One

Treatment Proposal and Opposition

It is difficult to determine exactly when northern pike were first introduced into Lake Davis. Most DFG personnel believe fishermen illegally introduced them. Regardless of the time or source, beginning in August 1994, northern pike were commonly caught in Lake Davis by anglers and DFG personnel during sampling.

By 1995, the DFG concluded that eradication of the predatory pike was necessary in order to prevent their further spread in the state and to protect the trout fishery at Lake Davis (DFG, February 7, 1995, Notice of Preparation). This same conclusion was made by the DFG prior to the Frenchman Reservoir project (DFG 1991). In response to DFG actions at Lake Davis, the local community began to organize in opposition to the treatment. The Save Lake Davis Committee (originally called Victims of Lake Davis) was formed by a group of local Lake Davis area residents in early 1995. They opposed the addition of rotenone to their domestic water supply. Shortly after its inception, officials from Plumas County and the City of Portola joined the group and became active. Later, the name was changed to Save Lake Davis Coalition to better reflect the makeup of the group.

In March 1995, the DFG conducted public scoping meetings in Reno and Portola as well as briefings to Portola City Council and Plumas County Board of Supervisors. Supporting documents were prepared and information collected. By the summer of 1997, northern pike were common in Lake Davis at the expense of the trout population and the local businesses dependent on the trout fishery. Northern pike lived up to their reputation of being a large, voracious and fast-growing predatory fish that can readily destroy other fisheries. The available trout population at Lake Davis was dramatically reduced by northern pike predation. What few trout remained were larger fish, seventeen inches long and longer.

By March 1996, the Draft Environmental Impact Report Lake Davis Northern Pike Eradication Project was completed and made available for public review (DFG 1996). In August 1997, the DFG filed a Notice of Determination for a chemical treatment of Lake Davis to eradicate northern pike. Following this action, several groups and individuals prepared and made legal challenges.

Treatment procedures

By early October 1997, the DFG received the necessary permits and cleared the legal challenges by promising to provide alternate water supplies and other mitigation. On October 14, 1997, the treatment procedure began. Due to threats of violence, DFG personnel with assistance of the California Highway Patrol, transported several truckloads of powdered rotenone and Nusyn-noxfish to state property near the Lake Davis dam at 0200 hours to avoid any confrontations. The containers were offloaded after dark, but a full media blitz began at first light with protests and heckling of DFG employees.

On the morning of October 15, 1997, chemical application began with surface water temperatures in the low 50s. In response to concerns from local residents, the Lake Davis project utilized powdered rotenone for about 75% of the treatment of the open-water area, while the remaining open-water and shoreline areas, and tributaries were treated with Nusyn-noxfish. A total of 64,000 pounds of powdered rotenone and 16,000 gallons of Nusyn-Noxfish were applied to the lake to achieve a goal 50 µg/L rotenone per acre-foot of water. At the time of treatment, Lake Davis held approximately 50,000 acre-feet of water, 20,000 acre-feet more than it would have contained if not for a temporary restraining order. Ironically, this resulted in the application of additional chemical to the lake relative to the amount that would have been used had DFG been allowed to reduce the volume as planned. For three days following treatment, DFG personnel removed all accessible dead and dying fish. Although numbers or species information was not collected, the majority of fish removed were northern pike. Other species included rainbow trout, pumpkinseed, largemouth bass, golden shiner, and brown bullheads. Approximately 20 tons of dead fish were removed from the reservoir following treatment.

By late-November 1997, water quality analysis indicated that all traces of all chemicals from the treatment had completely degraded except for the synergist, pipernyl butoxide (PBO). The unanticipated retention of PBO was the result if an 18-inch ice cap that eliminated sunlight, decreased water temperature, and restricted water movement. All fish stocking activities were held in abeyance as part of a DFG promise not to stock fish until the water quality parameters were the same as prior to the treatment.

Fish stocking

To appease local groups, and individuals, and provide increased fishing opportunities, trout originally allotted for Lake Davis following chemical treatment were stocked in alternative eastern Plumas County waters. Approximately 1,200,000 trout were planted in surrounding waters, including Frenchman Reservoir. In addition, the DFG requested the California Fish and Game Commission (FGC) to allow an early opening to the local trout season to provide economic relief. The FGC unanimously approved the request.

By June 1998, almost all traces of PBO were gone except those in the deepest part of the lake and the DFG initiated trout stocking in Lake Davis with concurrence of the local community. In late-July 1998, PBO and all other chemicals were undetectable and in September 1998, the California Department of Health Services deemed Lake Davis water safe to drink. More than 2 million trout were planted by the end of the season.

Treatment results

The DFG reported sampling Lake Davis in mid-September 1998, and collected several hundred rainbow trout, from the recent trout stocking, golden shiner *Notemigonus crysoleucas*, brown bullhead *Ameiurus nebulosus,* bluegill *Lepomis macrochirus*, and red ear sunfish *L. microlophus* (Manji 1998). No bluegill or red ear sunfish were identified in samples of fish from Lake Davis in 1999; however, several year classes of pumpkinseed *L. gibbosus* were collected suggesting that the sunfish collected in 1998 were misidentified. Based on numbers and year classes of fish collected during 1998 and 1999 sampling, it is likely that at least three species of fish survived the 1997 chemical treatment. In May 1999, seventeen months following chemical treatment, northern pike were rediscovered in Lake Davis. Subsequent monitoring efforts through the summer of 1999 collected two-year classes of northern pike including several hundred young-of-the-year fish suggesting that northern pike had reproduced in the spring of 1999. It is not known if northern pike survived the chemical treatment or were reintroduced after treatment.

Northern Pike in Lake Davis—Round Two

Future Plans

On May 31, 1999, DFG Director Robert Hight visited Lake Davis and the surrounding communities to meet with Coalition leaders and discuss the northern pike issue. Director Hight suggested a Task Force be formed to explore and develop a solution to the pike problem. A Task Force was formed composed of the Portola City Administrator, the Mayor, a representative of the County Board of Supervisors, the chairs of the Coalition and Fisheries groups, two local business people and various Department personnel to prepare a plan for Lake Davis. The Task Force was broken into two groups; the Steering Committee, consisting of the entire group; and an Oversight Committee consisting of the Portola City Administrator, the County Supervisor, Coalition Chair, and key Department personnel.

The Task Force began working in 1999 to develop recommendations for a proper course of action. During this period, DFG conducted additional research on the biology, life history, and management of northern pike, and methods of eradicating nuisance fish species in general (Lee 1999a). Biologists, engineers, and other technical experts were consulted by DFG and literature reviews were conducted.

At an August 5, 1999, coalition meeting in Portola, the public at large was asked for suggestions for northern pike control measures. In addition, several out-of-state fishery biologists were invited to visit Lake Davis and provide input. Three out-of-state biologists familiar with northern pike life history, biology, and management provided opinions and observations regarding northern pike at Steering Committee meetings. D.Rutz, Alaska Department of Fish and Game stated, - "In those systems with shallow lakes and ponds, some of them (salmonid fisheries) have been completely devastated to the point where there are none left." R. Pierce, Minnesota Department of Natural Resources stated, "Northern pike fry reported to be very adaptable and can live in a whole host of conditions" and "Minnesota experienced absolutely no success in angler control of northern pike populations" (Transcripts of Lake Davis Steering Committee meeting, August 25, 1999).

In late September 1999, a group of approximately 30 DFG biologists were assembled in a two-day workshop/meeting to review and discuss options for northern pike control in California. A list of 40 control options were presented and discussed and although results of the workshop were not published, chemical treatments and draining the lake were given the highest rating for success by the participants. However, in a letter dated October 7, 1999 to Supervisor Fran Roudebush, Leonard Marsh and Jim Murphy, Director Hight assured the Lake Davis area community that "no Proposition 65 chemicals, those that are known to be carcinogenic or have reproductive effects, and potentially harmful chemicals that are persistent in the environment would be used by the Department to treat Lake Davis." Since formulated rotenone is known to contain chemicals identified in the list of chemicals found in Proposition 65, passed by California voters several years earlier, the use of formulated rotenone was removed by Director Hight as a means for controlling northern pike at Lake Davis.

The various control techniques were subsequently compiled into an initial list of options and provided to the Steering Committee on October 28, 1999, and to the public at a coalition meeting on November 3, 1999.

During December 1999, the Steering Committee analyzed each of the proposed options and prepared a revised list. The Steering Committees alternatives were grouped into three categories: 1) options that should be implemented, 2) options needing further information or evaluation, and 3) options not recommended for implementation.

Through the winter of 1999–2000, the DFG assigned staff to prepare a plan for managing northern pike at Lake Davis and incorporate the Steering Committee's list of recommendations.

A draft plan was prepared and submitted to the Steering Committee for review and comment. A formal plan was subsequently established that included the Steering Committee's 12 specific action alternatives as recommendations in a plan for managing northern pike at Lake Davis (DFG 2000). These actions include

1. Use of experimental control measures involving the use of net barriers, electrofishing, detonation cord, and encircling nets in combination with other management activities. Barrier nets could be used to contain numbers of adult, juvenile, and larval pike for removal by electrofishing and by concussion from detonation cord during spring and early summer;

2. The installation of tributary barriers. Physical barriers could be placed in the tributaries to Lake Davis during spring thaw to prevent spawning and the establishment of stream populations of pike;

3. Blocking spawning areas. At spring thaw, block nets could be used to trap spawning pike in portions of the lake for elimination;

4. Reducing pike food supplies and stock brown trout as a predator species. The department could discontinue stocking fingerling trout, a prey source for pike, and plant only larger catchable-sized trout. Brown trout should be included in those plants to increase predation on smaller pike;

5. Encourage pike fishing in ways (including derbies) that do not promote angler interest in pike. Depending on the status of the pike population, the department may assist the local community in holding organized fishing events to remove pike from Lake Davis;

6. Use drag nets and purse seines (encircling nets). Following spring thaw, various nets can be fished for adult and juvenile pike to additively reduce the pike population;

7. Increase the use of electrofishing, particularly in the spring. Following spring "ice out" and continuing on to fall, electrofishing gear could be used to remove pike from Lake Davis and its tributaries;

8. Use electrofishing to herd pike toward traps and nets. On a monthly basis, an electrofishing boat could be used to drive pike into nets for removal;

9. Take various actions relating to the dam including 1) Installation of an upstream containment barrier, 2) Installation of an electric barrier, 3) Modification of the discharge orifice, 4) Maintenance of the lake level to avoid a spill, and 5) Retention of the fish grate at the outflow wall. In addition to the fish grate currently used, various devices, electrical barrier, aquatic exclusion system, and deep-water discharge orifice, could be deployed at the Grizzly Valley Dam to contain northern pike in Lake Davis;

10. Use fyke nets and trap nets. Following "ice out," fyke and trap nets can be set at various locations around Lake Davis to remove pike on an additive basis;

11. Increase enforcement activities. The department will increase its enforcement efforts to contain pike in Lake Davis and improve its ability to use DNA analysis as a tool of enforcement;

12. Improve public education. The department will substantially increase its public information efforts to motivate citizens to help contain and control pike in Lake Davis.

Summary

Intentional and unintentional introductions of unwanted fish species have plagued California for decades. Dill and Cordone (1997) chronicled the history and status of introduced fishes in California while Knutson (1999) and Lee (1999b) presented examples and described many of the recent problems and penalties associated with planting aquatic nuisance species.

It is the mission of the DFG to manage California's fisheries for their ecological values and for their use and enjoyment by the public. These fisheries provide tremendous recreational and economic benefit to the state and effective management is necessary to ensure resource continuance. Illegally introduced fish species alter existing resources, create undesirable populations and locally popular fisheries, and often lead to large financial expenditures for eradication and control. Lack of effective policies to provide consistent direction to fisheries managers for management of detrimental and undesirable fish species continues to plague agencies and departments. Lacking such a policy, historical goals and directions may become changed or distorted leading to lack of focus and direction, loss of existing resources, unnecessary expenditure of funds, and reduced agency credibility. Political forces weigh in and alter decisions based on scientific facts. In the case of northern pike, California residents will most likely have a new permanent resident to add to the list.

References

De Lain, L. I. 1983. Limnological conditions of Lake Davis, California, with emphasis on habitat suitability for salmonids. Masters thesis, University of California, Davis.

Department of Fish and Game (DFG). 1991. Environmental Impact Report Northern Pike Eradication Project. California Department of Fish and Game, Sacramento, California.

Department of Fish and Game (DFG). 1996. Environmental Impact Report Lake Davis Northern Pike Eradication Project. California Department of Fish and Game, Sacramento, California.

Department of Fish and Game (DFG). 2000. Managing northern pike at Lake Davis: a plan for Y2000. California Department of Fish and Game, Sacramento, California.

Department of Water Resources (DWR). 1971. Lake Davis Basin water quality investigations. Plumas County, Sacramento, California.

Department of Water Resources (DWR). 1973. An interagency multidisciplinary investigation of the natural resources of the Sierra Valley study area. Sacramento, California.

Dill, W. A., and A. J. Cordone. 1997. History and status of introduced fishes in California, 1871–1996. California Department of Fish and Game Fish Bulletin No. 178.

Knutson, C. 1999. Illegally plant aquatic nuisance species, face increased penalties. Outdoor California 60(4): 8-11.

Lee, D. P. 1999a. A review of the life history and biology of Northern Pike *Esox lucius* Linnaeus. Inland Fisheries - Informational Leaflet. California Department of Fish and Game, Sacramento, California.

Lee, D. P. 1999b. Invasive Fish Species In California. Pages 4–6 *in* The Environmental Monitor, Fall 1999.

Manji, N. T. 1998. Davis Lake sampling 1998. Information Report draft, California Department of Fish and Game, Redding, California.

Overview of a Large-Scale Chemical Treatment Success Story: Strawberry Valley, Utah

Leo D. Lentsch
The Conservation Association
11439 Lakeshore North, Auburn California 95602 USA
Lentsch@HelpConserve.org

Charles W. Thompson
Utah Division of Wildlife Resources
1694 West North Temple, Salt Lake City, Utah 84116 USA
nrdwr.cthompso@state.ut.us

Robert L. Spateholts
Confederated Tribes of the Warm Springs Reservation
Post Office Box C, Warm Springs, Oregon 97761, USA
Scruffy@technologist.com

Abstract.—The waters in Strawberry Valley, Utah, were chemically treated with rotenone to remove all fish species in 1990 to restore a recreational salmonid fishery. This treatment was one of the largest chemical rehabilitation projects ever undertaken, the area encompassing approximately 170 square miles including 55 tributaries to the upper Strawberry River and Strawberry Reservoir. Fish inhabited a total combined length of 161 miles of stream channel and numerous springs. Treatment volume was reduced from 400,000 to 300,000 acre-feet by treating the epilimnion when the reservoir was stratified. Approximately 875,000 lbs of powdered rotenone and 4,000 gallons of 5% liquid rotenone were used. Over 6,000 workdays using 260 personnel and $3.8 million were required to complete the task. Several innovative procedures for handling and applying rotenone (powder and liquid) were developed to include 1) use of 1,000 lb bags to handle the powder, 2) use of a epilimnetic treatment procedure, 3) mixing powdered rotenone into a slurry with a venturi device, and 4) development of rotenone sandmix that maintains fish toxicity in seeps for 12 hour periods. Summarized here are the objectives, treatment proposal approach, public involvement efforts, regulatory procedures, research and development efforts, and logistical strategies used by the Utah Division of Wildlife to accomplish a chemical treatment of this magnitude. The results of the Strawberry Valley treatment are more than one million hours of fishing pleasure and opportunities for large cutthroat trout and kokanee salmon.

Introduction

Strawberry Valley, Utah, has been the focus of a comprehensive sportfishing restoration project since 1986. Strawberry Valley, located in northern Utah, is a relatively large, high mountain valley that covers an area of approximately 170 sq mi (Figure 1). The waters in this area have some unique fish management characteristics to include 1) support one of the west's leading cutthroat trout (*Oncorhynchus clarki*) fisheries, 2) support of Utah's most popular and heavily used coldwater fisheries, and 3) an extensive stream system containing enough spawning habitat to allow for natural recruitment of salmonids inhabiting Strawberry Reservoir (Platts 1958). Therefore, the waters are intensively managed for sportfishing. Fishery management goals include 1) maintaining cutthroat trout as an integral component of the fishery complex, 2) providing a minimum sustained output of 1.2 million angler hours of fishing pressure annually, 3) achieving an angler catch rate of 0.4 fish/hour of fish at least 12 inches long, 4) producing 10 million cutthroat trout and/or kokanee salmon (*Oncorhynchus nerka*) young-of-the-year from Strawberry tributaries each year, and 5) collecting six million cutthroat trout eggs yearly from spawn taking operations for use elsewhere in the state.

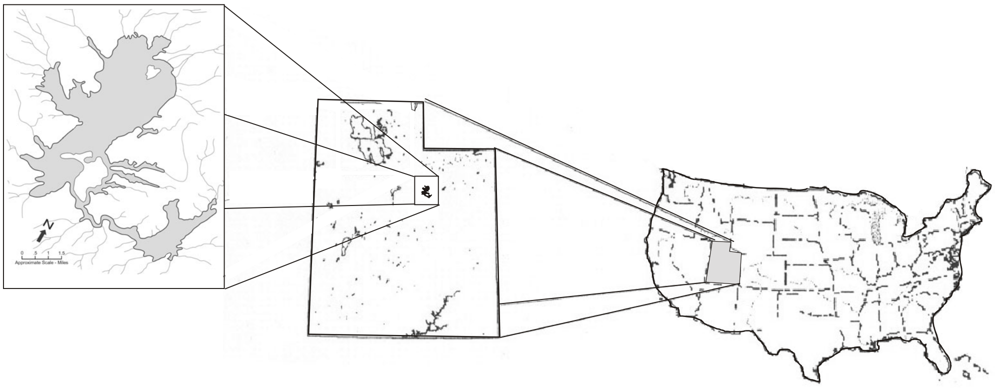


Figure 1. Location of Strawberry Reservoir, Utah.

In the early 1980s, an increase in the number of two nonnative species and deteriorating habitat conditions in Strawberry Valley streams started having a negative impact on sport fish populations. By 1986, 90.4% of fish caught in gill net surveys were Utah chub (*Gila atraria*) and Utah sucker (*Catostomus ardens*) (Lentsch 1987). Additionally, poor habitat conditions in the streams were contributing to the sport fishery decline. As a result, survival rates for stocked trout were extremely low and angler use was declining. The stream channels were no longer suitable for natural reproduction of salmonids. Over 99% of the young-of-the-year fish produced from the streams were Utah suckers (Lentsch 1987).

Beginning in 1986, an inter-agency technical team worked with the public to develop a long-term aquatic ecosystem management approach for the valley (Lentsch and Thompson 1986). This approach contained four primary components 1) elimination of 99% of the number of nonnative fish from the valley, 2) establishment of a monospecific population of cutthroat trout in the drainage, 3) establishment of a new fish community, and 4) enhancement of spawning habitat in the streams so that 10 million young-of-the-year could be produced annually. This plan was accepted and endorsed by the Utah Division of Wildlife Resources (UDWR), U.S. Forest Service (USFS), U.S. Bureau of Reclamation (USBOR), and U.S. Fish and Wildlife Service (USFWS).

In 1990, after more than four years of planning and preparation, UDWR successfully executed a rotenone treatment of all waters in Strawberry Valley. This action represents one of the largest chemical rehabilitation treatments ever undertaken. The treatment involved applying 873,000 lbs of powdered rotenone and 2,711 gals of liquid rotenone to a 12,040 surface acre reservoir (treatment volume of 300,000 acre-ft), while 2,000 lbs of powdered rotenone and 1,235 gal of liquid rotenone were applied to 161 mi of streams. No wildlife management agency in the world has ever undertaken a treatment requiring this large amount of chemical. The largest surface area ever treated with rotenone was conducted by the State of Florida. In the 1960's, the state treated two marshes with surface acres totaling approximately 30,000 acres (R. Fisher, Prentiss Inc., personal communication). The total volume of water treated in Florida, however, was approximately 100,000 acre-ft.

Site Description

Strawberry Valley has an average elevation of approximately 7,580 ft above sea level. The valley covers an area of approximately 170 sq mi. Strawberry Reservoir, a trans-basin-irrigation-storage reservoir, is the major geographic feature in the valley. The construction of Strawberry Reservoir began in 1905 and was completed in 1912. This was one of the first trans-basin-diversion reservoirs built in the west. It had a maximum storage capacity of 300,00 acre-feet and a surface area of 8,000 acres. As a component of the Central Utah Project, Soldier Creek dam was constructed 8.1 mi downstream from the original Strawberry Reservoir dam in 1973. In 1985, the original dam was breached and an enlarged Strawberry Reservoir was created. The maximum storage capacity of the enlarged reservoir is 1.2 million acre-feet with a total surface area of 17,000 acres. Associated with the enlargement of the reservoir was construction of recreational facilities. The total cost of building these facilities has been estimated at $40 million (USFS 1990).

In August 1990, Strawberry Reservoir had a surface area of 12,040 acres and a total volume of 400,000 acre-ft. Lentsch and Mills (1989) listed 55 streams containing approximately 120 reaches in the valley. The total combined length of the perennial stream channels was about 190 mi. In addition to the perennial stream channels, Lentsch and Spateholts (1988) identified approximately 400 seeps or springs throughout the valley.

Need For Action

The waters in Strawberry Valley comprise one of Utah's most economically important recreational fishing areas. In the late 1970's and early 1980's, Strawberry Reservoir attracted more trout anglers than any other Utah water (Johnson 1983; 1988). The angling popularity of Strawberry Valley appears to be a result of a few key factors. Strawberry Valley is located within a two-hour driving radius of Utah's major population centers along the Wasatch Front. Strawberry Valley has a scenic mountain setting that is appealing to urban anglers. Additionally, the reservoir has had a long-standing reputation among Utah anglers for producing more fish and larger cutthroat trout than other waters in the west. The current state record cutthroat trout (26.5 lbs.) was caught at Strawberry Reservoir in 1930.

Strawberry Reservoir has also been ranked as a popular fishery throughout the Western United States. During 1981, anglers spent over 816,000 h of effort fishing on the reservoir that, at the time, was 8,000 surface acres (Thompson and Sakaguchi 1982). This level of fishing intensity rivals other western angling areas such as Yellowstone National Park (YNP). During the same year, YNP received a total of 923,000 h of angling effort on all its waters combined (113,000 surface acres) (Jones et al. 1982). Yellowstone Lake (87,000 surface acres) that was over ten times larger than Strawberry Reservoir received less than half (383,000 h) as much fishing pressure.

History of the Influence of Nonnative Fish and Early Chemical Treatments

The quality of trout fishing and fisheries management decisions in Strawberry Valley have been influenced by introductions of nonnative fish for over 40 years. Fish species native to the valley include Colorado River cutthroat trout (*O. c. plureticus*), mottled sculpin (*Cottus bairderi*), and speckled dace (*Rhynichthyes osculus*). Nonnative trout were stocked in Strawberry Reservoir for the first time in 1923. These early stockings included rainbow trout (*O.*

mykiss) and Yellowstone cutthroat trout (*O. c. bouveri*). Through the 1930's and 1940's angling success was high but subsequently decreased due to a growing population of nonnative fish, particularly Utah chub. Initial introduction of Utah chub into Strawberry Valley occurred during the period of high angling success. Angling methods focused on the use of live bait. Establishment of redside shiner (*Richardsonius balteatus*), mountain sucker (*Catostomus platyrhynchus*), Utah sucker, common carp (*Cyprinus carpio*), yellow perch (*Perca flavesens*), and leatherside chub (*Gila copeia*) soon followed. By the late 1950's trout had almost completely been displaced in Strawberry Reservoir (Platts 1958).

In October 1961, the reservoir was chemically treated to remove several target nonnative fish species. The treatment consisted of applying 330 gals of liquid rotenone to 55 mi of streams, 3,500 gals of liquid rotenone along the shoreline, and 60,000 lbs of powdered rotenone mixed into a water-based slurry to the reservoir surface. Reservoir volume, at that time, was 22,661 acre-feet and covered 3,300 surface acres. The target treatment concentration of rotenone was equivalent to 1.77 parts per million (ppm) of 5% liquid formulation. Total cost of treatment was $43,000. This treatment successfully eliminated the target nonnative fish including Utah chub, Utah sucker, common carp, and yellow perch from Strawberry Reservoir. An excellent trout fishery was reestablished which was maintained for over twenty years.

In conjunction with the enlargement of the reservoir in 1973, the waters between the original Strawberry Reservoir dam and Soldier Creek dam were treated to remove Utah chub. The treatment consisted of applying 23 gals of liquid rotenone to 39 mi of streams, 2,300 lbs of powdered rotenone to impounded water, and utilizing 6,960 lbs of explosives with 39 mi of primacord to treat springs in the impounded water. This treatment also successfully removed nonnative species.

Utah chub reappeared in Strawberry Reservoir in 1973 and by 1978 Utah sucker had become established. The source of these re-introductions was not documented but a private bait-bucket introduction is suspected. Utah chub and Utah sucker numbers increased drastically between 1977 and 1986 (Table 1). By 1986, over 90% of the total catch from gill net samples contained Utah chub and Utah sucker. This explosion of nongame fish caused a reduction in growth and survival of stocked fingerling trout. Indeed, most of the trout sampled during periods when water temperatures were optimum for minnow and sucker species (July-August) had empty stomachs (Lentsch 1987; Lentsch and Spateholts 1988; 1989; 1990). The UDWR responded to the increase in these nonnative species by increasing the size of trout stocked from 3 in to 5 in. From 1978 through 1986, the number of larger trout and the total number of pounds stocked increased. An average of 862,600 trout (43,130 lbs) were stocked in 1978 (UDWR stocking record files). By 1986, 1,478,840 trout (73,942 lbs) were stocked annually. The associated cost of producing these fish increased from $105,000 in 1978 to $209,500 in 1986 (UDWR 1987). In spite of these efforts, the quality of fishing and subsequent response in angling effort decreased.

Spawning Habitat Condition

Strawberry Valley is one of the few locations in Utah that has a major reservoir associated with an extensive tributary system (Lentsch and Mills 1989). If trout-spawning habitat in the streams is maximized, this area offers the opportunity to produce enough young fish each year through natural reproduction to sustain a major trout fishery (Lentsch and Mills 1989). Most of the streams in Strawberry Valley, however, have degraded to the point that they are producing young-of-the-year (YOY) nongame fish instead of trout. Lentsch (1987) reported that, out of over 7,000 YOY fish captured in the Strawberry River in 1986, only four were trout, the remaining fish were Utah sucker.

Lentsch and Mills (1989) indicated that trout-spawning gravel in many of the streams in Strawberry Valley was washed out or buried by silt. In other streams, the channel was down cut reducing sub-irrigation to riparian vegetation. The removal of streamside vegetation caused the streams in the valley to become unstable. Subsequently, peak flows during high water years scoured these unstable channels. Mills (1984) and USBOR (1973) reported that the condition of streams in Strawberry Valley resulted from the cumulative practices of herbicide application, livestock grazing, water diversion, road construction/maintenance, and reservoir inundation. Most of the damage occurred after 1965; however, stream alteration in the valley has been prevalent for almost a century (Mills 1984).

Table 1. Summary of gill net catch statistics for Strawberry Reservoir, Utah, 1973-1986.

Year	**Gill Net Catch**			
	Percent Composition		**Rate (fish/h)**	
	Gamefish	**Other Species**	**Gamefish**	**Other Species**
1973	80.4	19.5	3.41	0.76
1974	76.2	23.7	2.17	0.66
1975	80.4	19.5	2.13	0.50
1976	76.5	23.4	1.66	0.55
1977	63.1	36.8	0.95	4.34
1978	15.5	84.4	1.40	7.58
1979	41.4	58.5	1.25	4.44
1980	26.2	73.7	2.27	6.67
1981	11.6	88.3	2.22	16.91
1982	10.4	89.5	1.56	13.70
1983	--	--	--	--
1984	15.4	84.5	1.25	6.04
1985	--	--	--	--
1986	6.7	93.3	1.65	17.40

Treatment Proposal and Public Involvement

In June 1981, UDWR alerted anglers and other resource agencies that the fishery in Strawberry Valley was in jeopardy. At that time, they proposed that targeted nonnative fish species be removed by chemical treatment before the reservoir was enlarged in 1984. An interagency/citizen team was formed to evaluate the proposal. Members of the original team represented the UDWR, USBOR, USFS, USFWS, Utah Division of Water Quality, Strawberry Valley Water Users Association, Utah Wildlife Federation, and Strawberry Bay Marina. The team met for the first time in October 1981. For over eighteen months, the team evaluated the proposal and alternatives for eliminating the nonnative fish from the reservoir. Little support for the treatment was found. Anglers could not see the need for treatment while fishing was still within an acceptable range. Additionally, agencies other than UDWR were not interested in providing funding for the program at that time. Without financial assistance from other resource agencies, UDWR could not afford to pay for the treatment. The 1983 treatment was therefore cancelled.

Two events transpired during 1985 that altered prospects for improving Strawberry Valley's trout fishery 1) additional funds were made available to the UDWR for chemical treatment through expansion of the Dingell-Johnson excise tax on fishing gear, and 2) the quality of fishing at Strawberry Reservoir declined to the lowest level experienced since the 1961 treatment. The interagency team reconvened and restarted the planning process. The team was expanded to include representatives from the Central Utah Water Conservancy District, Utah Division of Parks and Recreation, Wasatch County Health Department, Mountainlands Associations of Governments, and Utah Sportsman Alliance.

In November 1986, the interagency/citizen team completed a comprehensive plan for restoration of Strawberry Valley's fisheries (Lentsch 1987). That plan outlined the restoration of Strawberry Reservoir by taking a drainage-wide approach. It contained three essential components 1) elimination of targeted nonnative fish, 2) introduction of fish species that would maintain (through biological control) a quality trout fishery, and 3) improvement of stream habitat to foster natural reproduction by trout instead of Utah sucker. The plan was officially approved and adopted by agency heads on December 8, 1986 (Lentsch and Thompson 1986). Budgetary and strategic planning efforts were initiated immediately following the approval. The tentative target date for chemical treatment was set for August 1988. Public support and regulatory permits, however, were obtained before a final treatment date could be set.

Public Involvement

In 1981, the UDWR recognized the need for an aggressive program to inform the public and gather input on management of the Strawberry Valley fishery. As the need for treatment grew so did the public involvement program. By 1986, this program had four components: 1) public involvement on the interagency team, 2) news releases, 3) presentations to private and public groups, and 4) publication and distribution of informational brochures and bulletins. Once the agency heads approved the course of action, the public awareness program was intensified.

During 1986 and 1987, over 50 news releases, newspaper articles, and television reports related to the treatment appeared in the media. Over 40 presentations on the preferred alternative were made to private clubs and organizations. The total attendance at all of these meetings exceeded 1,000 people. The same program was presented at "fireside" chats at Strawberry Reservoir campgrounds. Over 500 people attended those presentations. Strawberry Valley and its fishery problems were featured as the theme of the 1986 and 1987 UDWR state fair display. Over 100,000 people view the UDWR State Fair display annually. An information brochure describing the preferred alternative was published. Approximately 40,000 copies were distributed. A "Strawberry Newsletter", featuring the alternatives, the proposed action, and the reason for its implementation were printed (100,000 copies) in 1987 and distributed to all Utah anglers with the 1988 fishing proclamation. Articles on the subject also appeared in the 1989 and 1990 proclamations. Over 300 workdays and $5,000 were expended on these combined efforts.

Permits and Regulatory Compliance

The magnitude of the Strawberry Valley chemical treatment demanded strict adherence to regulatory procedures and environmental impact analysis. The USFWS required acquisition of a pesticide use approval permit and completion of an Environmental Assessment (EA) under guidelines of the National Environmental Policy Act of 1973. The pesticide approval permit required a description of specific activities associated with the treatment such as chemical concentrations, pesticide detoxification procedures, etc. The EA addressed the social, environmental, and economical aspects of the treatment. A finding of no significant impact was issued by the USFWS on July 15, 1987 (UDWR 1987).

Compliance with state regulatory procedures were requested by three agencies 1) Utah Resource Development Coordinating Committee (URDCC), 2) Utah Department of Agriculture (UDA), and 3) Utah Department of Natural Resources (UDNR). URDCC reviewed the proposal and approved it on July 15, 1987. UDA required that it be kept appraised of the project. UDNR required a stream alteration permit for activities associated with beaver dam breaching. This permit became the most controversial to obtain and several demonstrations and onsite tours were required before it could be issued.

Research and Development Activities

Between 1986 and 1990 UDWR made significant advances in the application technology for powdered rotenone. Six research pilot projects were completed between 1987 and 1989 (Lentsch and Spateholts 1988; 1989; 1990). Project personnel gained additional experience by participating in five other fish eradication projects (two of which were out of state). Those efforts led to new ideas and concepts for treating stratified waters with powdered rotenone, handling large quantities of powdered rotenone, mixing the powder into a slurry, using powder to treat seep areas associated with streams, and using powder to treat weed bed areas in reservoirs. The performance of powdered rotenone during epilimnetic treatments was documented. A clearer understanding of the influence of in-reservoir currents on the movement of rotenone in reservoirs was gained. Additionally, the impact of epilimnetic treatments on zooplankton, chlorophyll a, and major nutrients was documented. This information was used to reconsider the original (1985) treatment plan and develop a new strategy. The following is a summary of the research and development efforts that were made in preparation for the Strawberry Valley treatment.

Mixing and Application Techniques

Utah biologists have used powdered rotenone for chemical rehabilitation projects since 1958 when approximately 86,000 lbs of the chemical was applied to Scofield Reservoir. During that treatment a platform barge utilized an auger device to mix the powder directly into the water as the barge moved over the surface of the reservoir. This technique was cumbersome and personnel were over-exposed to rotenone dust. In 1959, the UDWR utilized liquid rotenone with a crop-duster plane to treat reservoirs. In 1961 the powdered rotenone application technique was modified. A powdered-rotenone slurry was made by mixing approximately equal amounts of water and powder together. The slurry was then distributed on reservoirs with torpedo bomber planes. This method of application continued through 1977. By 1978, however, the cost of applying powdered-rotenone slurry by airplane became prohibitive. Therefore, in 1981, the method was modified and stocking barges were used to distribute the powdered-rotenone slurry on target waters. The method was further modified in 1982 when ready-mix cement trucks were used to mix the slurry. Approximately two pounds of powder was mixed with every gallon of water. This method was commonly practiced in 1986.

By 1990, a significant departure from Utah’s traditional method of mixing powdered rotenone was evaluated and developed (Thompson et al. 2001). This departure involved the use of a venturi device for mixing the chemical. The device was field-tested during three treatments prior to its use for the Strawberry Valley treatment. Approximately 1,500 lbs of chemical were used during the field tests. Equipment development for application of rotenone to the reservoir involved modifying National Guard bridge barges and army barges for carrying and mixing the powder and developing a method for distributing liquid in weed bed areas (Thompson et al. 2001).

Rotenone Sandmix

A powdered rotenone-sand mixture (sandmix) was developed to treat seeps and springs in the Strawberry Valley (Spateholts and Lentsch 2001). The mixture maintained toxic rotenone concentrations in seeps and springs for 12 h. The sandmix was compared to liquid rotenone and a powdered rotenone paste formulation in trials conducted at Strawberry Springs, Utah in 1988. Rotenone concentrations and fish mortality were monitored in seeps receiving 0.15, 0.25, and 0.35 ppm initial application rates of the three formulations. The sandmix and paste produced active ingredient concentrations above a minimum toxic level of 0.03 ppm in seeps for 12 h following application. Concentrations of the liquid formulation were below the toxic level at 4 h. Each formulation produced 100% mortality of trout fingerlings in place in the seeps at the time of application. The 0.25 ppm and 0.35 ppm sandmix formulations produced 60-100% mortality ($p < 0.05$ log-rank test) in cohorts of fingerlings placed 4,8, 12 and 24 h after application. Mortality was 0-70% for cohorts placed after 4 h in the liquid and paste trials.

Over 2,000 lbs of powdered rotenone was made into bulk sandmix and applied to more than 450 seeps and springs during the chemical rehabilitation of Strawberry Valley in August and October 1990. Field sampling of rotenone concentrations during the treatment verified that sandmix applied at 0.15-0.35 ppm active ingredient (ai) rotenone maintained toxic concentrations for at least 12 h. The sandmix proved to be an effective formulation for treating sources of upwelling groundwater that frequently provide refugia for target species during chemical rehabilitation projects.

Epilimnetic Treatment with Powdered Rotenone

Research studies on the performance of rotenone during epilimnetic treatments were conducted from 1987 through 1990 (Lentsch and Spateholts 1988; 1989; 1990). The results of this work indicated that the thermocline was an effective barrier, that a mechanical approach to distribution was effective, zooplankton populations would recover within 2-4 weeks following application, and that the rotenone would stay toxic for at least a six- to seven-day period at Strawberry Reservoir water temperatures.

Treatment Preparations

Division of Responsibilities

Early in the planning process, biologists recognized that the complexity of the Strawberry Valley chemical rehabilitation required clear definition of supervisory responsibilities for various aspects of the project. These responsibilities were divided between three biologists working full-time on the treatment. One biologist supervised activities associated with chemical acquisition, transportation, chemical mixing, and providing accommodations for personnel. The second biologist was responsible for activities associated with strategic planning, chemical application, detoxification, and personnel safety. The third biologist assisted with preparations for chemical application by primarily overseeing the stream treatment. All three individuals were involved with information/education, crowd control, intragency coordination, and other miscellaneous activities. A total of 22 additional leadership (crew leaders) positions were identified. Biologists from other duty stations throughout Utah were selected to fill these positions. They assisted the supervisors by managing crews, providing training, modifying equipment, and completing other duties as assigned.

Chemical Acquisition

Powdered rotenone was ordered, priced, and purchased on a unit basis. One unit of rotenone is equal to one percent active ingredient (ai). The amount of active ingredient chemical required for the treatment was approximately 61,250 lbs. The ai concentration of powdered rotenone generally ranges between 5 and 8%. Approximately 875,000 lbs of 7% or 1,225,000 lbs of 5% powdered rotenone were needed to obtain the quantity of ai-powdered rotenone for the treatment. The amount of chemical that needed to be handled and applied to the reservoir depended, therefore, upon the ai concentration. The ai concentration in each 1,000 lb bag of powdered rotenone was determined. Preparations for the treatment were adjusted, as the ai concentration of the powder in each shipment was determined.

The UDWR was required to follow state guidelines for purchasing the amount of chemical required for the treatment. During early discussions, the rotenone registrants indicated that the amount required represented a 35% increase in the world market for one year. These companies were concerned that such a large order would upset the market and greatly increase rotenone prices. The chemical suppliers, Foreign Domestic Chemicals Corporation and Roussel Bio Corporation, started negotiations to acquire rotenone for the treatment in 1987. At the same time, UDWR set a ceiling price for the project that could not be exceeded.

The price for the chemical was $0.31/unit. This purchase price was $2.17/lb for 7% (7 X $0.31) or $1.55/lb for 5% (5 X $0.31) powdered rotenone. An order for an equivalent amount of powdered rotenone containing 61,250 lbs of ai was placed in 1989. The ai concentration of the powdered rotenone received averaged 7% and ranged between 6.5 and 7.4%. The total cost of powdered rotenone for the treatment was $1,909,600.

Transportation and Storage

The product was shipped from Peru to United States via ocean barge in 20 large containers holding forty-four 1,000 lb bags of powdered rotenone. Within the United States the containers were shipped by railway. A total of four shipments were made from Peru to Utah from April to July 1990. Each shipment took 120 days from the time it left Peru until in reached Utah.

The first three shipments were stored in a warehouse in Salt Lake City, Utah. The storage contract stipulated that the storage company unload the containers from railroad cars and store the product. The cost of storage was $2.35/sq ft/year for a total cost of $33,000.

The same company that stored the chemical also transported it from Salt Lake City to Strawberry Reservoir over a three-week period. Twenty-six trailers stored 390,000 lbs of chemical at four locations around the reservoir. The rental cost of each trailer was $90/month. The remaining 490,000 lbs of chemical was unloaded at the staging sites and wrapped with visquine. The total cost of storage and transportation was $20,437.

Chemical Application Strategies and Approaches

The target concentration of ai rotenone for the treatment was 0.075 ppm based on weight. This concentration is equivalent to 1.5 ppm 5% powdered rotenone or a 5% liquid rotenone formulation. To achieve the target concentration approximately 873,000 lbs of powdered rotenone averaging 7% ai and 2,800 gals of liquid rotenone (5% ai) were applied to Strawberry Reservoir while 1,235 gal of liquid rotenone and 2,000 lbs of powdered rotenone were applied to 161 mi of stream channels. The general objectives were to: 1) maintain toxic concentrations for at least a 48 h period, 2) contain the chemical in the valley, and 3) ensure that the chemical was applied in a safe manner.

Reservoir Application

The chemical treatment took place between August 19 and August 24, 1990 (Table 2). The distribution of the powdered rotenone on the reservoir was based on an average ai concentration of 7%. The reservoir was subdivided into six primary treatment zones (Figure 2). Each of these zones represented the surface area that needed to be covered on an individual day. These areas were further subdivided into smaller areas for the purpose of establishing treatment areas for the individual boats applying the chemical. These smaller zones averaged 365 surface acres in size.

Chemical distribution began at the upstream area of the reservoir and proceeded downstream. Four loading sites were utilized to supply chemical to the distribution boats (Figure 2).

The rate the chemical was distributed on the reservoir averaged over 9000 lbs/h. Three types of boats were utilized to distribute the chemical 1) powder barges, 2) slurry barges, and 3) liquid application boats (Thompson et al. 2001). Powder barges mixed and applied the powder on the reservoir with the venturi devise. They were generally assigned to open water areas. The powder barges distributed an average of 123,300 lbs each day. Slurry barges distributed a powder/water slurry that was mixed by venturi devises at the loading sites. These barges were generally assigned to shallow water areas. They distributed an average of 18,200 lbs of powdered rotenone mixed into a slurry each day. The boats distributing the liquid rotenone were assigned to areas of the reservoir with dense weed beds. Liquid rotenone was used in these areas to enhance distribution of the chemical within the weeds. Approximately 467 gallons were distributed each day.

The chemical was applied for approximately 16 h each day. Crews were divided between two 8 h shifts. A total of 80 individuals assisted in distributing the chemical on the reservoir. Over 750 workdays were required to accomplish this task.

Table 2. Summary of the distribution of rotenone on Strawberry Reservoir, Utah, 1990.

		Rotenone Application		
Zone	**Date**	**Powder (lbs)**	**Slurry (lbs)**	**Liquid**
1	08/19/90	82,000	11,000	282
2	08/20/90	149,000	18,000	462
3	08/21/90	133,000	23,000	591
4	08/22/90	159,000	24,000	617
5	08/23/90	148,000	18,000	462
6	08/24/90	93,000	15,000	386
Total		764,000	109,000	2,800

Stream Application

A total of 1,800 gals of a liquid rotenone formulation and 2,000 lbs of powdered rotenone were applied to Strawberry Valley streams during 1990. Approximately 1,235 gals of the liquid rotenone formulation was applied with drip barrels (Thompson et al. 2001) to stream reaches through out the valley (Table 3). An additional 100 gals of chemical was applied with drip barrels at the confluence of tributaries to ensure that water entering the reservoir was toxic during the reservoir treatment. A total of 119 drip stations were used during the treatment (Figure 3). The locations of the drip stations were based on accessibility, discharge rate, and turnover rate. Turnover rate was defined as the number of times the volume of water in a stream channel was completely exchanged. The minimum number of turnovers allowed in a 48-h period was set at four. The amount of chemical used in the drip stations was based on the volume of stream flow at the furthest downstream location that the application needed to treat. The remaining liquid formulation was applied with backpack sprayers to seeps and springs through out the valley. The powdered rotenone was applied as the sandmix formulation (Spateholts and Lentsch 2001).

The streams in Strawberry Valley were treated during two separate periods in 1990. The first application was sequenced to correspond with the reservoir treatment (August 5 to 24, 1990). The second application occurred during September 24 and October 17, 1990. Each chemical application was organized into eight treatment zones (Figure 3). The application of chemical occurred sequentially through the eight zones. Streams above migration barriers were treated first (Zones I-II). The main stem of the Strawberry River and its tributaries were treated next (Zones III-V). The remaining stream channels surrounding Strawberry reservoir were treated last (Zones VI-VIII). Treatment of these channels corresponded with the reservoir treatment during the first application.

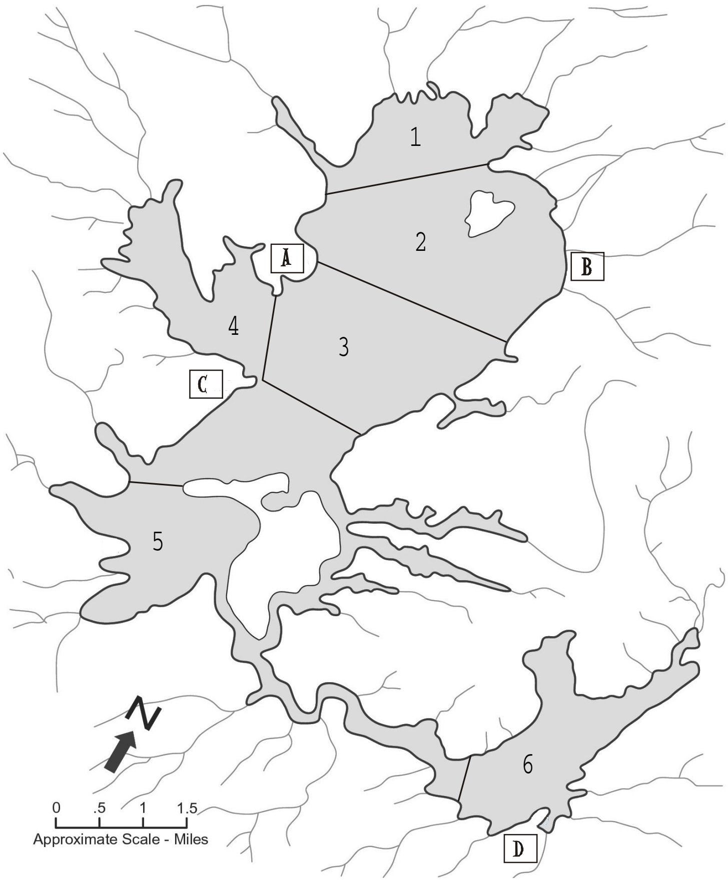


Figure 2. Treatment zones (1-6) and chemical loading sites (A-D) used for applying rotenone to Strawberry Reservoir, Utah, 1990.

Table 3. Summary of the water volume, amount of rotenone used, stream channel length, average travel time, and average turn over rate for stream treatment zones, Strawberry Reservoir, Utah, 1990.

Zone	Volume (ac-ft/day)	Liquid Rotenone (gal)	Stream Channel Length (mi)	Average travel time (h)	Average number of turnovers
I	10.2	10.0	17.7	4.5	43.2
II	27.6	21.3	23.45	3.7	30.11
III	30.6	27.4	9.0	4.8	23.0
IV	8.4	10.6	8.2	8.4	9.3
V	77.0	83.1	22.3	3.35	36.7
VI	39.5	40.0	20.1	3.1	52.3
VII	28.1	31.2	17.6	4.0	70.2
VIII	6.1	6.2	11.7	2.0	51.4
Reservoir Tributaries	30.4	30.6	3.3	.67	185.36

Key components within each treatment phase were 1) breaching of beaver dams, 2) treatment of the volume of water in each stream reach, and 3) treatment of seeps, springs, and problem areas along stream channels. It generally required three days to apply chemical to all of the waters within each zone. On day one, all of the beaver dams within the zone were breached. Ponds were modified into single stream channels. On day two, breached beaver dams were rechecked to make sure that the streams were remained free flowing channels. Drip stations were activated in the morning, checked and recharged throughout the day to ensure a constant application rate. After the chemical had been applied to the channel for 4 to 6 h, the treatment crews walked the stream channel applying liquid rotenone and sandmix to seeps, springs, and standing waters. On day three, drip barrels were recharged with chemical and stream channels were walked again to ensure that no water remained untreated. To accomplish these tasks in the appropriate sequence, work assignments were organized by activity 1) beaver dam breaching, 2) drip station operation, and 3) seep and spring treatment.

Beaver dams, within any reach, that could potentially interfere with chemical application and success of the treatment were removed. Initial removal of beaver dams in each treatment zone occurred the day before any chemical was applied. Water gel explosive was used to breach large dams. Small dams were breached by hand. Spotters were used to keep the general public out of areas where blasting occurred. Warning signs were placed at access points, and some roads were temporarily closed to the public access.

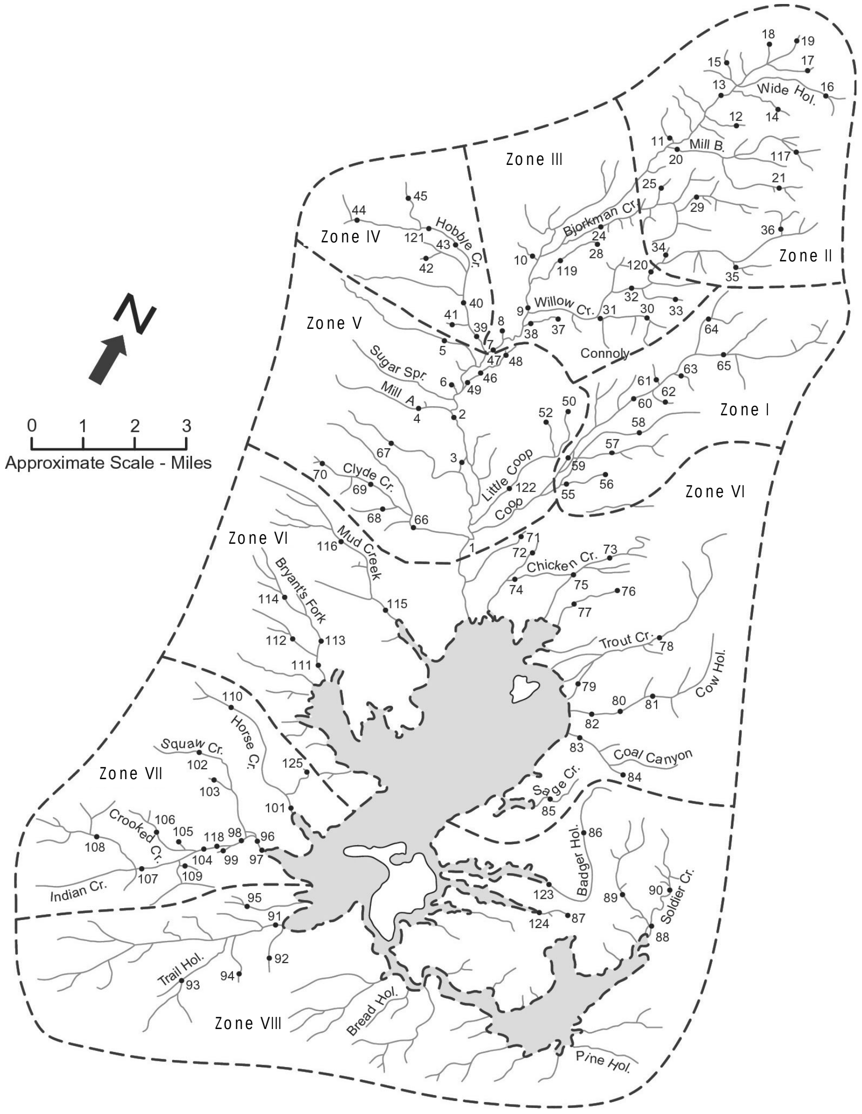


Figure 3. Treatment zones (I-VIII) and drip station locations used for applying rotenone to streams in Strawberry Valley, Utah, 1990.

Drip barrels were activated, checked, and refilled at specific stream channel locations within each zone (Figure 3). Drip stations consisted of a 33-gal barrel with PVC drip heads calibrated to drip at a constant rate for 12 h. They were operated for 48 h. Locations of the drip stations were selected so that it would take 12 h or less for the chemical to travel from the station to the furthest downstream location that needed to be toxic. The drip barrels were started as early as possible on the day after the beaver dams were breached. Between 15 and 25 drip stations were used within each treatment zone. They were checked as frequently as possible (up to one time/h) to make sure the chemical was applied at a constant rate.

Treatment crews walked the stream channels to check for the progression of chemical applied at the drip stations and to apply chemical to backwaters, seeps, springs, and other standing waters. This work generally began 4 to 6 h following application of the chemical at the drip stations. This procedure continued through the second day of chemical application. The quantity of liquid rotenone applied by walking the stream channel was calculated using a formula of 2 oz/seep plus 8 oz/mile. Approximately 8 oz of sandmix was packaged in bags. Each package was used to treat a seep with a volume of up to 0.25 cfs. Efforts were made to ensure that seeps, streams, and side channels were not treated until after the main channel was toxic from the drip station application of chemical. These areas were re-checked on the second day of chemical application.

Detoxification Strategies

All waters leaving Strawberry Valley were treated with potassium permanganate (KMnO4) to detoxify the rotenone. Treated waters included the Strawberry River below Soldier Creek dam (4,500 lbs), Daniels Diversion on the upper Strawberry River (2,160 lbs/treatment), and the Spanish Fork River (8,100 lbs) where it receives water diverted from Strawberry Reservoir. Detoxification stations on the Strawberry River and Daniels Diversion applied KMnO4 at a rate of 5 ppm. KMnO4 was applied to the Spanish Fork River at a rate of 0.5 ppm. This lower rate was based on the distance between the Spanish Fork River and Strawberry Valley and the time it would take water to travel that distance. The water hardness characteristics of waters in Strawberry Valley would have allowed KMnO4 to effectively detoxify rotenone concentrations up to 0.15 ppm ai. To ensure that the rotenone was contained within the target area the following precautions were taken: 1) application of KMnO4 was initiated concurrently with the application of rotenone; 2) fish were held in live cages upstream and downstream of the detoxification stations to monitor toxicity; and 3) a backup detoxification station, located further downstream, was operated concurrently with each primary detoxification station.

Detoxification stations were operated continuously during the period of rotenone toxicity. The Strawberry River and Spanish Fork River sites operated for 10 days. The Daniels site operated for six days. The KMnO4 was applied by mixing the chemical in a 450 gal holding tank at a rate of 110 lbs of chemical per 440 gal of water, then applying this mixture to the stream channel by using a barrel with a constant flow meter to maintain the application rate.

Safety Procedures

All personnel were required to use safety gear in any location where they may be exposed to the chemical. On a daily basis, safety suits, gloves, respirators, and protective face gear was issued to each individual. Certified emergency medical technicians were assigned to the treatment areas. A vehicle was designated as the emergency vehicle each day. Radio communication was maintained with each crew.

Successful Treatment Results

The Strawberry Valley treatment was a very successful sport fish management endeavor. The average annual fishing pressure for the five years following the treatment (1991-1995) was 996,051 h (Table 4). By 1995, fishing pressure had surpassed the goal set for the reservoir. In general, fishing pressure, success, and the size of fish caught by anglers have all increased following the treatment (Wilson and Spateholts 1997; Wilson and Spateholts 1998; Wilson et al. 1999; Wilson et al. 2000). Utah chub and Utah sucker have reappeared in the reservoir (Figure 4). However, their numbers are not expanding at the same rate or having the same impact on the trout populations as they did prior to the treatment (Lentsch 1987; Wilson et al. 2000).

Table 4. Summary of angling characteristics for Strawberry Reservoir, Utah, 1991-1995 (Wilson and Spateholts 1997).

YEAR	ANGLER HOURS	TOTAL CATCH	CATCH RATE	TOTAL CREEL	CREEL RATE
1991	323,587	163,083	0.50	117,128	0.36
1992	1,138,503	233,516	0.21	179,609	0.16
1993	991,275	261,984	0.26	138,049	0.14
1994	1,153,686	771,124	0.67	339,811	0.29
1995	1,223,205	N/D	N/D	N/D	N/D

Acknowledgements

The authors wish to express their sincere thanks to all of the individuals that assisted on the Strawberry Valley Treatment. Without the help of literally hundreds of individuals this project would never have been completed. We wish to give a special thank you to Glenn Davis whose career-long efforts at applying powdered rotenone in the State of Utah can not go unnoticed.

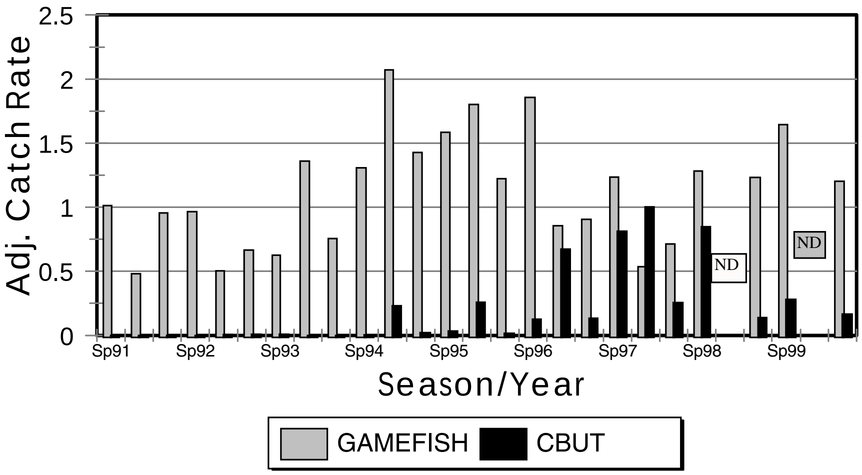


Figure 4. Summary of trend gillnetting catch rate statistics for gamefish species and Utah chub (CBUT) in Strawberry Reservoir, Utah 1991-1999.

References

Johnson, J.E. 1983. Statewide fishery management survey 1981 postal census. Utah Division of Wildlife Resources Publication No. 83-7. Salt Lake City, Utah. 30pp.

Johnson, J.E. 1988. Statewide fishery management survey 1986 postal census. Utah Division of Wildlife Resources Publication No. 88-7. Salt Lake City, Utah.

Jones, R.D., P.E.Bigelow, R.E.Gresswell, and R.A. Valdez. 1982. Annual Project Technical Report for 1981. Fishery and Aquatic Management Program, Yellowstone National Park.

Lentsch, L. D. 1987. Strawberry Reservoir fishery management enhancement project. 1986 Annual Report. Dingell Johnson Project F-50-R-1. Utah Division of Wildlife Resources memo report. Salt Lake City Utah.

Lentsch, L.D. and R. Spateholts. 1988. Strawberry Valley fisheries enhancement project annual report. Dingell Johnson Project R-50-R-3. Utah Division of Wildlife Resources. Sale Lake City, Utah.

Lentsch, L.D. and R. Spateholts. 1989. Strawberry Valley fisheries enhancement project annual report. Dingell Johnson Project R-50-R-4. Utah Division of Wildlife Resources. Sale Lake City, Utah.

Lentsch, L.D. and R. Spateholts. 1990. Strawberry Valley fisheries enhancement project annual report. Dingell Johnson Project R-50-R-5. Utah Division of Wildlife Resources. Sale Lake City, Utah.

Lentsch, L. D. and C. Thompson. 1986. Strawberry Valley's Fisheries Restoration Project. Utah Division of Wildlife Resources. Sale Lake City, Utah.

Lentsch, L. D. and A.D. Mills. 1989. Strawberry Reservoir fishery enhancement project special report. Utah Division of Wildlife Resources. Salt Lake City, Utah.

Mills, A.D. 1984. Aquatic habitat management rehabilitation on Strawberry Reservoir tributary streams. U.S. Forest Service, Uinta National Forest. Provo, Utah. 111 pp.

Platts, W.S. 1958. The natural reproduction of the cutthroat trout Salmo clarki richardson, in Strawberry Reservoir, Utah. M.S. thesis. Utah State University. Logan, Utah. 67pp.

Spateholts, R. L. and L. D. Lentsch. 2001. Utah's rotenone sandmix: A formulation to maintain fish toxicity in seeps or springs. (This Proceedings).

Thompson, C. W., C. L. Clyde, D. K. Sakaguchi and L. D. Lentsch. 2001. Utah's procedure for mixing powdered rotenone into a slurry. (This Proceedings).

Thompson, C. and D. Sakaguchi. 1982. Strawberry Reservoir 1981 creel census report. Utah Division of Wildlife Resources memo report. Salt Lake City, Utah.

Utah Division of Wildlife Resources. 1987. Environmental Assessment of plans to restore Strawberry fisheries. Utah Division of Wildlife Resources. Salt Lake City, Utah.

U.S. Bureau of Reclamation. 1973. Final Environmental Impact Statement, Bonneville Unit, Central Utah Project, INT FES 73-42. U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region. Salt Lake City, Utah.

U.S. Forest Service. 1990. Uinta National Forest. Strawberry Valley Management Area. Final Environmental Impact Statement. USDA Forest Service, Provo, Utah.

Wilson, R. and R. Spateholts. 1997. Strawberry Valley Fisheries Management Annual Performance Report. Utah Division of Wildlife Resources. Sale Lake City, Utah.

Wilson, R. and R. Spateholts. 1998. Strawberry Valley Fisheries Management Annual Performance Report. Utah Division of Wildlife Resources. Sale Lake City, Utah.

Wilson, R., R. Spateholts, and T. Cady. 1999. Strawberry Valley Fisheries Management Annual Performance Report. Utah Division of Wildlife Resources. Sale Lake City, Utah.

Wilson, R. T. Cady, and A. Ward. 2000. Strawberry Valley Fisheries Management Annual Performance Report. Utah Division of Wildlife Resources. Sale Lake City, Utah.

AFS Rotenone Stewardship Program

Rosalie A. Schnick
Michigan State University, 3039 Edgewater Lane
La Crosse, Wisconsin 54603-1088, USA
RozSchnick@centurytel.net

Abstract. —The American Fisheries Society obtained a grant for a stewardship program to balance reasonable environmental safeguards with more prudent use of rotenone to manage and assess fish communities. The objectives of the Rotenone Stewardship Program were to (1) ensure safe and effective use, (2) educate the public on the benefits and risks, (3) provide up-to-date information to fisheries biologists on all aspects of use, and (4) develop proactive strategies for the continued use. Rotenone Stewardship Program members started by conducting a survey of fish and wildlife agencies in North America that was the basis for a major manual for the safe and effective use of rotenone that emphasizes planning and public involvement. Ten products in total were produced to meet the objectives of this program.

Introduction

Fisheries managers rely on a wide variety of tools for the management and assessment of fish populations to maintain diverse and productive aquatic ecosystems and high quality recreational fisheries. One of the most valuable tools is rotenone. Rotenone has been used for almost 70 years in North America. Seven of the more important uses of this tool include:

- Manipulation of fish populations to maintain productive recreational fisheries
- Eradication of harmful exotic fishes that threaten habitats or sensitive native species
- Eradication of competing fish species in rearing facilities or ponds
- Quantitative assessment of fish populations and communities
- Treatment of drainages before initial reservoir impoundment
- Control and eradication of fish diseases that threaten hatchery and wild fish stocks
- Restoration of native, threatened, and endangered species

Chemical application is the only method available that will extirpate entire populations of fishes. The elimination of undesirable fish is needed to accomplish critical fishery management activities mentioned above. Furthermore, rotenone is the only sampling method that provides for an accurate estimation of diverse fish communities.

Rotenone is used in standing and flowing freshwaters. In various formulations, almost all state, provincial, and federal fishery management agencies use the compound. Despite the continuing need for rotenone, its continued availability is uncertain. Over the past several years, the use of rotenone has been temporarily prohibited or limited in several states. The use of rotenone is increasingly a concern to environmental and animal rights groups threatening its future use even for small projects. Several examples have recently occurred in New York and California. Putting any chemical into water, especially one that kills fish, creates controversy. A dire need exists for a public information program that will educate the public on the real impacts of rotenone and dispel emotional fears. As more demands are placed on the water bodies in North America, and the public becomes more environmentally aware, guidelines were needed for using rotenone prudently with minimal impacts.

Fisheries biologists also need an electronic information network to gain immediate assistance with technical and public relations problems.

The 1991 rotenone brochure produced by the U.S. Fish and Wildlife Service was not adequate for transfer of information to the public. The brochure was silent on several recent concerns regarding the use of rotenone. Recent concerns include the "inert ingredients" in the rotenone formulation, public health impacts, impacts of other chemicals in the formulations including synergists and solvents, contamination of surface and ground waters with rotenone and other chemicals, and impacts on non-target aquatic organisms, birds, and mammals.

Fisheries biologists receive little training on the use of rotenone. The product label provides general, minimal directions needed to apply the rotenone. The label does not, and should not, address specific issues because much of this information is subject to change and based on site-specific environmental, sociological, biological, and economic considerations. Only certified pesticide applicators can apply rotenone formulations. The certification procedure is costly, time-consuming, and seldom, if ever, provides information on environmental issues or training specific to rotenone use in aquatic environments. The available training focuses only on production agriculture crops.

In 1993, the American Fisheries Society's Fish Management Chemicals Subcommittee (AFS-FMCS) of the Task Force on Fishery Chemicals submitted a proposal to develop and implement a Rotenone Stewardship Program for fisheries management using U.S. Fish and Wildlife Service Federal Aid Administrative Funds of the Sport Fish Restoration Program. The proposal was accepted for funding in December 1997.

The Rotenone Stewardship Program reflects current practices of rotenone use by fisheries management agencies and consensus on the best management practices. Failure to develop and implement a Rotenone Stewardship Program could have resulted in the eventual loss of rotenone as a tool in fisheries management.

Objectives

The objectives of the Rotenone Stewardship Program were to (1) ensure the safe and effective use of rotenone, (2) educate the public on the benefits and risks of rotenone, (3) provide up-to-date information to fisheries biologists on all aspects of rotenone use, and (4) develop proactive strategies for the continued use of rotenone.

Methods

The AFS-FMCS members were selected by the AFS President to include broad geographic and diverse fishery ecosystem representation. These members contributed substantial volunteer time and expertise to develop and implement the Rotenone Stewardship Program. Eight fisheries professionals from seven state departments of fish and wildlife contributed in excess of 1,500 hours total to the two-year Rotenone Stewardship Program. The contribution in time by the AFS-FMCS members is estimated to be a minimum of $62,000, or more than 40% of the estimated total cost ($149,000) of this project. To accomplish this project, the AFS requested and received a grant of $86,972.

The members of the Rotenone Stewardship Program addressed the following four elements:

- Technical and administrative guidelines for the safe and effective use of rotenone in the full range of inland waters where the use of rotenone is a necessary management tool
- Public information program to educate the public on the benefits and risks of rotenone use

- Electronic information system for fisheries biologists that provides up-to-date information on current use restrictions, important issues and solutions, and the registration status of rotenone
- Proactive strategies for the continued use of rotenone that addresses long-term solutions for (1) public relations programs, (2) funding mechanisms to maintain use, (3) working in partnership with the rotenone registrants, and (4) information transfer among fisheries professionals

Results

The first task of the Rotenone Stewardship Program was to develop a survey of current uses, issues, and restrictions for distribution to all fishery management agencies in North America. A total of 78 responses were received from 95 questionnaires sent in 1998. Many agencies reported on public concerns and expressed the need for information on the following items (in order of frequency mentioned): (1) collection and disposal of dead fish, (2) impact of rotenone and other ingredients on public health, (3) impact of rotenone and other ingredients on surface and groundwater quality, (4) adequate public notification and education, (5) impact of rotenone on animal welfare--fish, (6) impact of rotenone on animal welfare--wildlife, (7) impact of rotenone on invertebrates, (8) rotenone residues in fish, (9) liability and property damage, and (10) impact of rotenone and other ingredients on air quality (McClay 2000).

Technical and Administrative Guidelines

Using the results of the survey as a guide, the Rotenone Stewardship Program members developed administrative and technical guidelines to help fisheries biologists to conduct proper rotenone applications (Finlayson et al. 2000). The guidelines discussed items not included on the product labels. The items included (1) current federal and state regulations, (2) licensing requirements of applicators, (3) environmental impacts and associated mitigation measures for public health, wildlife, fish, amphibians, invertebrates, and recreation, (4) the need and benefits of chemical and resource monitoring, (5) required technical and administrative procedures associated with planning and executing successful stream and lake treatments, (6) recommendations for assessing the short- and long-term success and impact of a rotenone treatment, and (7) successful public relations strategies. With these guidelines, fisheries biologists will do a better job of applying rotenone. The administrative and technical guidelines were distributed to state and federal fisheries management agencies by the AFS and have been made available for sale to individuals and other entities through the AFS and the rotenone registrants.

Public Information Program

The public information program includes (1) an article in *Fisheries* based on the rotenone use survey (McClay 2000), (2) an editorial on the importance of rotenone as a management tool for fisheries (American Fisheries Society, Fish Management Chemicals Subcommittee 2000a), (3) a short, one page, front-to-back fact sheet that can be easily modified for specific projects containing answers to the often asked questions on rotenone use in fisheries management, (4) a symposium entitled “Rotenone in fisheries management: are the rewards worth the risk?” at the 2000 annual AFS meeting in St. Louis, Missouri, (5) the symposium proceedings being published with this article, and (6) a revised, public information brochure with more up-to-date information on current issues (American Fisheries Society, Fish Management Chemicals Subcommittee 2000b). The brochure is available on the AFS website and for agencies to add their logos for their own use.

Electronic Information System

Previously, no system was established to accommodate the needs of a fisheries biologist for getting timely assistance with technical and public relations problems on rotenone. For current assistance, the Rotenone Stewardship Program members provided information and documents to the AFS website at www.fisheries.org/rotenone or at www.fisheries.org using the term "rotenone". The documents include the Rotenone Use Manual, information leaflets, public information brochure, important issues and answers, list of experts, and registration status. Important issues and answers are indexed by the categories (1) general information, (2) public health, (3) environmental quality, and (4) fish and wildlife. A user can get information by asking specific questions that are related to the categories and key words listed on the website. Information can be retrieved electronically. Members of the Rotenone Stewardship Program review and edit the information before it becomes available for access to others. The members of the Rotenone Stewardship Program have also been assigned as contacts for additional information on specific topics; office telephone and FAX numbers are included. The electronic information network will continue to provide up-to-date, accurate information to fisheries management agencies and organizations on current use restrictions, significant issues, and registration status of rotenone.

Long-term Strategies

The long-term strategies for rotenone use, including partnerships with the rotenone registrants, were developed. An annual report will be prepared on rotenone usage, issues, and restrictions. This report will be based on an assessment of responses to a questionnaire sent to the 50 states of the United States and the 12 provinces of Canada and other information gained from the Rotenone Stewardship Program website. The information gained from this process will be posted on the website, and updates will be made as needed to the Rotenone Use Manual and other Rotenone Stewardship Program products. The Rotenone Stewardship Program has developed a long-term funding mechanism through one of the rotenone registrants to support the continued use of rotenone and an implementation plan for long-term strategies.

Conclusions/Implications

The Rotenone Stewardship Program will assure the continued availability of rotenone for fisheries management. The guidelines will serve as a basis for the safe and effective use of rotenone. Use of rotenone by trained and informed applicators will minimize the occurrence of situations that have caused or have threatened to cause the prohibition of the use of this essential fisheries management tool. A better-informed public with a more positive attitude toward rotenone will result from implementing the public relations suggestions. Adherence to the procedures in the guidelines will demonstrate the importance of the use of rotenone for fisheries management and the concern of fisheries management agencies for the conservation of aquatic resources to those individuals and organizations that influence the activities of fishery management agencies. The information network will assure that those who use rotenone or other piscicides are aware of important issues, their implications and possible solutions, and how these may affect the current and future uses. A system was developed that will be capable of financing activities necessary to maintain use and that can be activated when necessary in the future. The partnerships with the rotenone registrants will provide for a balance of reasonable environmental safeguards while allowing for the effective and prudent use of rotenone.

References

American Fisheries Society, Fish Management Chemicals Subcommittee. 2000a. Editorial—Importance of rotenone as a management tool for fisheries. Fisheries 25:22-23.

American Fisheries Society, Fish Management Chemicals Subcommittee. 2000b. Better fishing through management: How rotenone is used to help manage our fisheries resources more effectively. American Fisheries Society, Bethesda, Maryland.

Finlayson, B.J., R.A. Schnick, R.L. Cailteux, L. DeMong, W.D. Horton, W. McClay, C.W. Thompson, and G.J. Tichacek. 2000. Rotenone use in fish management: Administrative and technical guidelines manual. American Fisheries Society, Fish Management Chemicals Subcommittee, Task Force on Fishery Chemicals, Bethesda, Maryland.

McClay, W. 2000. Rotenone use in North America (1988-1997). Fisheries 25:15-21.

Programmatic Approach for Rotenone Projects Funded through the Federal Aid in Sport Fish Restoration Program—Options for Balancing Risk with Environmental Compliance and Administrative Efficiency

Ray Temple
Oregon Department of Fish and Wildlife,
Post Office Box 59, Portland, Oregon 97207, USA

Abstract.— The U.S. Fish and Wildlife Service's Federal Aid Program is examining alternative approaches to developing a programmatic review of projects that involve the use of rotenone. The projects considered under programmatic review would consist of a large but as yet uncertain subset of projects funded by the Federal Aid Program. These would include (1) projects with no significant impacts expected, (2) projects where significant impacts could be avoided through the choice of management practices, and (3) those where potential impacts could be mitigated to less than significance. All other projects would require site-specific National Environmental Policy Act (NEPA) review as is currently required for all projects not categorically excluded. Objectives of the programmatic evaluations are to (1) better assess cumulative effects of rotenone use on the environment in the context of rotenone use nationwide, (2) assure more comprehensive and consistent review within the Federal Aid system for compliance with NEPA, (3) increase the efficiency of state fish and wildlife agencies and the Federal Aid system by developing a streamlined grant approval process for rotenone projects, (4) provide complete NEPA process coverage for a subset of projects funded by Federal Aid, thereby reducing state workloads associated with meeting NEPA requirements, and (5) provide an environmental consequences review text that could be used by projects that need site-specific documentation.

Introduction

Fish and wildlife management projects involving the use of rotenone commonly raise issues associated with the protection of drinking water sources, direct ecological impacts, and the collateral impacts of subsequent fish stocking. Public concern has grown for both recreational fishery management and conservation of native aquatic fauna. In the past two years, staff of the U. S. Fish and Wildlife Service's (USFWS) Pacific Region Division of Federal Aid recognized an opportunity to aid the states in their National Environmental Policy Act (NEPA) compliance responsibilities for rotenone projects funded with Federal Aid funds and to move closer to consistency in meeting the intents of NEPA by the Federal Aid community. The result is a programmatic approach to NEPA review of projects funded by Federal Aid (USFWS 2001).

The Federal Aid to Sport Fish Restoration (SFR) and Federal Aid to Wildlife Restoration programs collect excise taxes on sporting goods and boat gas, and allocate the revenues to the states for access improvements, fish and wildlife management, and research. States make proposals within the eligibility rules of the federal programs for project grants. These funds are important supplements to state base budgets and often enable specialized projects that may not otherwise be within reach of state programs.

Projects that use rotenone are frequently among those funded by the Federal Aid programs. Rotenone is widely used to eradicate, reduce, or sample fish populations. It is also quite expensive, which makes the availability of federal funding very attractive to many states. When the states use federal funds for such projects, the funding office is obligated by federal law to review the proposed actions in the context of the National Environmental Policy Act (NEPA). Much of the burden of assessing environmental issues associated with the use of rotenone falls to the states. The programmatic environmental assessment described here is intended to maintain the safeguards of NEPA review while relieving some of the administrative load on states and Federal Aid staffs.

Purpose

Federal Aid rules require that projects be substantial in character and design, which is interpreted to mean that they must meet a recognized need and be consistent with generally accepted approaches and provide benefits commensurate with costs. The use of rotenone as a fish toxicant to benefit fish or wildlife management is acceptable for funding given that the project otherwise meets the general requirements.

Rotenone is the most widely used fish toxicant in North America, and has been in general use for decades. Some 39 states are known to have used rotenone in fish management applications in the decade ending in 1997. I surveyed those states for their use of Federal Aid funds and found that 24 use Federal Aid funds in some way for rotenone projects and thus have NEPA compliance obligations. The Federal Aid Program (FAP), especially the SFR program, has a long involvement with the states in funding this work. If Oregon is a representative example, the FAP has made possible much of the fishery rehabilitation and successful trout fishery management that occurred in the 1950s and 1960s in the reservoirs that had been developed across the west.

Federal Aid programs fund projects that intend to kill representative samples of fish communities, to selectively reduce the abundance of target species, or to eradicate entire fish communities. In most cases the objective is associated with the management of recreational fisheries, but may instead be aimed at ridding waterfowl habitats of carp, *Cyprinus carpio* or eliminating introduced species in order to reestablish native fishes. The most commonly occurring projects funded by Federal Aid are for population sampling; the greatest use of rotenone occurs in the eradication of fish communities.

Compliance with NEPA requirements has become increasingly more complicated as public attitudes regarding ecological manipulations for fishery management and rotenone use specifically have changed from widespread support to a much greater sensitivity to environmental consequences. There is heightened concern and distrust for management agencies which embraces both the consequences of the use of chemicals and the underlying fish management approaches. Good public policy calls for agencies to routinely engage the public early in planning processes such that issues can be resolved if possible.

The obligation to comply with NEPA rests legally with the FAP, but functionally the states usually bear the workload of NEPA documentation. The issues and resultant workload vary from straightforward to highly complex. The necessity for NEPA documentation likely leads to more carefully considered projects than might otherwise be the case, but also adds specific processes and documentation requirements that many states are not well equipped to handle. Dedication of resources to meet NEPA compliance obligations are an opportunity cost to the agencies that varies greatly, depending on specific project complexities and the agencies' staffing approach to NEPA or analogous state environmental protection requirements. As an example, the Oregon Department of Fish and Wildlife does few environmental assessments or environmental impact statements and each poses a special staffing problem.

Projects vary in their environmental settings, objectives, and scope; but the potential environmental consequences of rotenone use are well researched (particularly in the extensive work done toward re-registration requirements in the 1970s and 1980s) and have been evaluated in several notable programmatic NEPA reviews of state programs. The California Department of Fish and Game has several comprehensive programmatic and project-specific evaluations of rotenone use (e.g. California Department of Fish and Game 1994). More recently, the American Fisheries Society has published its Rotenone Use in Fisheries Management: Administrative and Technical Guidelines Manual (Finlayson et al. 2000), describing desirable management practices and encouraging engagement of the public in preparation for rotenone projects.

NEPA requirements are met for all rotenone projects funded by the FAP. That means that each is "tested" for qualification for categorical exclusion and, if not qualifying, requires an environmental assessment. If significant impacts are found or expected, an environmental impact statement is prepared. Federal Aid grant approvals also require compliance with several federal statutes and executive orders in addition to NEPA.

With the workload issues and the extensive body of rotenone research in mind, the Pacific Region Federal Aid Office has offered an approach that maintains the environmental protection and public disclosure of site-by-site NEPA evaluations but which also streamlines the administrative processes for both the states and Federal Aid.

Approach

The FAP has examined rotenone use as funded by Federal Aid and its environmental consequences in a programmatic context. The fundamental approach is to describe a class of projects that avoid or mitigate potential significant adverse impacts and cover them under a programmatic assessment that results in a finding of no significant impact. Proposals for projects that fit the boundaries established for the programmatic assessment would qualify for streamlined processing; no separate NEPA documentation would be required of the state. Any projects not fitting the conditions and circumstances evaluated in the programmatic assessment would still require individual assessment of environmental consequences.

The FAP sees several benefits in the proposed approach. Overall, the protections and public notice of NEPA are maintained, but there is some relief for states and the FAP from the administrative burden. This programmatic look at nationwide uses of rotenone funded by Federal Aid provides an assessment of cumulative effects otherwise missing from the collective reviews of individual projects. Federal Aid will use one set of analyses to evaluate all projects, providing more consistent treatment among the U. S. Fish and Wildlife Service administrative regions and a streamlined grant approval process. Since complete NEPA coverage will be provided for the class of projects that is ultimately included in the programmatic assessment, states proposing projects meeting those characteristics will be able to avoid producing individual environmental assessments for their projects. For projects that cannot be included under the programmatic cover, the "environmental consequences" section of the programmatic assessment can be a basis for assessments of those specific projects, which will also provide some aid to the states.

In order to take a programmatic view of Federal Aid-funded rotenone usage, the FAP needed to know both about the nature of the projects and the environmental consequences of rotenone generally and in each category of projects specifically. The FAP polled the states that had been identified in McClay (2000) as having a recent history of rotenone use to ascertain the types of projects that involved Federal Aid funding. The FAP also reviewed several environmental assessments of rotenone use and included evaluations regarding environmental risk.

Our review led us to characterize types of projects for which Federal Aid funds are used, to identify characteristics that result in no significant impacts, to catalog measures that can be used to avoid significant impacts, and to identify mitigation strategies. From these the FAP constructed a programmatic approach to NEPA compliance and offered three options for implementation.

Programmatic Assessment

We identified two alternative action strategies that differ in the way that environmental risk is contained. The action alternatives describe classes of projects that would qualify for programmatic NEPA coverage and a finding of no significant impact. All other projects would require site-specific review. In the "minimal risk" approach, standards for inclusion of projects are very conservative with emphasis on those circumstances that will not pose potentially significant impacts. The "managed risk" approach has much more utility, using impact avoidance strategies and mitigation measures to eliminate or reduce potentially significant impacts in projects that might otherwise have such risks. In the "no action" alternative and both action options, the risk is the same: no significant impact.

"No action" means business as usual, with no programmatic approach. All proposals received by Federal Aid would continue to receive individual NEPA review, with appropriate evaluation documents developed as needed. There would be no change in either workload or environmental protection.

Projects included under the two action alternatives, "minimal risk" and "managed risk" share several characteristics but differ in others. Both include standing waters where either there are no listed species or take is authorized by the listing agencies. Neither option includes domestic water supplies.

Adoption of the "minimal risk" option would not affect environmental protection. Projects qualifying for inclusion by their nature do not present risk of significant impacts. Most projects that would qualify are already so minor in effect that they are categorically excluded from further review. With this option, there is little potential for affecting workloads for the states or Federal Aid offices. The additional considerations for inclusion in this option are no outflow until the treated water is non-toxic, and no implications upstream or downstream from treatment or preparations leading to treatment.

The approach that offers the greatest prospect of relieving administrative workloads while maintaining existing levels of environmental protection is the "managed risk" option. It is more broadly inclusive of Federal Aid projects and promises consistent environmental reviews. This approach recognizes that there may be potentially significant impacts associated with some projects, but also that those impacts may be actively avoided or mitigated to less than significance through management measures. Only those projects that identify the measures needed to avoid or mitigate impacts would receive coverage. Table 1 presents examples of avoidance and mitigation measures. Application of these and other measures is intended to result in NEPA findings of " no significant impact" for projects in the managed risk category.

Projects involving domestic water supplies must be individually reviewed no matter the nature of the projects otherwise. Outflow of toxic water must be avoided, or neutralization with potassium permanganate must be provided, or natural degradation based on dilution and travel time must be planned. To avoid cumulative effects on biotic communities and effects on sequential year classes, there must not have been a treatment of the area in the previous two years.

The key additional element is that impacts that have been identified in previous assessments of rotenone use must be anticipated and avoided or mitigated. Those impacts include catastrophic accidents, applicator health risks, aesthetic concerns, as well as ecological and water quality concerns. The measures proposed must be consistent with currently recommended practices and with approaches found in other NEPA reviews to avoid or mitigate significant impacts.

The identification of potential impacts, avoidance measures, and mitigation measures in Table 1 have been drawn from NEPA reviews of rotenone use from around the nation.

Impacts to the human environment are expected to be insignificant because the criteria exclude projects in the most risky or contentious settings, minimize impacts to non-target species, and focus additional measures on reducing specific impacts that can be expected from categories of projects. Strategies for avoidance or mitigation are consistent with technical practices recommended by the American Fisheries Society's Fish Management Chemicals Subcommittee (Finlayson et al. 2000). Projects not meeting the criteria, and/or not including appropriate measures to avoid or mitigate impacts, would require the same site-specific NEPA reviews that would be required for those not qualifying for coverage under the “minimal risk” alternative or under the “no action” alternative. Risks and impacts would be managed to the same levels of insignificance under any alternative adopted. This alternative alone provides an ancillary opportunity for process efficiency.

Adoption of either action alternative is not expected to influence the frequency or character of rotenone projects funded by Federal Aid. The factors constraining rotenone uses by the state fish and wildlife agencies are not affected by the approach taken by the FAP in selecting and approving fish management grants. While use will not increase, it is anticipated that comprehensive programmatic review will provide a better and clearer assessment of cumulative effects, a more systematic approach by the FAP for evaluating rotenone activities, and a reduction in the number of environmental assessments required of state fish and wildlife agencies.

Summary and Conclusions

The programmatic approach that we have proposed has the potential to reduce state agency and FAP workloads, producing a faster turnaround for grant requests. At the same time, the intent and requirements of sound environmental protection decisions through NEPA are maintained.

The establishment of consistent standards for local projects that are included in programmatic review facilitates the responsibilities of the U. S. Fish and Wildlife Service to assure compliance with NEPA requirements as well as maximally reducing unintended environmental consequences. The environmental assessment presents a comprehensive analysis of the environmental consequences of rotenone projects generally and describes a set of conditions under which projects will have no significant impacts. The nationwide perspective on Federal Aid projects is the basis for a comprehensive cumulative effects analysis as well.

Table 1. Examples of measures to avoid or mitigate potentially significant impacts

Potentially significant impact	**Avoidance measures**	**Mitigation measures**
Toxicity to gilled amphibians	Treat in late fall after most gilled juveniles have metamorphosed; provide untreated refugia to recolonize treated areas	Do not treat the same areas in sequential years, to minimize long-term effects on year-class composition in the populations
Toxicity to fish outside target area	Neutralize outflow with potassium permanganate to avoid downstream mortality	
Loss of food for bats (insects), birds (invertebrates and fish), mammals (fish)	Treat in late fall when food requirements are lower; time treatments to coincide with migration of birds to other locations	May require specific mitigation measures for sensitive or ESA-listed wildlife (develop in ESA Section 7 consultation); restock with fish as needed or provide alternative source of fish
Applicator health hazards	Wear USEPA approved or state mandated protective gear ; follow safety procedures; observe label instructions and warnings; require applicators to be certified by state for application of USEPA category 1 pesticides	
Potential spills, miscalculations, unforeseen consequences	Require that a certified applicator be in charge of rotenone application; provide adequate training for all project personnel; set up a system of redundant checks of the most critical calculations	Comprehensive, site specific contingency plans in operation before moving rotenone; potassium permanganate on hand to neutralize largest container of rotenone; adequate staffing for both project and spill response
Cumulative impacts	Do not treat any water more often than every two years; provide refugia to seed treated areas	

Grants managers in the Federal Aid Division are provided with the tools for a consistent review of projects to fulfill their NEPA obligation, and the programmatic approach provides complete NEPA coverage for projects that meet the criteria of whichever option is finally adopted. Grants managers will be able to more efficiently process proposals for funding rotenone projects as well as achieving some relief in the time available for other grants management tasks.

State managers who design their proposed rotenone projects to fit the adopted programmatic option will benefit from having complete NEPA coverage provided programmatically, freeing time for other management needs. The extent of relief will vary with the opportunity costs that are otherwise posed by NEPA documentation. Several states have dedicated staffs for NEPA and state environmental regulation documentation, but many use management staff diverted from other duties. Even if projects cannot be tailored to fit the adopted option, this environmental assessment will provide environmental consequences text that will save time in preparing NEPA documents.

This programmatic approach is under internal review within the Federal Aid and Fisheries and Habitat Conservation programs of the U. S. Fish and Wildlife Service. Following revisions to reflect that review, the document will be reviewed by state fish and wildlife management agencies and will receive a general public review. The “managed risk” alternative will be proposed for adoption based on the document that ultimately results from these reviews. If adopted, it would be integrated into the Division of Federal Aid's operational processes.

References

California Department of Fish and Game. 1994. Rotenone use for fisheries management – final programmatic environmental impact report (SCH 92073015). California Department of Fish and Game, Environmental Services Division, Sacramento

Finlayson, B. J., R. A. Schnick, R. L. Cailteux, L. DeMong, W. D. Horton, W. McClay,

C. W. Thompson, and C. J. Tichacek. 2000. Rotenone use in fisheries management: administrative and technical guidelines manual. American Fisheries Society, Bethesda, Maryland.

McClay, W. 2000. Rotenone use in North America (1988-1997). *Fisheries* 25(5):15-21.

USFWS. 2001. A Programmatic Environmental Assessment for Funding Rotenone Projects through the Federal Aid in Sport Fish and Wildlife Restoration Programs (in review).

Utah's Procedure for Mixing Powdered Rotenone into a Slurry

Charles. W. Thompson, Craig L. Clyde and Douglas K. Sakaguchi
Utah State Department of Natural Resources
Division of Wildlife Resources
1115 North Main, Springville, Utah 84663
nrdwr.cthompso@state.ut.us, nrdwr.cclyde@state.ut.us or nrdwr.dsackagu@state.ut.us

Leo D. Lentsch
Jones and Stokes
2600 V Street
Sacramento, California 95818-1914
Leol@jsanet.com

Abstract.—-An aspirator, was developed by the Utah Division of Wildlife Resources to mix rotenone slurry used to eradicate undesirable fish species from Strawberry Reservoir, Utah, in 1990. An aspirator was the best method that Utah has developed for mixing powdered rotenone into a slurry. Slurry characteristics were as good or better than those achieved by any other mixing technique tried. The system utilized a high pressure pump that forced water through the aspirator creating suction used to vacuum powdered rotenone from bulk bags (1,000 lb capacity). The powder and water combined inside the aspirator chamber forming a slurry. The slurry was discharged directly on to the reservoir surface or delivered into barge tanks from the aspirator nozzle. Rotenone loss in the form of dust was significantly reduced compared to other mixing techniques and there was limited exposure of the chemical to personnel. One person could operate the aspirator efficiently.

Introduction

Rotenone has been an effective piscicide used extensively by fisheries managers for the last 50 years (Gilderhus et al. 1988). Schnick (1974) indicated it was the most widely used piscicide in the United States. Rotenone is distributed in several emulsified forms and powder. Emulsified rotenone products are simple to apply, but powdered rotenone was more difficult to apply. It is nearly insoluble in water (Bradbury 1986), must be mixed with water prior to, or during, application and a significant amount of dust is generated during mixing.

Rotenone supply companies packaged powdered rotenone in 50-lb bags. Exposure of fisheries biologists to rotenone was excessive, while handling the powder and mixing the slurry from these bags. A significant amount of rotenone powder was lost as dust while mixing the slurry in this manner and many biologists were needed to complete treatment projects. Fisheries managers in most states avoided using powdered rotenone in chemical treatments for these reasons (Schnick 1974). However, biologists in Utah continued to use powdered rotenone because it was effective and averaged about one third the cost of emulsified rotenone products. McClay (2000) reported that agencies in North America appeared to be placing greater emphasis on the use of powder during the years of 1993-1997 compared the period 1988-1992.

Several powdered rotenone mixing and application methods have been tried by fisheries biologists. The State of Washington used burlap drag bags pulled behind boats, using the prop wash to help mix the chemical with the lake water (Bradbury 1986). Colorado used very little powdered rotenone, but mixed it using drag bags and by hand in a water tank (Rod VanVelson, Colorado Department of Natural Resources, personal communication). Idaho and Wyoming mixed powder using drag bags and large cement mixing trucks (Bill Horton, Idaho Fish and Game Department; Roy Whaley, Wyoming Game and Fish Department, personal communication).

Fisheries biologists in Utah tried several methods of mixing powdered rotenone for treatment projects. These methods, not published in peer-reviewed journals, are described in Division reports. The first treatment with powder was in 1958 at Scofield Reservoir, seventy miles east of Provo, Utah. A hopper and worm gear system was mounted on a pontoon boat. Powder was poured from 50 lb bags into a hopper and the worm gear metered it out dry into the water as the boat traveled on the reservoir. This proved to be a dusty process and some personnel suffered temporary blindness as a result of exposure. Rotenone powder was mixed into a slurry in a cone shaped hopper for the Minersville and Strawberry Reservoir treatments in 1961 (Figure 1), and again for Panguitch Lake and Scofield Reservoirs in the 1970's (Bangerter 1961; Livesay 1977). The powder was conveyed through a grain auger or poured directly into a large cone shaped hopper. Water was sprayed into the tank as the powder was added. The slurry formed in the swirl created by the water injection (Livesay 1977). The slurry was then pumped into a DC-9 modified for fire fighting and flown to the reservoir and aerially sprayed or dumped into designated zones. This process was used effectively for many years, but required a large number of applicators, and projects could be scheduled only when airplanes, whose priority was fire fighting, were available. Airplane rental time was expensive, the mixing process was extremely dusty and exposure of rotenone to personnel was excessive.

Mixing slurry in ready mix cement trucks and distributing it on reservoirs in large barges was initiated at Mantua Reservoir in 1982 (Summers 1984). This system was further improved at Minersville Reservoir (Hepworth and Duffield 1984). This was an effective method using Division employees and equipment without dependency on rental aircraft. However, 50-lb bags had to be lifted onto a scaffold and then dumped into the mixer by hand. Rotenone was lost as dust, personnel exposure remained excessive and manpower needs remained high.

The cement truck method was improved in 1987 by experimenting with bulk bags that held 750 to 1000-lbs of powder. Bulk bags were placed in a bag dumper, dumped onto a belt conveyor and conveyed to the cement mixing truck. Water was added to the mixing truck and the slurry mixed (Lentsch and Spateholts 1988) (Figure 2). Though an improvement, this method still resulted in substantial powder loss as dust and excessive exposure of rotenone to applicators. Utah biologist applied from 8,400 to 60,000 lb of powder in various projects around the state (Table 1).

In early 1990, the Division of Wildlife Resources was prepared to treat Strawberry Reservoir (approximately 300,000 acre feet) using the bag dumper, conveyor and ready mix truck method. However, project personnel were experimenting with the aspirator method described in this paper and were convinced this method would work avoiding many of the problems associated with mixing rotenone into a slurry.

Methods

The aspirator system utilizes a high pressure pump that forces water through the aspirator creating suction used to vacuum powdered rotenone from bulk bags (1,000 lb capacity). The powder and water combine inside the aspirator chamber to form a slurry. The slurry is discharged directly onto the reservoir surface or delivered into barge tanks from the aspirator nozzle. Rotenone loss in the form of dust is significantly reduced compared to other mixing techniques and there is limited exposure of the rotenone to personnel. This system can be operated efficiently by three to four people.

Figure 1. Rotenone slurry mixing hopper.

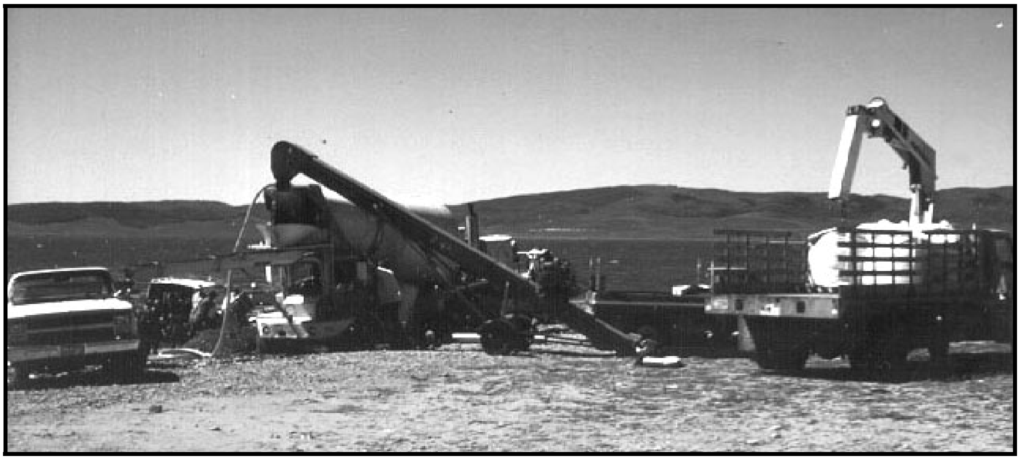


Figure 2. Slurry mixing system using cement truck.

The technology for this system has been available for many years. Delhaye (1886) first patented this type of venturi or aspirator system (patent #351,854). A patent search was conducted and the Utah aspirator does not violate any patent rights.

The rotenone aspirator was field tested in 1990, during four chemical treatment projects; Towne Reservoir, North Salt Lake Marsh (twice) and Strawberry River (Table 2). Operational performance noted during each test included amount of chemical mixed, mixing time required, slurry consistency, effect of vacuum hose diameter (1.0, 2.0 and 2.5 inch) and operations problems.

Shoreline and barge mixing systems were developed for the Strawberry project. The shoreline mixing system consisted of a rotenone aspirator, suction and delivery hose, pvc pipe, a foot valve, two water pumps and two water holding tanks (Figure 3). The powder and water combine inside the aspirator chamber to form a slurry. The slurry hauling barge contained a holding tank and pump to distribute the slurry (Figure 4). The barge mixing system used the same equipment, except that one water pump and the holding tanks were not required (Figure 5).

Table 1. Examples of powdered rotenone projects completed in Utah.

Water Treated	Slurry Method	Pounds Mixed
Strawberry Res (1961)	Slurry Hopper	60,000
Panguitch Lake (1973)	Slurry Hopper	60,000
Scofield Res (1977)	Slurry Hopper	52,000
Minersville Res (1984)	Cement Truck	9,000
Newton Res (1987)	Cement truck	8,400
Hyrum Res (1988)	Cement truck	23,000
Strawberry Res (1990)	Aspirator	878,000
Scofield Res (1992)	Aspirator	96,000
Navajo Lake (1996)	Aspirator	9,800
Nine Mile Reservoir (1998)	Aspirator	6,500
Mantua Reservoir (1999)	Aspirator	16,000

Table 2. Rotenone aspirator tests conducted in the development of a system for mixing rotenone slurry for the treatment of Strawberry Reservoir, Utah, 1990.

Mixing Site	Lbs-Chemical	Vacuum Line	Mixing Rate
Town Reservoir	200	2.5 in	Not Measured
Salt Lake Marsh	200	1.0 in	20 lb/min
Salt Lake Marsh	800	2.5 in	80 lb/min
Strawberry River	300	2.0 in	100 lb/min

Aspirator

The rotenone aspirator was constructed using galvanized pipe and fittings available from most plumbing supply stores (Figure 6). The critical parts of the aspirator are a street elbow, a 1.25-inch diameter by 12-inch long nipple and a bell reducer (Figure 7). A hole was cut in the back of the street elbow and the 1.25-inch nipple was slipped through this hole and slid forward until there was 0.125-inch (1/8 inch) clearance between the nipple and the front of the bell reducer. The nipple was then welded into this position. The front of the nipple was ground until it formed a 45-degree angle from the outside edge in. Threads on the small end inside the bell housing were ground smooth. The bell reducer and street elbow were marked so the unit could be taken apart at the union of these two parts for cleaning. The unit could then be put back together so the marks were aligned and proper clearance was maintained. The clearance was critical because water forced by the pressure pump through this small gap created the vacuum on the powder suction line and the energy necessary to create the slurry.

Hose

The water and slurry delivery hose was a three inch diameter Kanaflex® V-130 light weight suction hose fitted with female camlok quick release fittings on each end. Aluminum quick release fitting were used on most hoses, however, it was found that polypropylene cam and groove fittings were as functional and were less expensive. Male camlok spools were used to connect lengths of hose together as needed. This light-weight hose was used to deliver fresh water from the reservoir to two holding tanks, to a high pressure pump and deliver slurry to barge slurry tanks (Figure 7). Goodall N-624® heavy-duty suction hose rated at 100 lbs per square inch delivered water from the high-pressure pump to the aspirator. We recommend using an even heavier petroleum hose rated at 150 lbs/square inch. In projects completed since 1990 the aspirator was coupled directly to the high-pressure pump eliminating the need for high-pressure hose. Powder suction hose was 2-inch diameter Kanaflex V-130®..

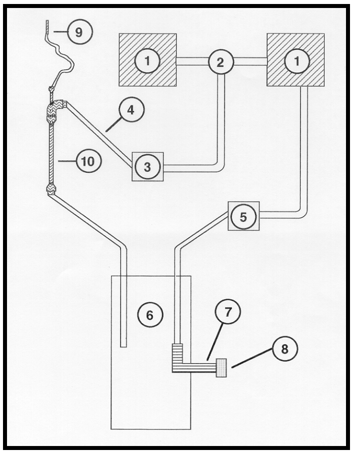


Figure 3. Utah's shoreline powder rotenone slurry mixing system, for the Strawberry Reservoir chemical treatment in 1990. (1) 500 gal holding tanks, (2) gate valve and "T", (3) high pressure pump, (4) high pressure hose, (5) trash pump, (6) boat dock, (7) PVC elbow, (8) foot valve, (9) suction hose (10) aspirator.

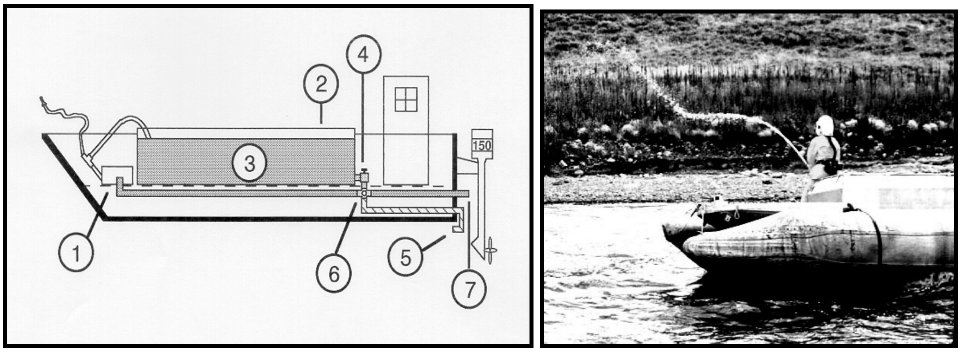


Figure 4. Utah's powder rotenone slurry hauling barge, used for the Strawberry Reservoir chemical treatment project in 1990: (1) pressure pump, (2) 2,000 gal holding tank, (3) rotenone slurry, (4) gate valve, (5) fresh water intake and delivery line, (6) gate valve, (7) discharge line.

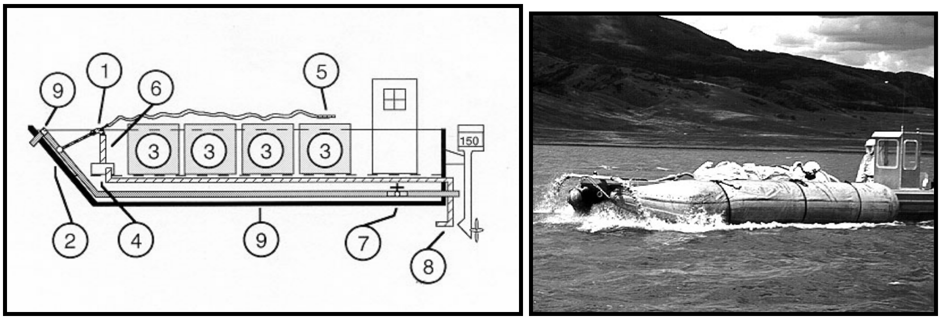


Figure 5. Utah's powder rotenone slurry mixing barge, used for the Strawberry Reservoir chemical treatment project in 1990: (1) rotenone aspirator, (2) gate valve, (3) 1,000 lb bulk bags, (4) high pressure pump, (5) vacuum hose and PVC pipe, (6) high pressure hose, (7) gate valve, (8) water delivery hose, (9) slurry discharge hose.

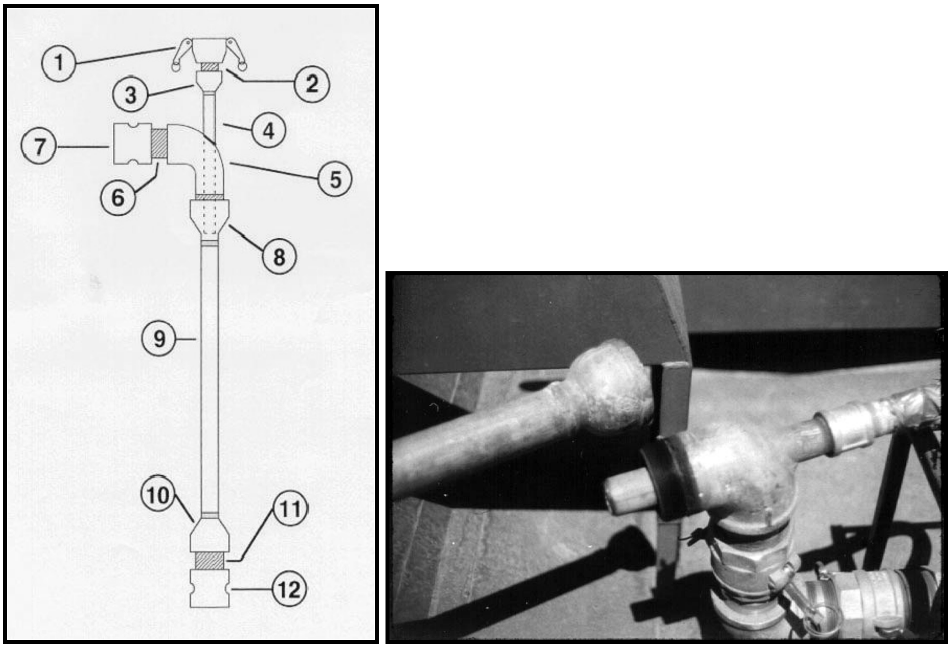


Figure 6. Utah's rotenone aspirator used to mix rotenone slurry for the Strawberry Reservoir treatment project in 1990. (1) 2" female camlok fitting, (2) 2" x 2" nipple, (3) 2" x 1.25"bell reducer, (4) 1.25" x 12" nipple, (5) 3" 90 degree street elbow, (6) 3" x 3" nipple, (7) 3"male camlok fitting, (8) 3" x 1.5" bell reducer, (9) 2" x 48" galvanized pipe, (10) 2" x 3" bell reducer, (11) 3" x 3" nipple, (12) 3" male camlok fitting. Rotenone aspirator was constructed of galvanized pipe.

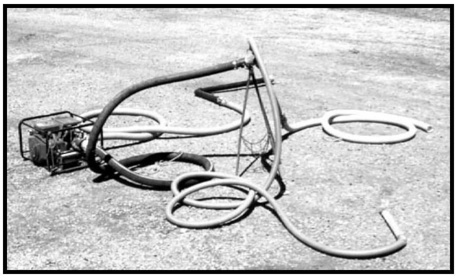



Figure 7. High-pressure pumps attached to light weight water delivery hose, rotenone suction hose, high pressure hose and aspirator.

PVC pipe

Two, three foot long pieces of pvc pipe (3 inch diameter) were fastened together with a 9O degree elbow to form an "L" shaped pipe. This pipe was used to extend over the edge of the boat dock into the reservoir. A three-inch diameter foot valve was attached to the end of the pvc pipe. The water delivery hose was attached to this pvc pipe.

Pumps

Two types of pumps were used at shore mixing sites. A Multiquip Model QP-301® trash pump rated at 300 gal/min at five foot of head, close coupled to a Wisconsin-Robbins® 4.6 hp air-cooled gasoline engine delivered water from the reservoir to holding tanks. A three- inch Gorman Rupp® series 60 high pressure pump, designed for agricultural or fire fighting service, operated the rotenone aspirator. It was close coupled to a Briggs and Stratton Model 422437® twin cylinder, 18 hp, air-cooled gasoline engine. This pump was rated at approximately 150 gal/min and 65 ft of head.

Holding tanks

Two, 500 gal tanks were used to hold fresh water for delivery to the aspirator on demand because they were easier to move and set up at various sites around the reservoir than a single large tank. The outlet on these tanks was about one foot above the bottom of the tank. This allowed debris pumped into the tank to settle out and not be sucked into the high-pressure pump and aspirator. Aspirators occasionally became plugged with fine gravel, vegetation and fish.

The foot valve on the end of the suction line maintained water in the line keeping the trash pump primed. Water pressure in the holding tanks kept the pressure pumps primed.

Bags

Rotenone was ordered and shipped to Utah in 1,000 lb bulk bags. These bags had loops sewn into the four corners so they could be picked up from the top with a fork lift or back hoe equipped with a fork lift apparatus. The bags were manufactured by Stone Container Corporation (Salt Lake City, Utah) and shipped to Peru where the rotenone was produced.

Results and Discussion

Utah's rotenone aspirator was very efficient at mixing powdered rotenone into a slurry. All field tests conducted produced similar results (Table 2). The system mixed powder into a slurry at a rate of 100 lb/min. The consistency of the slurry was one-pound powder per gallon of water. During pilot projects at Newton, Hyrum and Strawberry Reservoirs, Lentsch and Spateholts (1989) reported mixing slurries of 2-2.5 lb/gal using the conveyor and cement mixer method. It was not difficult to accomplish this mixture, but problems were experienced with material settling out in the bottom of the barge tanks. They also reported instances when the powder in the slurry was not entirely wetted. In earlier projects where powder was mixed for airplanes in the cone hoppers, the mixture rate was approximately 1.2 lbs per gal (Glenn Davis, Utah Division of Wildlife Resources, personal communications). This mixture could be pumped into aircraft using low-pressure pumps. The heavier mixture 2-2.5 lb per gal could not be pumped using similar equipment.

Strawberry reservoir was treated with 878,000 lbs of powdered rotenone. It was mixed using nine rotenone aspirators in a six-day period (Lentsch et al. 2001). The equipment was easily operated and interchanged. A piece of equipment in the system was replaced in minutes when a breakdown occurred.

Powder suction

Two-inch diameter Kanaflex V-130® suction hose that was 10 to 15 ft long was used on the mixers during the Strawberry Reservoir treatment. It was rigid enough, that is would not collapse under pressure, but flexible and light enough for easy handling. Reducing the vacuum hose diameter and/or lengthening the hose reduced the suction. Diameter sizes of 1, 2, and 2.5 inch and lengths of hose up to 30 feet functioned acceptably. However, the 2 inch and 2 1/2 inch hose allowed for the desired mix of water and powder (one lb powder/gal).

Slurry

The slurry mixture achieved with this equipment met all expectations and needs for the Strawberry project. This mixture rate was consistently achievable on shore and on mixing barges. At shore mixing sites, personnel were able to mix 1,000 lb of powder into a slurry in 10 minutes, and on mixing barges 4,000 lbs of powder could be mixed and distributed in approximately one hour.

Manpower

Shoreline mixing sites, mixing rotenone for slurry barges, had five man crews consisting of a coordinator, pump operator, and two or three aspirator operators. Slurry barge crews consisted of two people, a barge pilot and pump operator. Mixing barge crews consisted of a barge pilot, two aspirator operators, and a pump operator.

Utah's previous shoreline mixing systems using cement mixers and conveyors required a minimum of ten men per crew, a coordinator, four bag dumpers, one water pump operator, one all purpose man, a cement mixer operator and two barge personnel for distribution.

Dust

A cloud of dust enveloped every mixing system that has been tried in Utah except the aspirator system. We estimated that 0.5 to 1.0 percent of the powder was being lost as dust in most projects. Exposure to the chemical had been excessive causing irritation to employees' eyes, nasal passages and groin. The aspirator mixing method greatly reduced dust loss and exposure. However, there was exposure to the chemical using the aspirator because operators must manipulate the suction hose by hand. All employees working on the Strawberry treatment project were clothed and protected by safety equipment (Lentsch et al. 2001). Although exposure was greatly reduced some personnel still experienced irritations to mucous membranes. However, this was a result of exposure over the entire six-day project.

Operational considerations

Problems were encountered while mixing slurry for the Strawberry reservoir project. The powder became compacted in the bags during shipment and could not be easily vacuumed. Massaging the bags with a backhoe to loosen the powder solved this problem. Aspirators on mixing barges occasionally became plugged with fine gravel, vegetation and/or fish. Changing aspirators solved this problem. The use of camlok fittings allowed the exchange in less than five minutes. The malfunctioning aspirator was taken apart, cleaned and ready for use again in 15 minutes.

Mechanical problems developed with some pumps on the barges. The primary problem was dust clogging the air intake to the carburetor and wet distributor points. These problems did not develop until after five days of operation. Malfunctioning pumps were replaced with a spare pump in approximately 30 minutes.

The use of the aspirator mixer reduced manpower needs for the Strawberry Reservoir project. An aspirator crew could mix 3,000 pounds of powder into slurry in 30 minutes. Using the cement mixer conveyer system a crew could mix 3,000 pounds of powder in approximately one hour.

The mixing barges, using the aspirator, could mix and distribute 4,000 pounds of slurry in one hour compared to two hours to mix and distribute 3,000 pounds of powder using the cement mixer conveyor system.

Improvements to the system

By 1997, at least one rotenone provider was packaging powdered rotenone in 200 lb containers (Figure 8). These containers are barrel shaped and have a plastic liner to insure containment of the powder. These containers are superior to other packages because of their size. They can be loaded on a boat by one or two men at nearly any location on a lake, eliminating the need for a crane or back hoe to move and load them. In three projects in Utah (Navajo Lake, Nine Mile Reservoir, and Mantua Reservoir) Utah biologists have not experienced problems with compaction of the powder in these container and one container replaces 4, 50 lb bags. In an 18 foot John boat Utah biologist have loaded 5 barrels at one time along with a boat operator and aspirator operator and mixed and distributed the slurry on the lake. We have loaded 3 or 4 barrels on 16 foot John boats. Several smaller projects have been completed using 16 and 18 foot John boats. Utah biologists have used the 30-foot barges on only one project since the Strawberry Reservoir Project (Scofield Reservoir in 1992).

The development of a powder conditioning process, not yet accomplished, would improve efficiency, and greatly reduce the need for personnel to come in contact with powdered rotenone. This type of container called a palletized container is available from Semi Bulk Incorporated, in St. Louis Missouri and is used for fire retardant. The base is hollow; a fine screen supports the powder. Air is injected into base of the bags fluidizing the powder so it can be drawn through the aspirator directly from the bag. Such a system would work for rotenone. The bag would not have to be opened.

Aspirators are versatile and can be built on any scale. Limited experimentation was done with a 0.75-inch aspirator and a backpack fire fighting pressure pump (Mark 26 Pacific Pumper, Wajax Pacific Fire Equipment Incorporated). It was possible to spray slurry approximately 50 yards with this pump. A small pump and aspirator could easily be placed in a 16-ft John boat.

Figure 8. 16-foot John boat fitted with high pressure pump, aspirator system and 4-200 lb barrels of powdered rotenone.

During recent projects Utah Biologist found that by placing a valve on the powder suction line it was possible to reduce the amount of pressure on the suction hose as desired. This not only facilitated removing all rotenone from the bags without sucking the plastic liner into the hose, but also allows the use of the large 3-inch pumps even on small projects. We are certain that as biologists use this gear its applications will increase.

Acknowledgements

This project was partially funded under the Federal Aid to Fisheries Restoration (Utah project F-50-R) and was administered by the Fisheries Section of the Utah Department of Natural Resources, Division of Wildlife Resources. We thank Kelly Nelsen and Brent Spencer for assistance in the development of the aspirator mixer.

References

Bangerter. A. 1961. Chemical rehabilitation of lakes, reservoirs, ponds, springs, 1961. Utah Department of Fish and Game Publication, Salt Lake City, Utah.

Bradbury, A. 1986. Rotenone and trout stocking. A literature review with special reference to Washington Department of Game's lake rehabilitation program. Washington Department of Game. Fisheries Management Report 86-2.

Delhaye, H. 1886. Grain-conveyer. United States Patent Office No. 351,854.

Gilderhus, P. A., V. K. Dawson and J. L. Allen. 1988. Deposition and persistence of rotenone in shallow ponds during cold and warm seasons. Investigations in fish control: 95. U.S. Fish and Wildlife Service, Washington, DC 20240.

Hepworth, D. K. and D. Duffield. 1984. Renovation of Minersville Reservoir 1984 chemical treatment project. Utah Department of Natural Resources Division of Wild life Resources Report, Salt Lake City, Utah

Lentsch, L. D., C. W. Thompson and R. L. Spateholts. 2001. Utah's 1990 chemical rehabilitation of Strawberry Valley. (This volume).

Lentsch, L. D. and R. L. Spateholts. 1988. Strawberry Reservoir rehabilitation 1988 annual report. Fisheries Enhancement Projects, Dingel-Johnson project F-50-R-3. Study IV. Utah Division of Wildlife Resources, Salt Lake City, Utah.

Lentsch, L. D. and R. L. Spateholts. 1989. Strawberry Reservoir rehabilitation 1988 annual report. Fisheries Enhancement Projects, Dingel-Johnson project F-50-R-4. Studies I and IV. Utah Division of Wildlife Resources, Salt Lake City, Utah.

Livesay, J. C. 1977. Chemical treatment of Scofield Reservoir and upper drainage, Sept.-Oct., 1977. Utah Division of Wildlife Resources Salt Lake City, Utah.

McClay W. 2000. Rotenone use in North America (1988-1997). Fisheries, Vol. 25, No. 6. 15-21 pp.

Schnick, R. A. 1974. A review of the literature on the use of rotenone in fisheries. U.S. Fish and Wildlife Service, Fish Control Laboratory, LaCrosse, Wis. NTIS No. PB-235 454. 130 pp.

Summers. K. 1984. The use of ready-mix concrete truck to wet powdered rotenone. Utah Division of Wildlife Resources, Salt Lake City, Utah.

Utah's Rotenone Sandmix: A Formulation To Maintain Fish Toxicity in Seeps or Springs

Robert L. Spateholts
12000 North East Damselfly Lane
Prineville, Oregon 97754 USA
scruffy@coinet.com

Leo D. Lentsch
Jones and Stokes
2600 V Street
Sacramento, California 95818-1914 USA
LeoL@sanet.com

Abstract.—Sandmix (powdered rotenone-sand-gelatin mixture) proved to be an effective formulation for treating sources of upwelling groundwater that frequently provide refugia for target species during chemical rehabilitation projects. In trials conducted at Strawberry Springs, Utah, in 1988, 0.25 mg/L and 0.35 mg/L (active ingredient based on 24-h flow volume) rotenone applications of sandmix produced 100% mortality of trout fingerlings placed 4,8, 12 and 24 h after application. Mortality was only 0-70% in trials with the same application rates of liquid rotenone and powdered rotenone and water paste. Over 2,500 lbs of powdered rotenone were made into sandmix and applied to more than 450 seeps and springs during the chemical rehabilitation of Strawberry Valley in 1990. The sandmix generally maintained toxic concentrations for at least 12 h.

Introduction

In 1990, the largest chemical rehabilitation project ever undertaken was completed in Utah's Strawberry Valley. Major components of the project were chemical rehabilitation of 12,000 surface acres of Strawberry Reservoir and 161 miles of tributaries (Lentsch et al. 2001). The rehabilitation plan for the Strawberry Valley fishery identified total removal of fish from the drainage followed by establishment of a new fish species complex as the preferred management alternative (Johnson 1988). The streams were treated twice (August and October, 1990) to increase the likelihood of total fish eradication. During the planning phase of the project, we recognized the need for a method to effectively treat over 450 seeps and springs throughout the drainage. The channels of the larger tributaries would be treated with drip stations that would maintain a continuous application of liquid rotenone for 48 h. However, it would not be feasible to place drip stations on each small spring, and many seepage areas had inflow over broad areas. These sources of fresh groundwater could provide refugia for fish to avoid toxic rotenone concentrations in the stream channels.

In order to achieve total eradication of fish from Strawberry Valley streams, a rotenone formulation was needed that met three objectives. First, it must sink to the source of the groundwater inflow. Second, the formulation must release rotenone gradually to maintain toxicity for a minimum of 12 h to ensure adequate exposure and a complete kill. Finally, it would need to be portable, relatively safe and easy to transport by application crews working on foot in remote locations. Utah biologists have used a variety of techniques to treat seeps with both powdered and liquid rotenone. Success has been variable, but ineffective treatment of groundwater refugia is believed to be one reason that some projects have had incomplete elimination of target species (Leppink 1977).

Gilderhus et al. (1986) determined that the minimum rotenone concentration required to produce 100% mortality of fathead minnows *Pimephales promelas* in 24 h at 75 °F was 0.022 mg/L. We chose 0.03 mg/L as the minimum rotenone concentration that was needed to be effective. We reviewed literature on the use of fish toxicants (Lennon et al. 1970; California Fish and Game Department 1985: Bradbury 1986) and made numerous personal contacts with state/federal agencies and piscicide manufacturers, but failed to identify an existing formulation of rotenone that met all three objectives.

Antimycin, the only other fish toxicant registered for general use, was once manufactured in a solid formulation for use in flowing waters. The bricks slowly dissolved and released toxin. The antimycin bricks were used to remove undesirable fish from Strawberry Valley streams in the 1970s. Ayerst Laboratories at one time manufactured formulations of Antimycin (Fintrol®) that was adhered to sand particles with carbowax (Union Carbide Company) and sank through the water columns of stratified lakes and released toxin. Different density formulations released the toxin at different depth (5, 15,30 ft). Manufacture of these products was discontinued. We did not consider Antimycin because it loses effectiveness in alkaline waters (Everhart et al. 1975), and Strawberry Valley streams are alkaline. However, the concept of a substance that would sink through the water column and gradually release toxin had excellent potential to meet our objectives.

This paper describes a powdered rotenone-sand-gelatin mixture (sandmix) we developed and tested to maintain toxic conditions in seeps and springs. We compared the performance of sandmix to the two commercially available rotenone formulations (liquid rotenone and powdered rotenone) in controlled experiments conducted in 1988. The sandmix met our objectives, and we incorporated the use of sandmix as a tool during the 1990 treatment of Strawberry Reservoir and its tributaries. We describe the performance of sandmix during the 1988 trials and the 1990 Strawberry Valley treatment, and discuss observations on its applicability to other projects.

Methods

Study Site Description

Strawberry Reservoir and its tributary system are located in Wasatch County, Utah (Figure 1). More than 450 springs and groundwater seeps, ranging in flow from only a few gallons per day (gpd) to over three cubic feet per second (ft^3/s) were identified during ground surveys of the drainage (Lentsch and Spateholts 1988). Strawberry Springs is a dendritic network of springheads, that emerge from the floor of Strawberry Valley and flow into the Strawberry River from both sides, approximately five miles upstream from the reservoir (Figure 2). Groundwater enters the channels from concentrated sources of 0.25 ft^3/s or more (springs) or seeps in from the banks or bottom over large areas. Seeps may often be identified by visible percolation of the sandy substrate. There are three primary zones of inflow with several dozen seeps with a combined total flow of approximately 4 ft^3/s. The area was intensively grazed by livestock, with little riparian vegetation or aquatic macrophytes. Water depth of the seeps and channel averaged 6 in or less, with a few pools 16 to 20 in deep. Resident fish species observed in the Strawberry Springs channel included trout hybrids (*Oncorhynchus clarki x O. mykiss*), brook trout (*Salvelinus fontinalis*), and mottled sculpin (*Cottus bairdi*). A complete list of species in the Strawberry Reservoir drainage is included in Johnson (1988). No federally listed threatened or endangered species occurred in the treatment area (Johnson 1988).

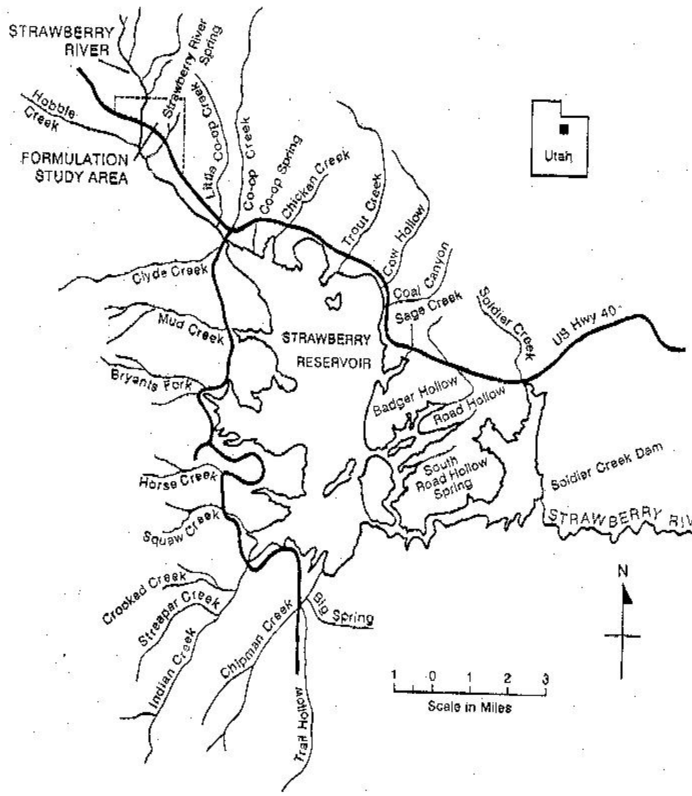


Figure 1. Location of the Strawberry River and Strawberry Reservior in Strawberry Valley, Utah.

1988 Trials

Twelve Strawberry Springs seeps were selected for study in 1988. Rotenone concentrations and fish mortality were monitored in open bottomed cages in seeps. Sandmix, liquid rotenone (liquid) and powdered rotenone (paste) were assessed in three seperate trials conducted at Strawberry Springs in September and October 1988. At least one week was allowed between trials to prevent carryover of rotenone concentrations. In each trial, the selected rotenone formulation (sandmix, liquid or paste) was applied to nine seeps that were randomly grouped into three sets of three. Each group received application rates of 0.15 mg/L, 0.25 mg/L or 0.35 mg/L. Three additional seeps did not receive any application and were used as controls in each trial. The amount of rotenone applied to the seeps at each treatment rate was based on a 24-h period (total outflow from seep) and the rotenone content of the formulation (5% for liquid and 7% for powder). The seeps received the same application rate (but different formulations) in each of the three trials (Table 1). Open-bottom cages (15 in x 15 in, 12 in tall) of 1/8 in mesh hardware cloth were placed around the upwelling water of the seeps. The walls of cages were worked approximately 2 in into the substrate to prevent fish from escaping. Removable hardware cloth lids prevented fish from escaping while facilitating placement and removal of fish, application of rotenone formulations and collection of water samples.

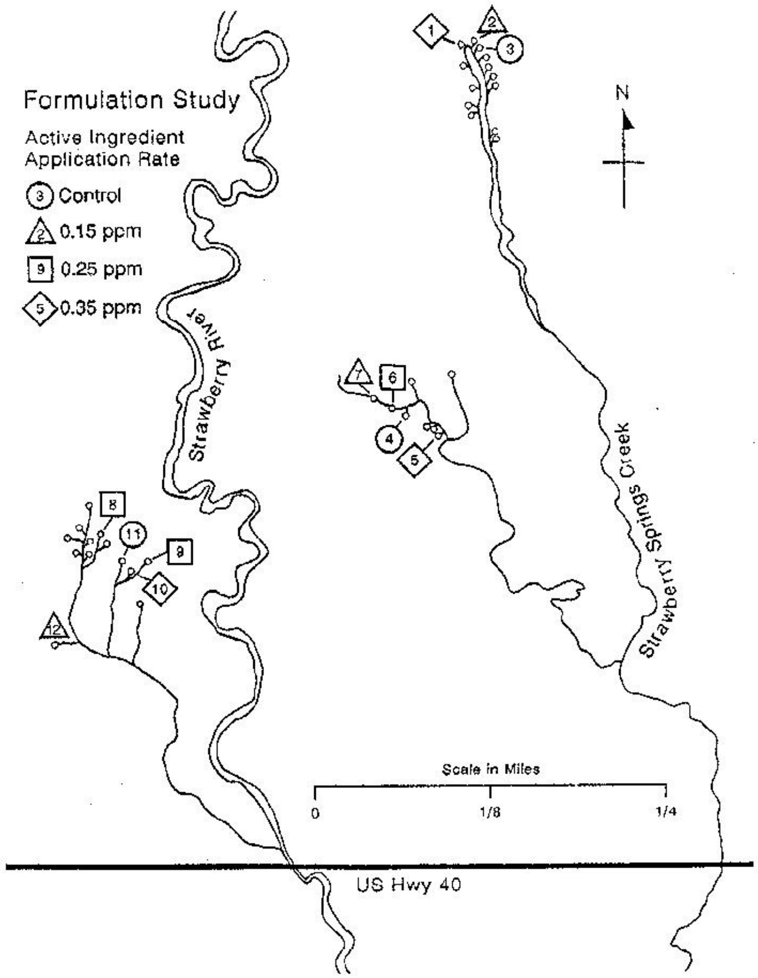


Figure 2. Map of Strawberry Springs showing seeps used for rotenone liquid, paste, and sandmix formulation trials in 1988.

Water temperature, dissolved oxygen, pH and conductivity were measured in each cage with a Hydrolab® 4000 series meter. Discharge estimates were made by averaging three separate flow determinations. These determinations were made by placing Flourescein® dye into the cages and recording the time for the volume of water enclosed within the cage to be completely displaced by inflow. Chemical parameters, flow estimates and rotenone application rates for the experimental seeps are summarized (Table 1). Chemical parameters and discharge were assumed to be constant throughout the formulation comparison trials (September and October 1988), since the seeps had stable flows.

Rotenone formulations were prepared at the time of application. Sandmix was prepared by mixing the required amount of powdered rotenone (0.01-0.12 lb) with an equivalent volume of dry sand, approximately 0.1 oz of unflavored gelatin powder (available in the home canning section of most supermarkets), and just enough water to cause the powder to adhere to the sand.

Table 1. Flow rates, chemical parameters and rotenone application rates for Strawberry Springs seeps trials, September and October, 1988.

Seep	Approximate Discharge ($ft^3/s \times 10^{-3}$)	Temperature (°F)	Dissolved Oxygen (ppm)	pH	Specific Conductance (S)	Rotenone Application (mg/L)
1	4.73	47.5	3.5	7.2	497	0.35
2	0.95	48.3	3.0	7.4	537	0.15
3	0.79	48.0	3.3	7.3	533	Control
4	0.63	48.0	3.2	7.6	505	Control
5	0.68	50.9	3.2	7.5	522	0.35
6	3.79	48.2	3.0	7.3	541	0.25
7	3.53	48.7	3.5	7.4	520	0.15
8	1.41	48.6	3.9	7.3	364	0.25
9	0.95	49.8	3.7	7.5	353	0.25
10	0.87	48.6	3.8	7.6	346	0.35
11	1.12	48.0	4.0	7.4	322	Control
12	2.40	46.6	4.6	7.4	296	0.15

Rotenone paste was prepared by mixing powdered rotenone (0.01-0.12 lb) with water to form a thick paste (similar in consistency to cake batter). Sandmix and paste were applied inside the cages over the upwelling groundwater by hand. The liquid formulation was prepared by diluting the required quantity (0.2-2.7 oz) of 5% emulsified liquid rotenone (Noxfish®) with 1/4 gallon of seep water. The liquid formulation was sprayed onto the seeps from a backpack weed sprayer. We did not attempt to detoxify the outflowing rotenone from the study cages. Inflow from other seeps in the Strawberry Springs complex quickly diluted the rotenone to nontoxic concentrations.

Rotenone concentrations were measured by collecting water samples from the nine seeps at 1, 4 and 12 h following application. The samples were drawn using 2 oz syringes held close to the source of upwelling inside the cages. These samples were analyzed by a modification of the high performance liquid chromotography (HPLC) technique developed by Dawson et al. (1983). The detection limit for this analysis was 0.002 mg/L. The protocol used to process samples in the field and laboratory is described in Lentsch et al. (2001).

The duration of toxicity to fish was tested concurrently with the rotenone analyses at Strawberry Springs in October 1988. Groups of five (liquid and sandmix trials) or ten (paste trial) fingerling (30 to 40 mm) trout hybrids were placed in the cages (Table 1). Fish were placed at 18 h before and were replaced at 4, 8, and 12 h following rotenone application. A cohort was defined as all fish placed in the same formulation application rate, (control, 0.15 mg/L, 0.25 mg/L or 0.35 mg/L) at the same time. Combinations of partial fin clips were used to identify the times. Fish mortality was checked at 1, 4, 8, 12, 24, 48 and 72 h. At each check, dead fish were removed from the cages and the number of mortalities by cohort was recorded.

Mortality curves for cohorts in the treated seeps were compared to control cohorts using the log-rank test of Mantel (1966). The log-rank test was chosen because it allows comparison of multiple mortality curves throughout their entirety. Cohorts exhibiting higher rates of mortality than control cohorts can be identified by significant summary chi-squared values (Guthrie 1982).

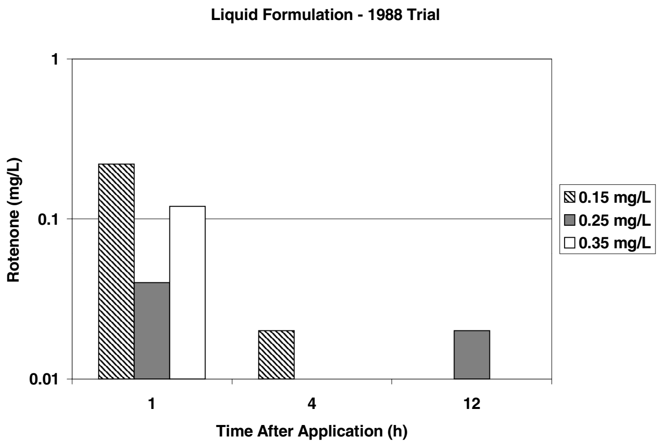
1990 Chemical Treatment

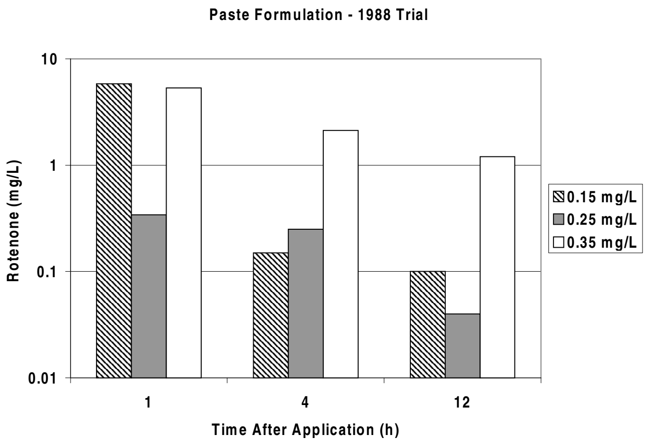
The rotenone sandmix was used during the treatment of Strawberry Valley streams in 1990. Over 2,500 pounds of powdered rotenone was made into sandmix and applied to the 450 seeps and springs in Strawberry Valley during the August and October treatments. The sandmix was prepared in a portable cement mixer.

During the August treatment, sandmix was prepared in bulk using a 1:1 ratio (by volume) of powdered rotenone and sand. Eight shovels of powdered rotenone (approximately 20 lbs) and 8 shovels of fine sand (<1 mm diameter) were added to the mixer. The sand was uniform in consistency and had been screened to separate out most of the organic material. Two ounces of unflavored gelatin powder (obtained in bulk at a commercial food service supply) was added. All three were mixed in the mixer to a uniform consistency. Water was then sprayed on the turning mixture to moisten the sand and gelatin just enough to cause the powdered rotenone to adhere to the sand granules. During the October treatment, the method of preparation of the sandmix was the same as for the August treatment, but the ratio of powdered rotenone to sand was lowered to 1:3 (four shovels powdered rotenone to 12 shovels of sand).

Finished sandmix would form a ball when squeezed tightly, but readily broke apart upon contact with the water. The volume of each batch was approximately 14 gallons. Sandmix was transported in buckets and backpacks. The mixing and application crews wore respirators with dust filtering cartridges, safety suits, and rubber gloves to minimize exposure to the chemical. Drip stations applied liquid rotenone to the mainstems of the streams flowing more than 0.25 ft^3/s. Application crews walked the entire length of the tributary streams and used sandmix to treat seeps and springs. Backpack sprayers were used to apply liquid rotenone to standing water, side channels and beaver ponds. Application crews sprinkled sandmix by hand over seepy areas, springs, deep beaver ponds and dense weed beds throughout the drainage.

We monitored the rotenone concentrations produced by bulk sandmix applications to seeps in the Strawberry Springs area during the October 1990 treatment. We measured the amount of sandmix applied to seeps 9, 10, and 11 (Table 1). Sufficient sandmix was applied to result in 0.25 mg/L rotenone for a 24-h period given the discharge from each seep. Water samples were collected from each seep 1, 4 and 12 h after application and analyzed for rotenone concentrations.





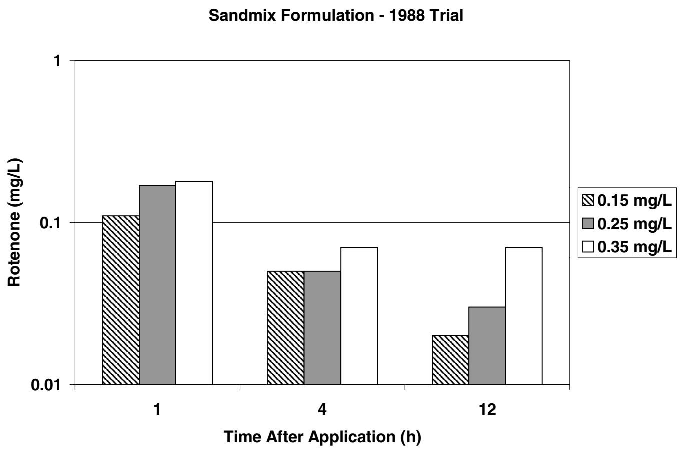


Figure 3. Mean (n=3) rotenone concentrations (mg/L) in water from Strawberry Springs seeps at 1, 4 and 12 h post application of 0.15, 0.25 and 0.35 mg/L rotenone in September and October 1988 trails. Application rates were based on total volume flow for a 24-h period.

Results

1988 Trials

The sandmix and paste formulations produced rotenone concentrations that were generally higher than concentrations for the liquid rotenone (Figure 3). In the liquid trial, only the 0.25 mg/L and 0.35 mg/L rotenone applications had mean concentrations that were above the minimum toxic level of 0.03 mg/L rotenone at 1 h post application. At 4 h and 12 h post application, none of the seeps treated with liquid were toxic, and some had rotenone concentrations below the limits (0.002 mg/L) of detection.

All sandmix and paste applications had mean rotenone concentrations higher than the selected toxic level of 0.03 mg/L at 1 h and 4 h post application. At 12 h, mean concentrations for the 0.25 mg/L and 0.35 mg/L treatments were above 0.03 mg/L in both the sandmix and paste trials (Figure 3).

Rotenone concentrations varied considerably between individual seeps receiving the same application rates. Coefficients of variation for samples collected at the same time ranged from 16% in the 0.35 mg/L rate in the sandmix trial at 12 h to 81% for the 0.15 mg/L rate in the liquid trial at 4 h. Mean coefficients of variation for nine sets of three samples were 34% for the sandmix trial, 48% for the liquid trial, and 53% for the paste trial (Table 2).

Toxicity occurred with all formulations (Table 3). The sandmix maintained fish toxicity in seeps longer than either the liquid or paste formulations. Survivorship curves for all cohorts in place at the time of application differed significantly from controls ($p < 0.05$; Mantel log-rank chi-squared test) and mortality was generally 100% within 1 hour.

The seeps in the liquid formulation trial did not remain toxic for long: only two cohorts placed more than 4 h following application had significant chi-squared values, and survivorship to 72 h was 33 to 100%. In the paste formulation trial, several of the cohorts placed at 4 to 24 hours had significantly lower survival than controls, but none had 100% mortality at 72 hours. Chi-squared values were significant for all cohorts in 0.25 mg/L and 0.35 mg/L rate rotenone sandmix. All cohorts in the 0.25 mg/L and 0.35 mg/L rate rotenone sandmix application had 0% survivorship to 72 h (Table 3).

Mortality caused by handling stress and crowding of the fingerlings may have been compounded by the low dissolved oxygen concentrations (3 to 4 ppm). Fish survived in all cages for 24 h before and between trials. However, 20% of control fish died during the 72-h sandmix trial, and control mortality was 10% and 5%, respectively, in the liquid and paste trials.

1990 Chemical Treatment

Approximately 2,500 pounds of 7.2% rotenone powder was made into sandmix and applied to seeps, springs and stream channels during the two treatments of Strawberry Valley streams in August and October 1990 (Lentsch et al. 2001). Rotenone sampling from Strawberry Springs seeps indicated that the bulk sandmix behaved similarly to the sandmix tested in the 1988 trials.

Application crew personnel applied 3/4 cup of sandmix to seep 8, 1/2 cup to seep 10, and 1/4 cup to seep 12 in October 1990. Based on the estimated discharge estimates for 24 h, rotenone application rates were 0.31 mg/L, 0.26 mg/L and 0.17 mg/L, respectively. The rotenone concentrations (Figure 4) were above the selected 0.03 mg/L rotenone level at 12 h in the 0.26 ppm application. The 0.17 mg/L rotenone application had 0.0255 mg/L rotenone at 12 h post application. Three samples were taken from the 0.31 application at each collection interval to assess variability due to experimental error in extraction, handling of samples and analytical processes. Coefficients of variation in rotenone concentrations for triplicate samples at 1 h, 4 h, and 2 h following application were 36%, 12% and 35%, respectively.

Discussion

Development of sandmix met the need for a rotenone formulation to effectively maintain fish toxicity in seeps and springs for periods up to 12 h. Sandmix was inexpensive, simple to prepare and safe and easy to apply. The sandmix formulation sank directly to the source of inflow, and rotenone was released over time. Fish in the sandmix-treated seeps did not exhibit avoidance behavior after application of the material. Potential refugia in which undesirable fish could survive were eliminated because submerged groundwater inflows in streams were effectively treated with rotenone.

Several noteworthy observations were made during the 1988 trials in the Strawberry Springs seeps. Most noteworthy was the uneven release of rotenone, with a high proportion released within 1 h to 4 h. None of the three formulations produced rotenone concentrations at 12 h that were close to the target concentration expected, based on the outflow of the seeps over 24 h. The application rates used in the trials were 5 to 12 times the minimum concentration needed to assure 100% mortality. However, at 12 h following application, the measured rotenone concentrations in most of the seeps treated with sandmix barely exceeded the minimum toxic level. Further experimentation with changing the quantity of gelatin used to bind the rotenone to the sand or using a different material as a binder, may result in an even rotenone dissolution rate. We did not measure rotenone concentrations in any of the seeps more than 12 h after application. However, fish cohorts placed at 12 h and 24 h in the sandmix trials experienced significant or total mortality, indicating the toxicity was persistent.

Table 2. Coefficients of variation (CV% = ((SD/X)x 100) of rotenone concentrations from groups of three seeps at 1 h, 4 h, and 12 h following applications of 0.15 mg/L 0.25 mg/L and 0.35 mg/L liquid rotenone, paste and sandmix in 1988 trials.

Rotenone Formulation	Rotenone Application Rate (mg/L)	1 h Post Application (CV%)	4 h Post Application (CV%)	12 h Post Application (CV%)
Liquid	0.15	44	81	25
	0.25	29	44	56
	0.35	72	35	43
Paste	0.15	75	71	66
	0.25	37	69	34
	0.35	44	16	69
Sandmix	0.15	45	61	36
	0.25	42	29	30
	0.35	23	27	16

Table 3. Percentage survival at 72 h for 45 cohorts of trout hybrid fingerlings placed into seeps treated with 0.15 mg/L, 0.25 mg/L or 0.35 mg/L rotenone in 1988 trials. Asterisks indicate cohorts with mortality curves that differ significantly from control cohorts ($p<0.05$; log-rank test; Mantel 1966).

Rotenone Formulation	Application Rate (mg/L)	18 h Pre	4 h Post	8 h Post	12 h Post	24 h Post
Liquid	0.15	O%*	67%	53%	100%	100%
	0.25	O% *	33% *	40%	47% *	80%
	0.35	O% *	73%	60%	87%	100%
Paste	0.15	43% *	70% *	60% *	80% *	83%
	0.25	O% *	40% *	30% *	60% *	70% *
	0.35	3% *	50% *	66%	83%	97%
Sandmix	0.15	O% *	20%	43%	60%	80%
	0.25	33% *	O% *	O% *	O% *	O% *
	0.35	O% *	O% *	O% *	O% *	O% *

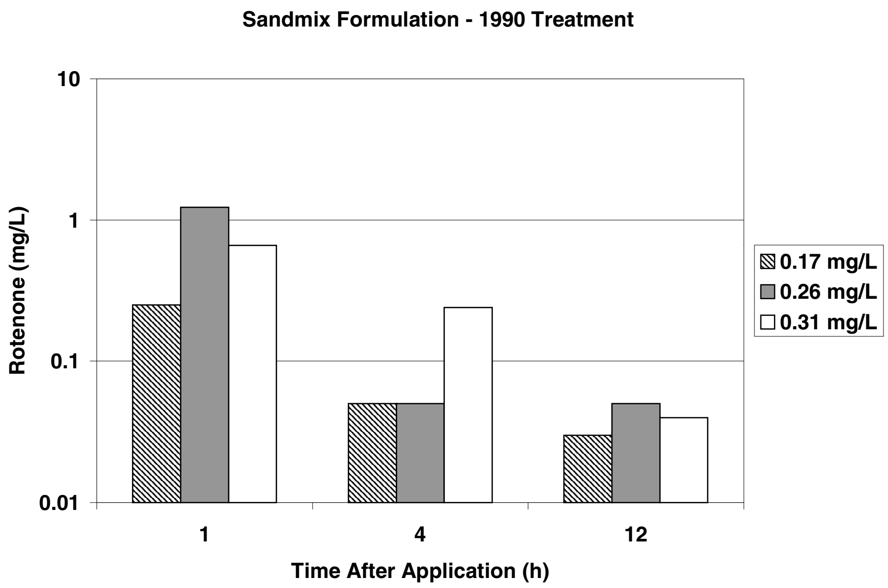


Figure 4. Rotenone concentrations (mg/L) in Strawberry Springs seeps at 1,4, and 12 h following application of rotenone. Application rates were based on total volume flow for a 24-h period.

Also noteworthy was that fish were visibly affected and were killed within 15 min of application of liquid. However, the emulsified liquid was soon flushed out of the cages by inflowing water and few fish were affected 4 h or longer post application.

The paste tended to float on the surface of the seeps, and was retained by the hardware cloth cages used for the trials. Undissolved rotenone powder in the floating paste contaminated the samples during the extraction process, and may have caused the exceptionally high estimates of rotenone concentrations (Figure 3). The trout fingerlings tended to remain on the bottom of the cages near the fresh inflow, where rotenone concentrations were apparently sublethal (Table 3).

Sandmix met our objectives as an effective formulation for treating seeps and springs during the August and October 1990 chemical treatments. Thorough and effective coverage resulted in successful eradication of fish from Strawberry Valley streams (Lentsch et al. 2001). Application crew personnel used sandmix to produce extended toxicity in potential refuge areas.

During the August treatment, bulk sandmix was prepared using a 1:1 ratio (by volume) of powdered rotenone to sand. Application crew personnel were instructed that each pound of sandmix (about 1 cup volume) contained enough rotenone to produce toxic conditions in a 1/2 ft^3/s seep for 24 h. Because the sandmix did not turn the water "milky" or cause evident stress and immediate mortality to fish and aquatic invertebrates (characteristic of liquid rotenone), application crew personnel tended to apply more than was needed. Crews were issued enough sandmix at the beginning of each day to treat the volume of flow from all the seeps in their assigned reaches, but they generally ran out and requested more. Residual release of rotenone from the sandmix produced toxicity that lasted longer than anticipated and may have produced rotenone concentrations that were too high. It was necessary to operate a detoxification station on a diversion canal from the Strawberry River for more than a week following completion of the treatment.

The ratio of powdered rotenone to sand was reduced to 1:3 for the sandmix used during the October treatment. The 1:3 ratio produced a formulation that resulted in measured application rates and rotenone concentrations that were within the target range (Figure 4).

Following the Strawberry treatment, sandmix has become a frequently used formulation for treating seeps in chemical rehabilitation projects in Utah and in other states. Sandmix has also been used to treat submerged springs in lakes, and to penetrate dense weed beds. Unused formulation will maintain its toxicity for many months if stored in tightly sealed containers.

Acknowledgements

This study was funded under the Federal Aid in Fisheries Restoration (Utah project F-50-R) and was administered by the Fisheries Section of the Utah Division of Wildlife Resources. We thank R. Harrison, B. Franano, D. Bone and E. Hanson for their assistance in fieldwork. Dr. B. Doucette of the Utah State University Water Research Laboratory analyzed samples by HPLC. Morgan Williams prepared bulk sandmix during the 1990 treatment project.

References

Bradbury, A. 1986. Rotenone and trout stocking: a literature review with special reference to Washington Department of Game's lake rehabilitation program. Washington Department of Game, Fisheries Management Report 86-2, Seattle, Washington.

California Department of Fish and Game. 1985. Final programmatic environmental impact report: rotenone use for fisheries management. California Department of Fish and Game, Sacramento, California.

Dawson, V.K., P.D. Harmon, D.P. Schultz, and J.L. Allen. 1983. Rapid method for measuring rotenone in water at piscicidal concentrations. Transactions of the American Fisheries Society 112:725-727.

Everhart, W.H. A.W. Eipper, and W.D. Youngs. 1975. Principles of Fishery Science. Cornell University Press, Ithaca, New York. USA.

Gilderhus, P.A., J.L. Allen, and V.K. Dawson. 1986. Persistence of rotenone in ponds at different temperatures. North American Journal of Fisheries Management 6:129-130.

Guthrie, C.A. 1982. Acclimation of brook trout (Salvelinus fontinalis) to acidified waters. Master's thesis. Cornell University, Ithaca, New York.

Johnson, J. 1988. Environmental assessment of plans to restore the Strawberry Reservoir fishery. Utah Division of Wildlife Resources Publication 87-14. Utah Division of Wildlife Resources, 1596 West North Temple, Salt Lake City USA.

Lennon, R.E., J.B. Hunn, R.A. Schnick, and R.M. Burress. 1970. Reclamation of ponds, lakes, and streams with fish toxicants: a review. FAO Fisheries Technical Paper Number 100. Rome, Italy.

Lentsch, L. and R. Spateholts. 1988. Strawberry Reservoir fishery enhancment project. Utah Division of Wildlife Resources Federal Aid in Fish Restoration, F-50-R-2 Study 1, Job Performance Report, Salt Lake City, Utah.

Lentsch, L.D., C.W. Thompson, and R.L. Spateholts. 2001. Overview of a large-scale chemical treatment success story: Strawberry Valley, Utah. This volume.

Leppink, J. 1977. Beaver River drainage rough fish eradication. Utah Division of Wildlife Resources Project Completion Report, Salt Lake City, Utah.

Mantel, N. 1966. Evaluation of survival data and two new rank-order statistics arising in its consideration. Cancer Chemotherapy Reports 50:163-170.

The Use of Rotenone on National Forests

Donald A. Duff
USDA Forest Service, 125 S. State Street, Rm 8236
Salt Lake City, UT 84138, USA
dduff@fs.fed.us

Abstract.—The use of rotenone is allowed on National Forests for stream and lake renovation projects, particularly to eradicate non-native species for native fish restoration. The State Fish and Wildlife Agency usually administer rotenone. Strict environmental controls set its limits of use, and care must be observed to assure minimal impact on other stream or lake dwelling organisms. Rotenone can be applied in wilderness areas.

Introduction

The piscicide rotenone has been used on National Forest System (NFS) lands since the 1930s. Rotenone is the most extensively used piscicide in the United States (Cummings 1975). Fisheries managers have used this tool for the management and assessment of fish populations to maintain a diverse and productive aquatic ecosystem and high quality recreational fisheries (Finlayson et al. 2000). Only four piscicides are currently registered for use in the United States by the U.S. Environmental Protection Agency (EPA). These are the general piscicides, rotenone and antimycin, and the lampricides, Lamprecid® and Bayluscide®. The USDA Forest Service (FS) can use only registered piscicides on NFS lands.

In past times rotenone was originally used to control undesirable fish populations so that sport fish could be stocked and managed for recreational purposes in streams and lakes without interference from other undesirable fish. In recent times, the use of rotenone on NFS lands has been for eradication of undesirable or exotic fish for the restoration of threatened, endangered, or sensitive (TES) fish species, especially native salmonids. It has also been used to control undesirable fish to support recreational fisheries. When used for native fish restoration, rotenone is usually applied to an entire watershed or subbasin stream(s) where restoration is needed. A complete elimination of fish is usually needed to assure that the genetic purity of native (or TES) species is protected. Non-native or exotic species are usually identified as the primary threat to native species restoration where hybridization with non-native salmonids results in an irretrievable loss to the original genome of the native species.

The piscicides, rotenone and antimycin, are approved for use on NFS lands. Rotenone is available from producers, such as in two liquid formulations known as Noxfish® and Nusyn-Noxfish®, or in powdered form as Pro-noxfish®. Antimycin is registered as the product Fintrol®. Rotenone is usually applied on NFS lands by the State Fish and Wildlife Agency (SFWA) in cooperation with the FS and other partners, such as the U.S Fish & Wildlife Service (FWS), Bureau of Land Management (BLM), Trout Unlimited (TU), and others (McClay 2000). The piscicide can only be applied by certified applicators employed by state and federal resource agencies, or private persons with specific permits. Very rarely does the FS, or another Federal agency, administer the rotenone. But if this does occur, it is done with coordination and approval from the SWA.

Forest Service Policy

The U.S. Department of Agriculture Policy Regulation 9500-4 provides broad policy direction for fish, wildlife, and plants management activities on NFS lands, as well as in partnerships with SFWA's (USDAFS 1991; USDAFS1995a). If state or federal funds are being used for the project, if permits are required, or if there may be an impact to lands administered by the FS, then as environmental assessment (EA) or an environmental impact statement (EIS) is required as part of the National Environmental Policy Act (NEPA) requirements for federal actions. These NEPA documents will describe the impacts (chemical, physical, and biological) from the treatment, and potential mitigation, if needed. The document(s) can be jointly written or the lead agency could be a SFWA, but approval must be by the administrative units FS official. Forest land and resource management plans, or Forest Plans (ForPlans), generally mandate principles and standards for pesticide-use activities. All pesticide-use activities on NFS lands must be consistent with standards and guidelines and other management direction in the ForPlans (USDAFS 1994a).

Project planning

In preparing for a rotenone project, the biologist needs to identify and analyze any risks or threats to wildlife, fish, and other aquatic organisms as part of NEPA direction outlined in USDAFS (1992), as well as USDAFS (1994a), which provide specifics to be addressed in any proposal. A Pesticide-Use Proposal Form, FS-2100-2, is required (USDAFS 1994a). Forest Supervisor's have usually been delegated the responsibility to approve project proposal for projects outside wilderness, but a copy of the form and accompanying NEPA documents is to be sent to the Regional Forester (RF) for information and review (USDAFS 1994b). Some FS Regional Office's, such as the Intermountain Region, require that all proposals be sent to the RF annually by April 1. Following the project or treatment, a Pesticide-Use Report, Form FS-2100-1, is than required and it is due to the RF by October 15 annually. In all FS Regions the RF must approve all proposed uses of chemicals in wilderness (USDAFS 1990).

Biological assessment

Previous to any treatment, FS and SFWA fisheries biologists conduct aquatic inventory assessments to determine presence or absence of species and taxa. Fish, amphibian, macroinvertebrates, and water quality and quantity are the usual parameters surveyed. Any post-treatment monitoring of waters for biological and chemical parameters will be identified and a monitoring schedule or timeframe identified. The characterization of effects on macroinvertebrates, for example, may specify timeframes for annual sampling up to five years in order to track re-colonization of a species. Guidance for fish and wildlife habitat monitoring, biological diversity requirements, habitat capability, and conservation strategies are provided in (USDAFS 1995a). Monitoring guidance for watershed and water related characteristics and riparian area management and protection is covered in USDAFS (2000). If TES species occur in the project area, or if the project is to benefit a TES species, a biological evaluation will be prepared by the Forest Supervisor or District Ranger to determine potential effects on the species and habitat (USDAFS 1995c). Consultation, either informal or formal or conferencing, with the U.S Fish and Wildlife Service (FWS) or the National Marine Fisheries Service may be necessary for threatened or endangered species.

Public review

Once a project's draft EA document had been developed, the FS and/or SFWA will release the draft for public review before agency approval is finalized. A public media news release is usually issued in conjunction with the EA and/or the project. A specified time period is given for public review after which all written comments will be analyzed and considered before final approval of the EA. Public concerns in the use of rotenone on NFS lands usually focus on public health and safety. Typical concerns expressed by the public during an EA review process are impacts on water quality and public health; effects on animal welfare, i.e. fish, wildlife, macroinvertebrates, livestock; recreation or water-based uses; and possible liability-public damage. Rotenone use for fish control does not present a threat or risk of unreasonable adverse effects to humans or the environment, if administered in the proper application (Finlayson et al. 2000). However, the EPA advises that fish containing rotenone residues should not be consumed, as they have not established residue tolerances, not because the fish are a treat to humans after a treatment.

Approval for use

The SFWA has the responsibility to administer protection and management of fish and wildlife populations on NFS lands within a State. The FS has the jurisdiction and responsibility for occupancy, use, and management on NFS lands. The FS must approve all uses of chemicals on NFS lands. The Forest Supervisor is the responsible and approving official for treatments on NFS land, streams and lakes, within a specific National Forest under his jurisdiction, excluding wilderness areas. Any piscicide treatment, which involves NFS lands within a designated wilderness area, must have the RF as the responsible and approving FS official. The RF must approve treatments within all wilderness areas on National Forests within the Region in which his/her jurisdiction applies (USDAFS 1994b). Usually treatments in wilderness are done for native or indigenous species restoration or recovery. Stocking of non-native or exotic species is prohibited (Duff 1995; USDAFS 1990). Chemical treatments for fish and wildlife in wilderness is covered under a joint directive agreed to, in 1986, by the FS, BLM, and International Association of Fish and Wildlife Agencies. These guideline's entitled, "Policies and Guidelines for Fish and Wildlife Management in National Forest and BLM Wilderness" are listed in the FSM, and are a result the American Fisheries Society's efforts, in the mid-1970's, to resolve the issue of joint state-federal use of piscicides for coordinated resource management (USDAFS 1990).

References

Cummings, K.B. 1975. History of fish toxicants in the United States. Pages 5-21 *in* P.H. Eschmeyer, Ed. Rehabilitation of fish populations with toxicants: a symposium. American Fisheries Society, North Central Division, Special Publication 4. Bethesda, Maryland.

Duff, D.A. 1995. Fish Stocking in U.S. Wilderness Areas: Challenges and Opportunities. International Journal Wilderness 1: 17-19.

Finlayson, B.J, R.A. Schnick, R.L. Cailteux, L. DeMong, W.D. Horton, W. McClay, C.W. Thompson, and G. J. Tichacek. 2000. Rotenone Use in Fisheries Management: Administrative and Technical Guidelines Manual. AFS, Bethesda, Maryland.

McClay. W. 2000. Fisheries Management-Rotenone Use in North America (1988-1997). Fisheries 25 (5): 15-21.

USDA Forest Service. 1990. Wilderness Management - Management of Fish and Wildlife. Forest Service Manual 2323.3. USDA Forest Service, Washington., D.C.

USDA Forest Service. 1991. Wildlife, Fish, and Sensitive Plants Habitat Management. Forest Service Manual 2600. USDA Forest Service, Washington, D.C.

USDA Forest Service. 1992. Environmental Policy and Procedures. Forest Service Manual 1950. USDA Forest Service, Washington, D.C.

USDA Forest Service. 1994a. Pesticide-Use Management and Coordination Handbook. Forest Service Handbook 2109.14. USDA Forest Service, Washington, D.C.

USDA Forest Service. 1994b. Pesticide-Use Management and Coordination. Forest Service Manual 2150. USDA Forest Service, Washington, D.C.

USDA Forest Service. 1995a. Stocking and Harvesting. Forest Service Manual 2640. USDA Forest Service, Washington, D.C.

USDA Forest Service. 1995b. Habitat Planning and Evaluation. Forest Service Manual 2620. USDA Forest Service, Washington, D.C

USDA Forest Service. 1995c. Threatened, Endangered, and Sensitive Plants and Animals. Forest Service Manual 2670. USDA Forest Service, Washington, D.C.

USDA Forest Service. 2000. Watershed Management. Forest Service Manual 2500. USDA Forest Service, Washington., D.C.