AMERICAN FISHERIES SOCIETY

Maintaining North America's Healthy Native Aquatic Ecosystems:

Rotenone's Role in Eradicating Invasive Fishes, Parasites and Diseases

Fish Management Chemicals Subcommittee - 2010

This publication discusses how rotenone has been used by fish and wildlife, environmental and natural resource management agencies to restore native ecosystems out of balance because of IAS fish. It presents scientific evidence demonstrating the safety of rotenone, and lists the precautions that have been taken in North America to assure the continued safety of people and the environment.

North Americans Love To Go Fishing

North America is fortunate to have many healthy native aquatic ecosystems that support recreational and commercial fishing of native species. Fisheries include king and silver salmon in the West along the Pacific Ocean, Atlantic salmon in the Northeast along the Atlantic Ocean, cutthroat trout in the West, lake whitefish and walleye in the Great Lakes, and brook trout in the East. In the United States alone, more than 35 million people go fishing for 626 million days and spend more than $38 billion in pursuit of this recreational sport. Recreational fishing is also popular in Canada where an estimated 3.2 million people participate in this leisure activity each year, generating approximately $7.5 billion for local economies. Recreational fisheries management promotes public awareness and community stewardship for the conservation and sustainable use of fisheries resources.

Tourism associated with angling and visiting unique aquatic ecosystems generate the needs for accommodations, shops, and local craftsmanship that produce revenues and jobs. The revenues generated are directly proportional to the quality of aquatic habitats and biodiversity. North Americans now enjoy open spaces, clean water and abundant biodiversity. However, native biodiversity in North American waters is increasingly under attack from the invasion of nonnative (alien) species.

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Invasive Alien Species

Purposeful and accidental movements of alien fishes by humans have been worldwide over the past two centuries. Intentional and authorized introductions often began as a means to establish food fishes, create new fisheries, restore depleted fish stocks, and control plants, invertebrates, and other fishes. Unauthorized introduced aquatic species have become established through sources such as release of live bait, aquarium pets, and ship ballast water. Foreign parasites and diseases have often unintentionally moved with the movement of introduced species.

Many of our agricultural crops and livestock have originated elsewhere from where they are currently grown. However, only a few of the terrestrial introductions have become problem species because they often required active cultivation and care. However, introductions of alien aquatic organisms have often resulted in significant problems in the new waters because the physical and biological mechanisms that were controlling the introduced organisms in their native environment were often absent. Many of these alien species are likely to cause economic or environmental harm or harm to human health and are thus, considered invasive.

Invasive alien species (IAS) are nonnative species whose introduction and/or spread outside their natural past or present ranges poses risk to biodiversity. IAS have been recognized as the second most important threat to biodiversity at the global level (after direct habitat loss or destruction). IAS fish often cause severe problems to native ecosystems and reduce biodiversity through:

- Competing for food and habitat utilized by native fish species and wildlife
- Directly preying on native fish species
- Hybridizing with native species, leading to genetic introgression and the loss of genetically pure native fish stocks
- Changing selection pressures that operate on native species and ecosystems
- Exposing native fishes to parasites and diseases that were not historically present in habitats
- Modifying habitat including degradation of water quality
- Altering energy and nutrient flow within the aquatic ecosystem
- Altering the food web in the aquatic ecosystem
- Extirpating native species

Over 50,000 alien species have invaded the United States and Canada. In the United States and Canada, 536 and 55 alien fish, respectively, have been identified. The total costs of IAS in United States are estimated at over $120 billion per year according to a Cornell University study in 2004. Although similar figures are not available for Canada, cumulative annual costs for just 16 alien species in Canada have been estimated at $13.7 to $34.5 billion. These costs result from damage caused by IAS and their control measures. The most heavily affected industries are agriculture, fisheries, aquaculture, forestry and health. The most serious aquatic invading species, based on damages and control in terms of dollars per year, are fishes which cost the United States $5.4 billon annually. Over 40% of the threatened and endangered species in the United States and 24% of species at risk in

Canada are threatened with extinction because of predation, parasitism and competition from IAS.

There are several notable examples of how IAS fish have disrupted the biodiversity and function of native ecosystems worldwide. Asian bighead and silver carp were imported into the United States in the 1970s, now inhabit the Missouri, Mississippi, Illinois and Ohio river systems, and may invade the Great Lakes through the Chicago Ship and Sanitary Canal with potentially, highly deleterious effects on the Great Lakes fishery worth billions of dollars. The European minnow historically had a very restricted distribution in Norway, now they are found throughout Norway the result of spread by fishermen who use it as live bait for catching brown trout; ironically, the minnow competes directly with native brown trout for invertebrate food items, resulting in lower trout growth and significant reductions in benthic invertebrates. Northern pike not native to south central Alaska were illegally released into lakes and streams on the Kenai Peninsula and the Matanuska-Susitna Valley; the pike spread quickly through connected water bodies and changed the entire balance of species. This has had devastating impacts on native salmon stocks which have never recovered.

Active intervention, such as eradicating the IAS fish, is usually required to restore a native ecosystem to its original healthy balance. Success of eradication is typically high if the IAS fish is caught soon after invasion when populations and distribution are low; success is proportionately less with their increased numbers and distribution over time. If not all IAS fish or disease infected fish are removed, they are able to reproduce and the problem continues. Environmental and natural resource management agencies rely on a wide variety of tools for the management and assessment of fish populations. One of the most valuable tools is rotenone which has been used by these agencies since the 1930s. Rotenone is a naturally occurring plant substance that is derived from the roots of tropical plants in the bean family. Rotenone has been used for decades by organic farmers, and rotenone has been used for centuries by native peoples to capture fish for food in areas where these plants are naturally found.

Use of Rotenone

The use of piscicides (fish management substances) like rotenone is the only method available other than complete dewatering or draining (e.g., removal of all water from the habitat) that will eliminate entire populations of fishes. Typically, draining a lake or dewatering a stream are not viable options, let alone technically feasible, and often require immense resources and will likely cause significant environmental damage.

Methods other than piscicides or complete dewatering for controlling fish communities have been used. These include (1) modification of angling regulations (modifications to promote or favor over harvest of IAS fish), (2) physical removal techniques (using nets, traps, or electrofishing), (3) biological control techniques (predators, intraspecific manipulation, pathological reactions on IAS fish), (4) stream flow augmentation techniques (create water temperatures or current conditions that negatively impact the IAS fish or that favor native fish), (5) fish barriers (protect against entry by IAS fish), and (6) explosives for flowing waters and impoundments. The major advantage of these methods are their low cost but their collective limitation is that they are limited to partial control (not capable of removing all fish), not eradication which is required for IAS.

To be acceptable, a piscicide must work quickly, break down in a short period of time, and leave no harmful residues. It must not pose a health hazard to those applying the substance or to animals or birds that might consume treated water or organisms. It also must not affect aquatic plants or deplete the dissolved oxygen in the water. After application, the substance must break down rapidly so populations of non-target organisms can quickly recover to allow restoration of the native ecosystem. Rotenone meets all these requirements and is the best option to restore biodiversity to waters infected with IAS fish or disease without permanently affecting the native ecosystem.

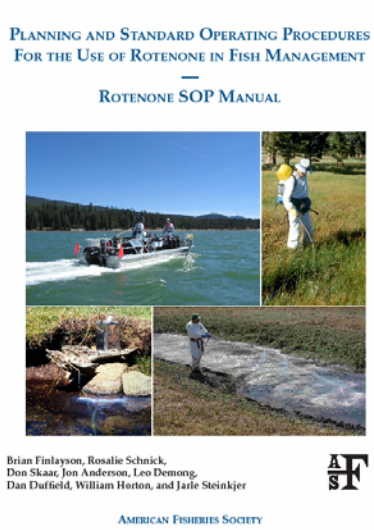
Rotenone: The Approval Process

Before rotenone can be used as a piscicide to eradicate IAS fishes in United States, it must be registered (approved for use under specific conditions) by the U.S. Environmental Protection Agency (EPA) under the conditions listed in Federal Insecticide, Rodenticide and Fungicide Act (FIFRA). Having met all of the safety requirements, rotenone has been registered continuously for fishery uses in the United States since 1947. A similar process is regulated by the Pest Management Regulatory Agency in Canada. Before a substance is registered, research must have been conducted to show that the product does not constitute a health hazard or have any long-term effects on humans or the environment. Years of required scientific testing on rotenone have been completed to demonstrate its (1) physical and chemical properties, (2) effectiveness against target organisms and use in IAS fish eradications, (3) toxicological profile for man and animals, and (4) ecotoxicological profile including environmental fate and behavior. These data are used to complete risk

Millions of dollars have been spent on research to determine the safety of rotenone prior to registration.

assessments to ensure a high level of protection of human and animal health and of the environment. Rotenone was accepted for reregistration by EPA in March 2007.

The American Fisheries Society (AFS), an organization of professional fisheries scientists, has been actively involved in the Rotenone Stewardship Program since 2000; more information can be found at the website www.fisheries.org/units/rotenone. The AFS in cooperation with the EPA and the product registrants developed feasible and effective risk mitigation measures to protect man and the environment. These measures were included in the EPA's March 2007 Rotenone Reregistration Eligibility Decision or RED (EPA-HQ-OPP-2005-494-0036 available at www.regulations.gov) and were also incorporated by the Pest Management Regulatory Agency for rotenone products in Canada. As a requirement for the Rotenone RED, AFS wrote the *Rotenone Standard Operating Procedures (SOP) Manual* that provides detailed instructions on the safe and effective use of rotenone; *Rotenone SOP Manual* can be obtained at www.afsbooks.org/55061P .



American Fisheries Society released the Rotenone SOP Manual in 2010.

Success Stories

Here are a few examples of how rotenone has been used to repair damage caused by IAS fish in North America and Europe:

Restoring Cutthroat Trout in the West

Native inland cutthroat trout populations in the western United States have been greatly impacted by IAS trout. Introduction of IAS trout has contributed to the decline of most, if not all, nine inland native cutthroat trout subspecies. Colorado River cutthroat in Colorado, Wyoming and Utah, greenback cutthroat in Colorado and Wyoming, Bonneville cutthroat in Utah, Idaho, Nevada and Wyoming and Lahontan cutthroat trouts in Nevada, California and Oregon are impacted by competitive interactions with brook and brown trouts. Lake trout introduced into Lake Tahoe (California and Nevada) have become established in the niche that the top native predator Lahontan cutthroat trout formerly occupied. Although competition and predation have displaced native cutthroat trout populations, the greatest danger to the conservation of these subspecies is introgressive hybridization among subspecies and with rainbow trout. Beginning in the 1990s, California, Colorado, Nevada, Oregon, Utah and Wyoming entered into conservation agreements and recovery plans for the cutthroat trouts that rely on rotenone. The general approach has been to treat with rotenone for several years a stream reach that is isolated by barriers, either natural or artificial, and subsequently stock the stream with native fish from extant wild or hatchery populations. Stream reaches, lakes, and fish populations are then connected, working downstream with successive rotenone treatments.

Bonneville cutthroat is one of several native inland trout species in the West that have been greatly impacted by nonnative trout.

Restoring Trout and Water Quality in Oregon

The IAS Tui chub were introduced into Diamond Lake in 1988. These small minnows are omnivores and rapidly exploited both the zooplankton and the benthic invertebrate populations. By the late 1990s, their presence had resulted in the loss of much of the benthic invertebrates and a significant reduction in large zooplankton of the lake. This resulted in the loss of the world-renowned rainbow trout fishery and ultimately, the excellent lake water quality. The number of trout caught dropped from 56,000 in 1992 to 5,000 trout in 1999, and number of anglers dropped from 54,000 to 6,000 during the same time period. Because most of the zooplankton had been depleted by the Tui chub, uncontrolled algae blooms ensued including cyanobateria (*Anabaena flos-aquae)* that produced neurotoxins to humans and pets, and forced the closure of the lake to all contact in 2001, 2002, 2003 and 2006. Diamond Lake's clear blue water turned a blue-green color as algae blooms persisted for most of the summer months. In 2006, Diamond Lake was treated with rotenone and the Tui chub was eradicated. Within one year, benthic invertebrates and the excellent water quality rebounded. Benthic insect biomass increased from 1 kg/ha prior to the rotenone treatment to 238 kg/ha within one year after treatment, and several species of invertebrates including caddisflies and mayflies not seen in the previous decade had re-colonized the lake. The rotenone treatment cost around $1 million but the benefits over the next 12 years are estimated at over $20 million.

Tui chub were illegally introduced into Diamond Lake which resulted in the loss of the world-renowned rainbow trout fishery and excellent water quality.

Protecting Native fish in British Columbia

The spread of yellow perch, small and largemouth bass, and pumpkinseed sunfish has become a major concern for fisheries in southern and central regions of British Columbia. During the last 10 years, these IAS fish have been introduced into 9 small lakes, 4 of which are directly connected to the Thompson River Drainage. Once in these small lakes, their spread into adjacent larger systems (Shuswap and Adams Lake) could have devastating impacts on recreational inland fisheries currently valued at $44 million annually. A risk assessment concluded that perch and bass introductions will likely lead to extirpation of native fish in small lakes and possible major food web shifts in larger, salmon producing systems. The response has been to manage the illegal movement IAS fish through eradication of carefully selected, high-risk populations in locations with a high likelihood of success. To date, successful eradications using rotenone have been conducted for 5 of the 9 small lakes in the Thompson River Drainage; the remaining four lakes are scheduled to be treated in September of 2010.

The invasion of spiny-ray fish in British Columbia has been met with eradication of carefully selected, high-risk populations in locations with a high likelihood of success using rotenone.

Protecting Atlantic Salmon in Norway

The Atlantic salmon parasite *Gyrodactylus salaris* is considered to be the most serious threat to salmon stocks in Norway. The parasite is native to the Karelian part of Russia and the Baltic parts of Finland and Sweden. The parasite likely arrived in Norway with infected salmon and rainbow trout from Sweden in the 1970s. The parasite affects salmon fins and skin leading to secondary fungal and bacterial infections and has caused epidemics that have devastated salmon stocks in many Norwegian rivers. By 2007, 46 Norwegian salmon rivers had been affected with the parasite, and the total yearly loss in the river salmon fishery was estimated at 45 tons of salmon having an estimated value of 125 million Euros. A number of infected rivers in Norway have been treated with rotenone and the parasite eradicated. A notable example is the treatment of six rivers of the Mo-i-Rana region which had the parasite since 1978. The rivers were treated with rotenone in 2003 and 2004 to remove the parasite, and the rivers were monitored for reoccurrence of the parasite from 2005 through 2009. The rivers were declared parasite free in October 2009, five years after the initial rotenone treatment.

The Atlantic salmon parasite G. salaris is considered to be the most serious threat to salmon stocks in Norway.

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Protecting Native Fish in England

Topmouth gudgeon (TMG) has been called Europe’s most invasive fish. TMG is a small (10 cm), cyprinid (member of carp family) that was first found in Eastern and Central Europe beginning in the 1960s. TMG was introduced into England in the 1990s with ornamental fish originating from Southeast Asia. TMG has infested over 32 small lakes and ponds in England and threatens several river systems. The highly invasive cyprinid matures within one year, likely reproduces several times a year, and quickly overpopulates waters. TMG is a healthy vector for infectious disease that is a threat to both native and farmed fish, eats the eggs of other fish species and vast amounts of aquatic vegetation, and disrupts the native ecosystem. England began an eradication program centered on rotenone in 2005, and by the end of 2009, TMG has been successfully eradicated from 8 water bodies. In England, rotenone is considered their most cost-effective tool in the management of IAS fish. Without rotenone, their ability to manage IAS fish would be terribly crippled. The goal is to eradicate TMG from all water bodies in England and restore natural biodiversity.

TMG has been called Europe's most invasive fish, matures within one year, may reproduce several times a year and quickly overpopulates waters.

Questions and Answers

From time to time, people have questions about the use of rotenone in maintaining ecosystem balance. They want to know, "Has rotenone been adequately tested to assure our safety and the safety of the environment?" The answer is "Yes". Below are questions that have been raised in the past and answers to those questions based on scientific evidence from in-depth studies.

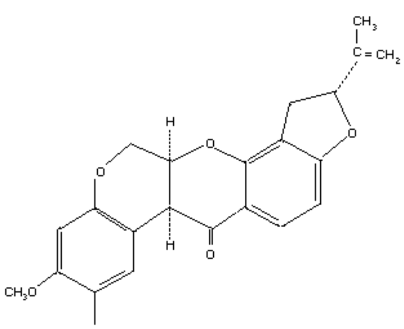
General Information

Q. What other uses are there for rotenone?

A. Rotenone in the past was used as an insecticide to control chewing insects on agricultural crops and on cattle and dogs to control external parasites.

Q. What is rotenone?

A. Rotenone is one of several naturally occurring rotenoids found in the roots of certain plants belonging to the bean (Leguminosae) family. Plant roots are dried and ground into a powder that is used as a piscicide in standing water. Since rotenone is relatively insoluble in water, it is often formulated as a liquid emulsion in order to allow for rapid dispersion and improved efficacy in running water.



Rotenone is one of several naturally occurring rotenoids found in the roots of certain plants belonging to the bean (Leguminosae) family.

Q. How does rotenone work?

A. The toxicity of rotenone stems from its specific effect on cellular aerobic respiration (i.e., phosphorylation inhibitor). This suspends utilization of oxygen for energy production at the cellular level, eventually leading to cardiac and neurological failure at the organ level. Rotenone is highly toxic to fish due to the rapid uptake across the gill surface. Waterfowl and other birds as well as mammals are comparably resistant.

Q. How and when is rotenone applied?

A. Rotenone liquid is typically packaged in 1-, 5-, 30- and 50-gallon containers and powder is typically in 50- and 200-pound containers. Applications are generally made with boats in lakes, reservoirs and ponds, with direct metering into moving water such as streams, and with hand-held equipment such as backpack sprayers in difficult to reach areas. Rotenone may be applied at any time of year, but most applications typically occur during warm months when the compound is more effective and degrades more rapidly. Rotenone is usually applied during low water conditions to limit amount of area treated and piscicide needed.

Q. How much rotenone is used?

A. The concentration of active rotenone used to eradicate fish varies with the target species and environmental conditions from 12.5 to 200 parts per billion; 12.5 to 200 parts of rotenone in 1,000,000,000 parts of water (equivalent to 0.07 to 1.1 pounds of rotenone in an Olympic-size swimming pool of 666,430 gallons).

Q. When is it appropriate to use rotenone?

A. It is appropriate to use rotenone in aquatic management situations where eradication (e.g. complete removal and elimination) of a target population of fish is required to prevent severe problems to a native ecosystem and reduction in biodiversity. Other fish management techniques such as physical removal and explosives only control, but do not eliminate, the IAS fish population.

Rotenone applications are generally made with boats in lakes, reservoirs and ponds.

Public Health

Q. How safe is rotenone to the public and applicators?

A. Millions of dollars have been spent on research in testing laboratories and environmental monitoring studies to determine the safety of rotenone prior to registration in the U.S. by the EPA and in Canada by the Pest Management Regulatory Agency. Extensive acute (short-term) and chronic (long-term) tests on rotenone have been conducted. Rotenone is not considered a carcinogen (capable of causing cancer), mutagen (capable of causing genetic mutation), teratogen (interferes with normal embryonic development), or reproductive toxin (affects reproductive capabilities). The public will be excluded from treatment areas until rotenone residues have dissipated to safe levels, and applicators wear safety gear to minimize rotenone exposure.

Q. What is a safe level of rotenone exposure?

A. The EPA has suggested a safe level for rotenone in drinking water of 40 parts per billion and a safe level for water contact (e.g. swimming) of 90 parts per billion. These safe levels assume a conservative worst-case lifetime exposure to rotenone. These are conservative levels since most treatments result in rotenone residues persisting for no longer than a few weeks to a few months.

Q. Can rotenone-treated water be used for irrigation of crops?

A. As an additional precaution, water containing residues of rotenone cannot be used on crops. This does not mean that doing this is actually unsafe, it is just not allowed because a tolerance (rotenone residue level legally allowed on crops) has not been established.

Q. When can the public access the water after treatment?

A. The public will not be allowed in contact with the treated water until rotenone residues have dissipated below 90 parts per billion. Many treatments will occur at rotenone levels less than 90 parts per billion and contact can commence immediately after the treatment process has been completed.

Q. What is Parkinson's disease (PD) and its relationship to rotenone?

A. People with PD have less dopamine producing cells in the brain which typically results in tremors and rigidity. It is a complicated disease likely affected by both genetics and the environment. Published literature over the past ten years indicated that rotenone exposure under certain laboratory conditions could reproduce several features of PD in rodents. Although rotenone is toxic to the nervous system of insects and fish, commercial rotenone products have presented little hazard to humans over many decades of use and are not considered a cause of PD.

Q. Does rotenone use in fisheries management cause PD?

A. There is little doubt that rotenone and other chemicals that directly inhibit the mitochondrial energy chain can under certain laboratory exposure conditions reproduce features of PD in animal models. These studies used intravenous (directly into the vein), subcutaneous (below the skin) or intragastric (stomach tube) routes of exposure with the rotenone dissolved in solvents and stabilizers to enhance tissue penetration. The purpose of these studies was often to document possible PD models, not in finding the cause(s) of PD. These laboratory exposures limit their applicability to humans because these avoid the normal protective measures of the human body through dermal and oral exposure. For example, a two-year long study where rotenone was mixed in the food of rats, using much higher dosages of rotenone, did not produce PD pathology. A recent review of these published studies suggests that rotenone causes atypical Parkinsonism rather than an unknown cause of PD.

Q. What are the dangers from consuming fish from rotenone treated water?

A. Fish killed by rotenone should not be consumed by humans because of concern for salmonella and other bacteriological poisoning that may occur from consuming fish that have been dead for a period of time. The rotenone residues in dead fish carcasses are quickly broken down by physical and biological reactions.

Environmental Health

Q. How are the effects of rotenone kept restricted to the treatment site?

A. Potassium permanganate, through a chemical reaction called oxidation, deactivates rotenone. Potassium permanganate can be injected into the flowing water stream at the point where the effects of rotenone are no longer desired. Potassium permanganate is used worldwide in treatment plants to purify drinking water.

Q. What happens to rotenone after it is applied to the water?

A. Rotenone is a compound that breaks down very rapidly in the environment. Rotenone degrades quickly through physical (hydrolysis and photolysis) processes and biological mechanisms. An increase in temperature or sunlight increases the breakdown rate of rotenone.

Q. How long does rotenone persist in water and sediment?

A. Numerous monitoring studies have shown that rotenone residues typically disappear within about one week to one month, depending on environmental conditions. The half-life (time required for ½ of material to breakdown) for rotenone varies from about 12 hours to 7.5 days, and is inversely related to temperature. Rotenone is typically applied when water temperatures are warm to optimize effect on the fish and the breakdown rate in the environment. If necessary, potassium permanganate can be used to speed-up (within 30 minutes) the breakdown of rotenone.

Q. What are the dangers of contaminating ground water?

A. The ability of rotenone to move through soil is low. Rotenone is strongly bound to organic matter in soil so it is unlikely that rotenone would even enter ground water. Monitoring studies in ground waters adjacent to treatment areas have found no contamination associated with rotenone treatments.

Fish and Wildlife

Q. How does rotenone affect aquatic animals?

A. Because rotenone is selectively toxic to gill breathing animals, fish are the most sensitive, followed by aquatic invertebrates and gill breathing forms of amphibians. Benthic invertebrates appear less sensitive than planktonic invertebrates, smaller invertebrates typically appear more sensitive than their larger counterparts, and aquatic invertebrates that use gills appear more sensitive than those that acquire oxygen through the skin, or that use respiratory pigments or breathe atmospheric oxygen. Studies have shown that amphibians and invertebrates will repopulate an area after rotenone breaks down.

Q. Will wildlife be affected from consuming water or food containing rotenone?

A. Birds and mammals are tolerant of rotenone having natural enzymes in the digestive tract that neutralize rotenone. Birds and mammals that eat dead fish and drink treated water will not be affected. Rotenone does not concentrate in fish tissue, rotenone residues are broken down quickly in the environment, and rotenone is not readily absorbed through the gut of an animal eating the fish or drinking the water. Most fish quickly sink to the bottom of treated water and rapidly decompose making the likelihood of extended exposure through the diet of terrestrial animals very low. This difference in toxicity between fish and birds and mammals coupled with its lack of environmental persistence makes rotenone an ideal fish management substance.

Q. Will wildlife be affected by the loss of their food supply following a rotenone treatment?

A. During rotenone treatments, fish-eating birds and mammals can be found foraging on dying and recently dead fish for up to several days after treatment. Following this abundance of dead fish, a temporary reduction in food supplies may result until fish and invertebrates have been restored. However, most of the affected species are mobile and will seek alternate food sources or forage in other areas. In unique situations like the fledging of young raptors, dead fish may be brought into the treated water body for extended periods of time to provide for an uninterrupted food supply or the timing of the treatments can avoid periods of time when raptors are raising their young.

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Rotenone

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